The Garland Company

AIM HIGH

A seminar.

CREATING HIGH PERFORMANCE BUILDINGS

Presented by:

John Straube Ph.D. P.Eng.

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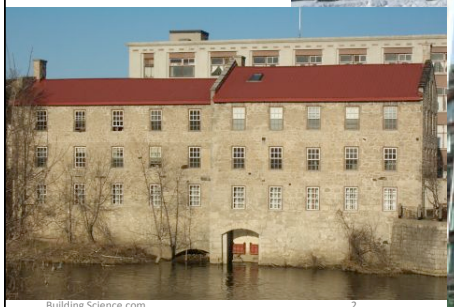
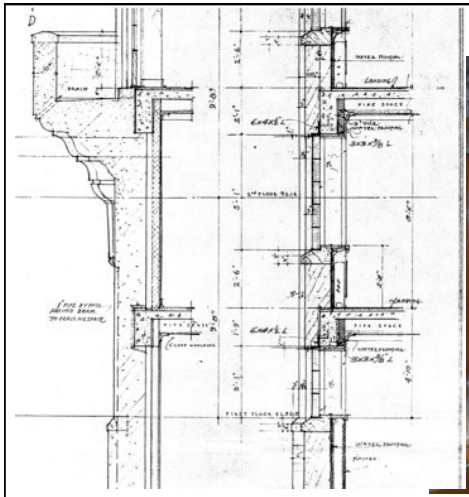
Solid masonry





Wet Applied Plaster

Old Growth Timber

Pre-WWII Buildings

- No added insulation (or very little)
- Heating systems and some natural ventilation
- No air conditioning
- No vapor barriers
- Few explicit air-tightening or "draft-stopping" details
- Masonry and old-growth solid timber structures
- Plaster is the dominant interior finish

Pre-WWII Buildings

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Five Fundamental Changes

1. Increasing Thermal Resistance
2. Changing Permeance of Enclosure Linings
3. Water/Mold Sensitivity of Materials
4. Moisture Storage Capacity
5. 3-D Airflow Networks

Changes …

- Expectations are rising
  - Faster design and construction
  - Lower risk of delays / cost over runs
  - Lower operating costs
  - less energy consumption (Codes)
  - more comfort and IAQ
- In short …

  better buildings at less total cost

Performance?

- More than on-time, on-budget, to code
  - Safe
  - Healthy
  - Comfortable
- A growing clamor for….
  - Durable
  - Low-energy
  - Maintainable
  - Modifiable
  - Repairable
- All delivered reliably, predictably

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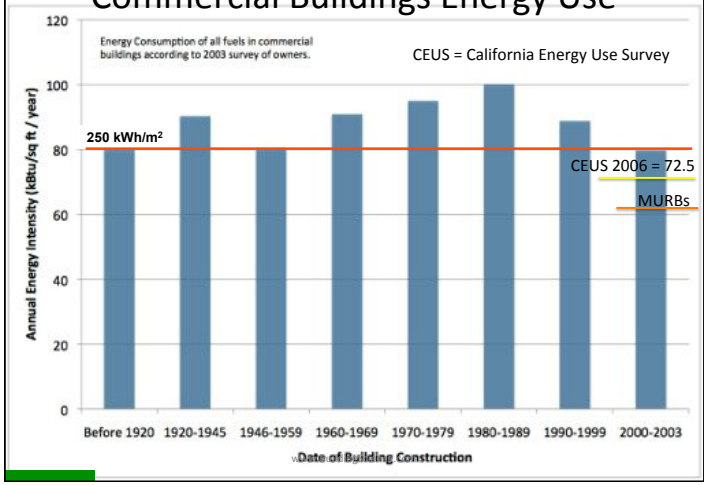
Commercial Buildings Energy Use



R2

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R2

R4

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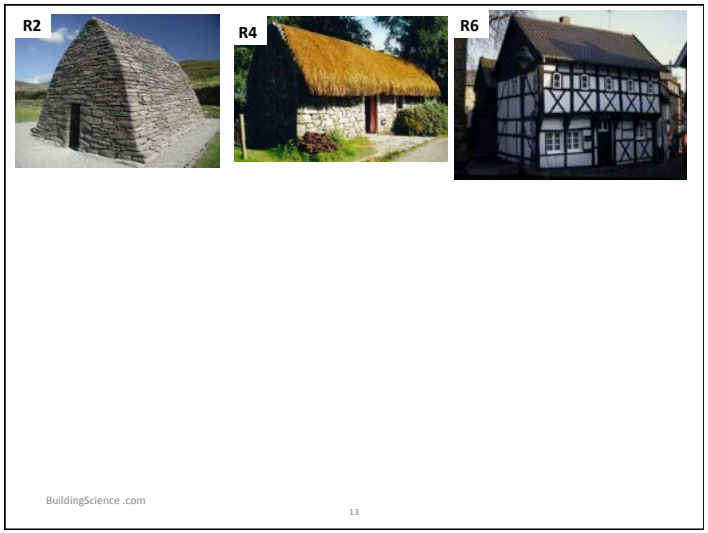
R2
R4
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R2
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R2
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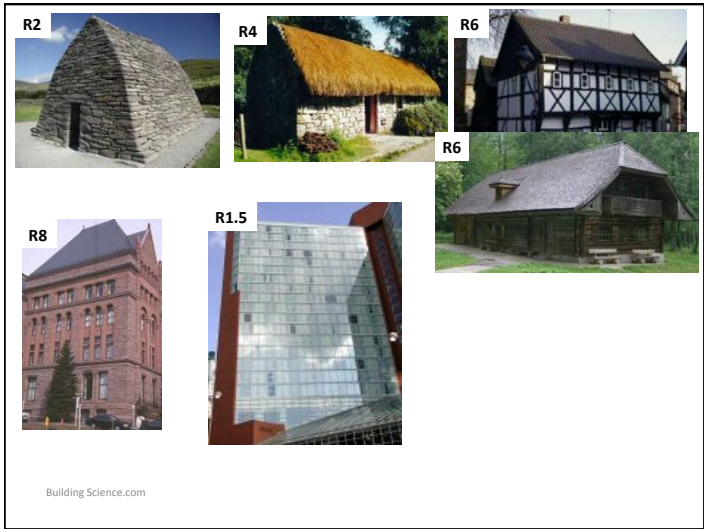
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R8
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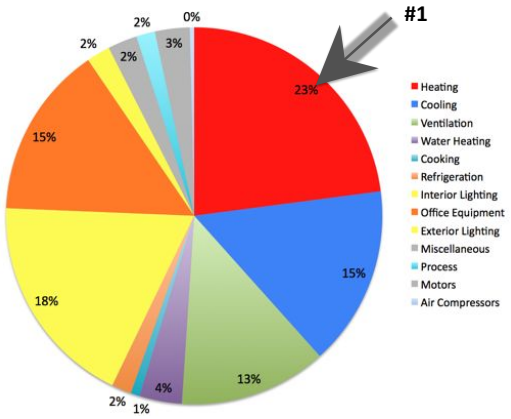
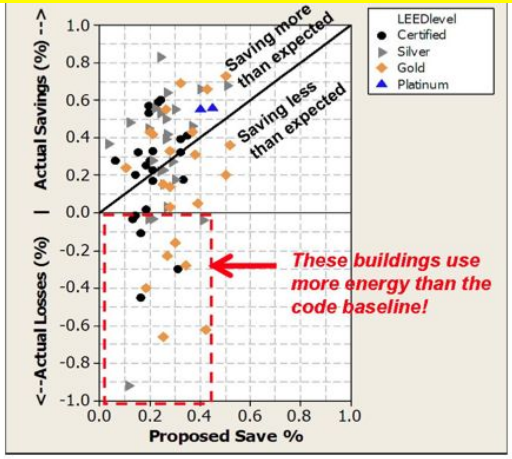
California Large Office: All Energy



Modeling is not reality. Precision in not Accuracy.



From: New Buildings Institute Study

Why such poor performance?

- Not enough insulation, too much air leakage
  - Thermal bridges (windows R3, steel stud R5-R6)
- Not enough solar control
  - Windows! (too large, overhangs, trees)
- Too much ventilation
  - And/or poor control of it
- Too many complex systems
  - HVAC systems no one understands

Beware Unintended consequences

- Improving enclosure (windows/ roofs) changes things
- Less heat gain
  = change in AC performance
  = more condensation
- Less heat flow
  = less drying
- More airtightness
  = mech ventilation required

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, robust, assemblies and systems
  – More tolerant of operational/construction errors
  – Less complex, easier to manage

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

Skin: Enclosures in Context

- Enclosures are key to comfort and durability
- Enclosures **reduce** space heating/cooling
  - and help with lighting, ventilation
- We still need **energy** for other things
  - Dehumidification, cooling, lights, computers, etc
- But
  - **Bad enclosures ruin good HVAC**
  - **Bad HVAC can ruin good enclosures**

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This seminar

- Enclosure
  - Roofs
  - Walls
  - Windows
- HVAC - briefly
  - Humidity
  - Ventilation
  - Energy

Enclosure Design Principles

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The Enclosure: An Environmental Separator

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

Building Science Enclosures No. 28 /

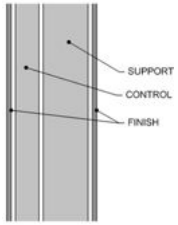
Climate Load Modification

- 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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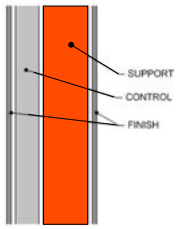
Basic Enclosure Functions

- **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

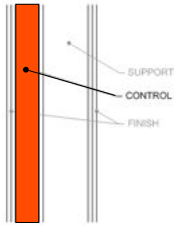


Building Science Enclosures No. 31 /

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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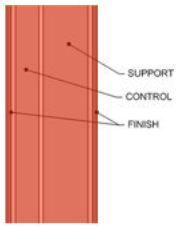
Other Control . . .

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

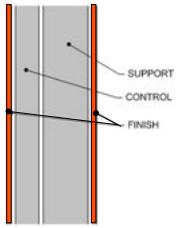
Functional Layers



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

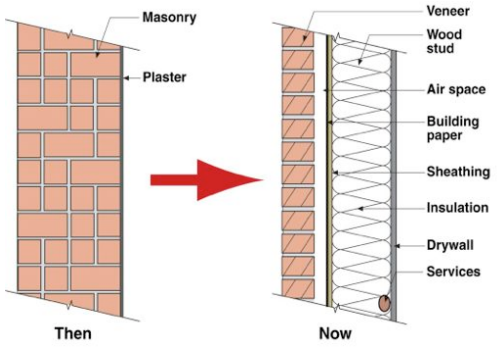
Functional Layers



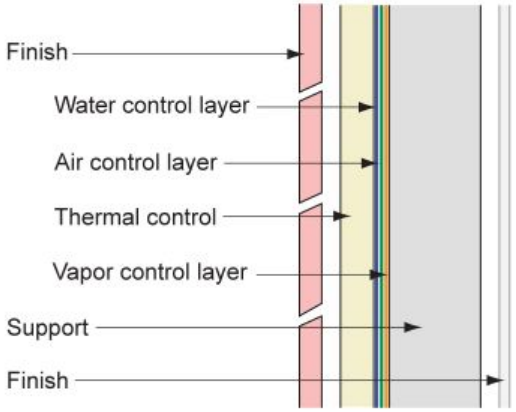
History of Control Functions

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

Changes



The Perfect Wall



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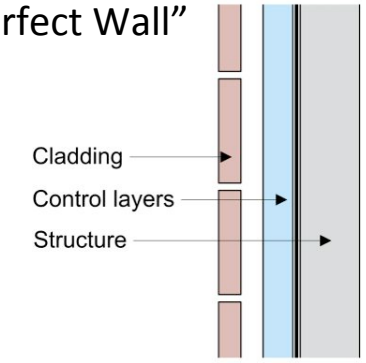
The "Perfect Wall"

- 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?

- High levels of control
- **But**, 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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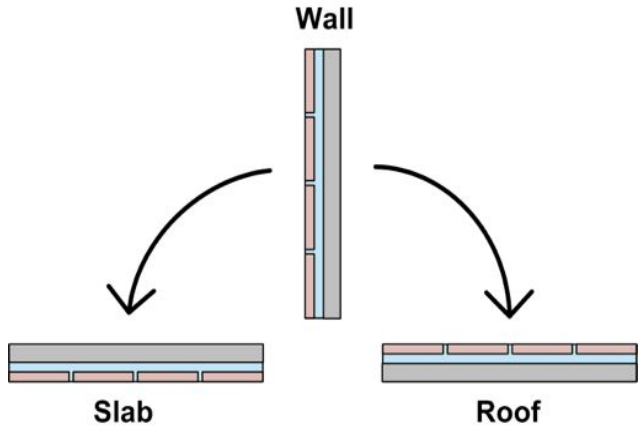

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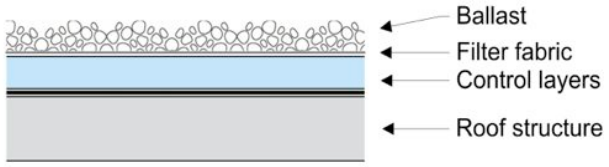

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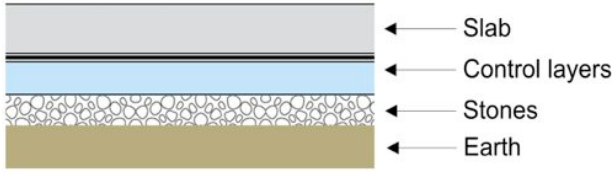

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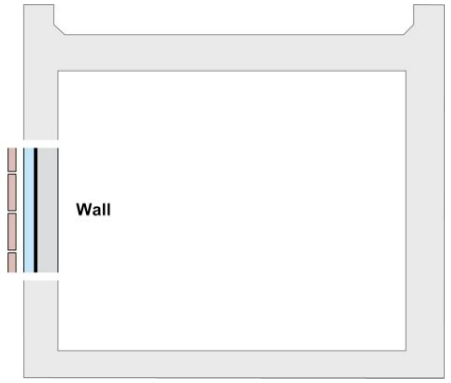

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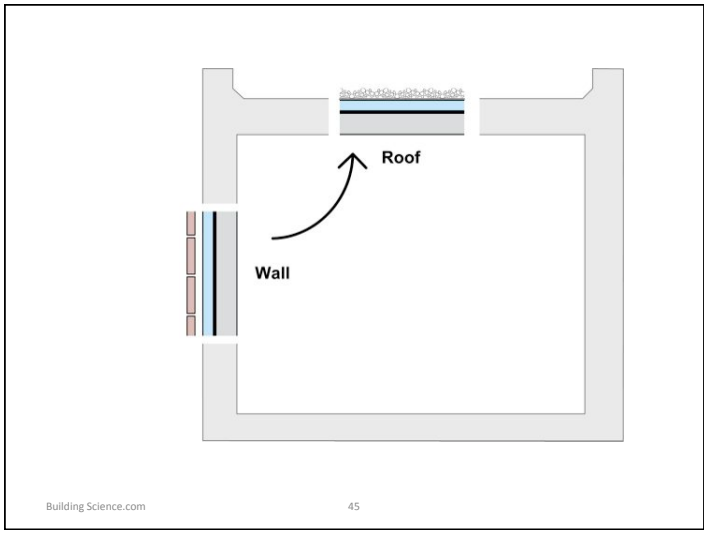
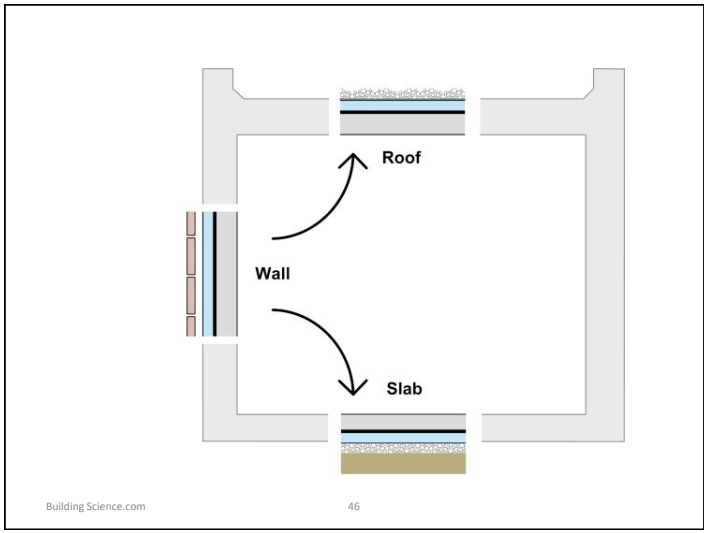
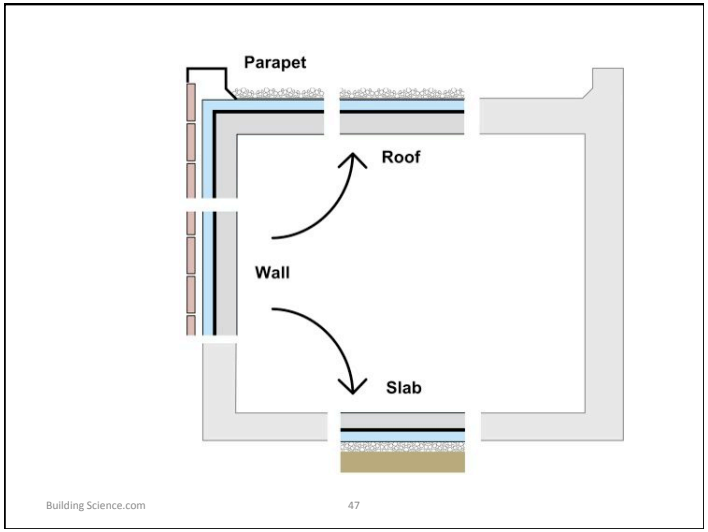
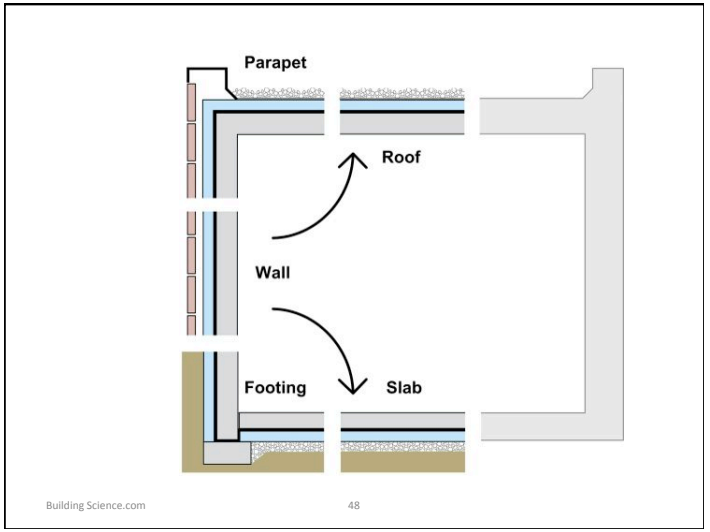
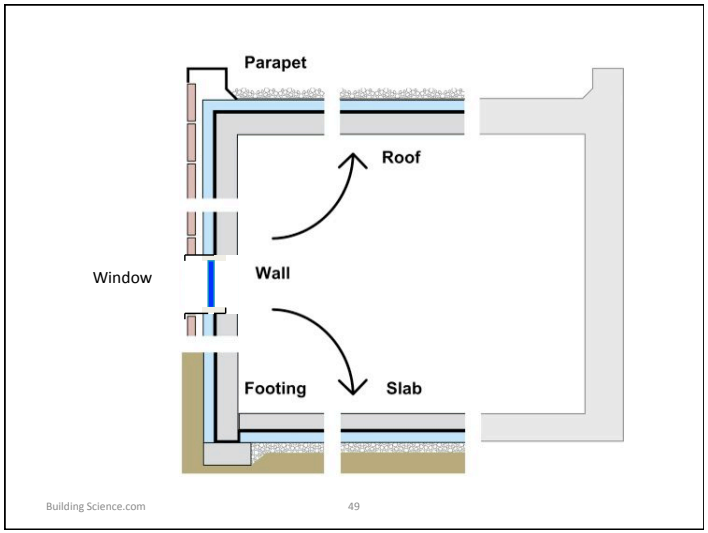
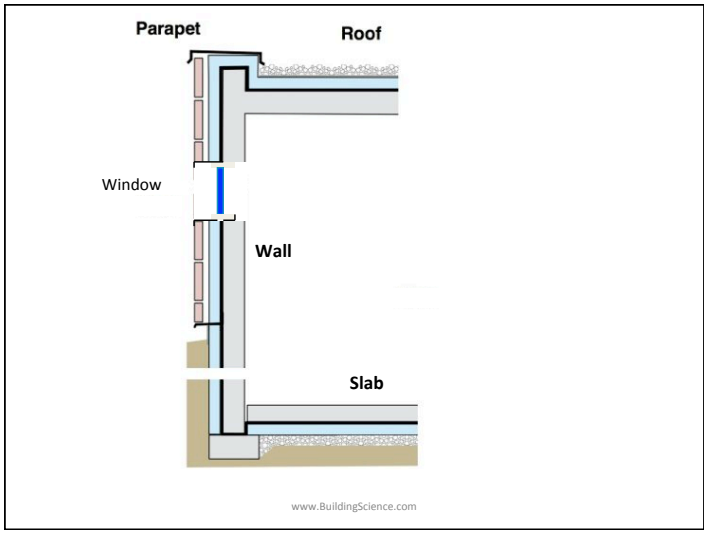

Roof
Wall
Building Science.com
45


Roof
Wall
Slab
Building Science.com
46

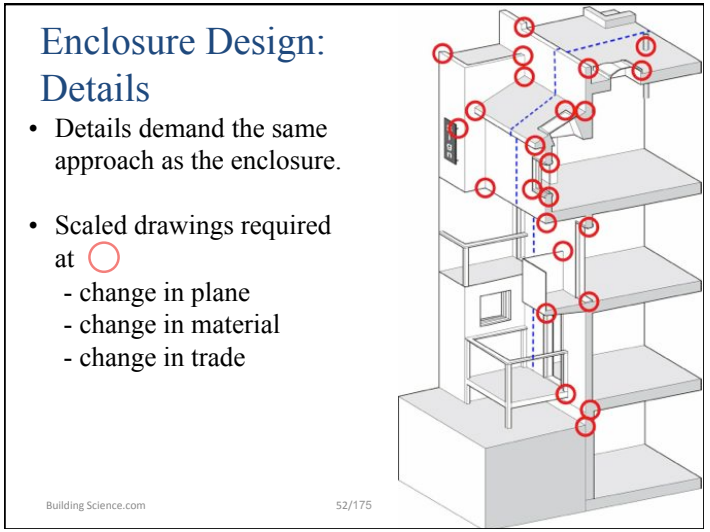

Parapet
Roof
Wall
Slab
Building Science.com
47


Parapet
Roof
Wall
Footing
Slab
Building Science.com
48

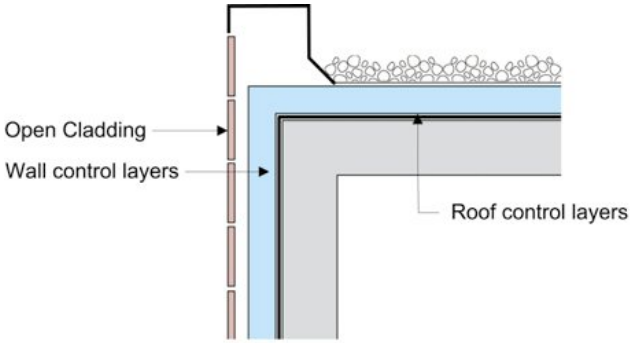

Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
49


Parapet
Roof
Window
Wall
Slab
www.BuildingScience.com


Complexity increases detailing effort, risk of failure, and cost and reduces performance


Enclosure Design: Details
• Details demand the same approach as the enclosure.
• Scaled drawings required at
- change in plane
- change in material
- change in trade
Building Science.com
52/175

Connections: Who is in charge



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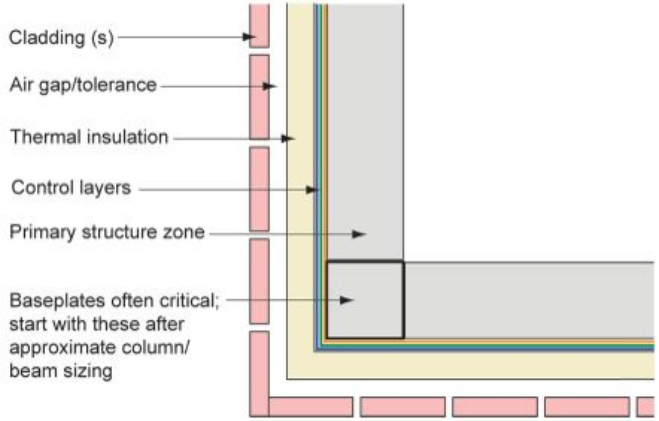
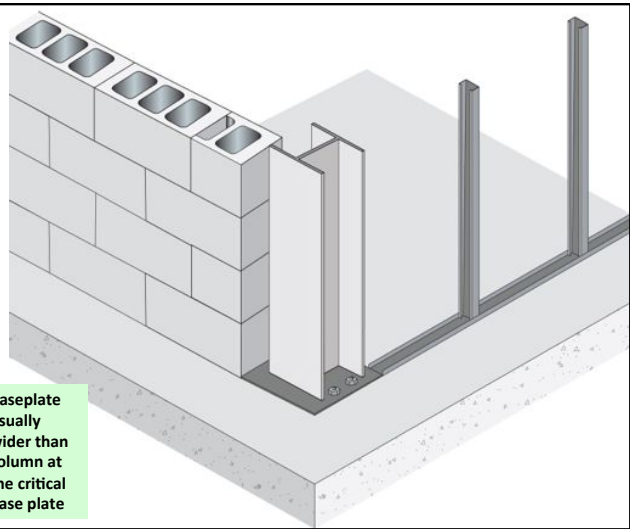
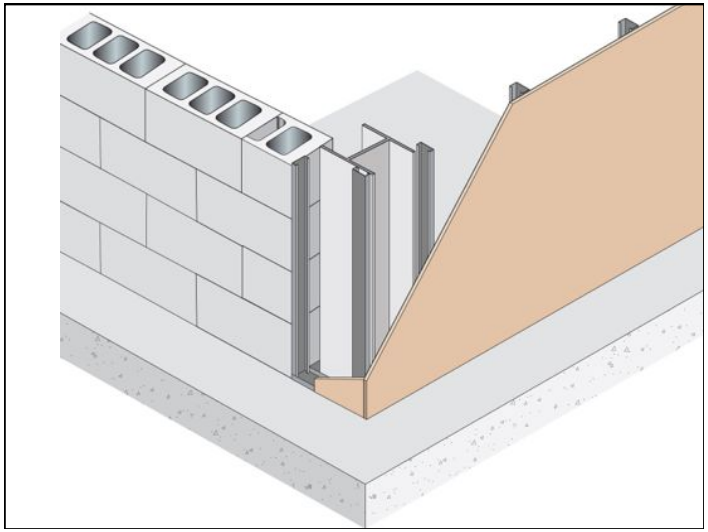
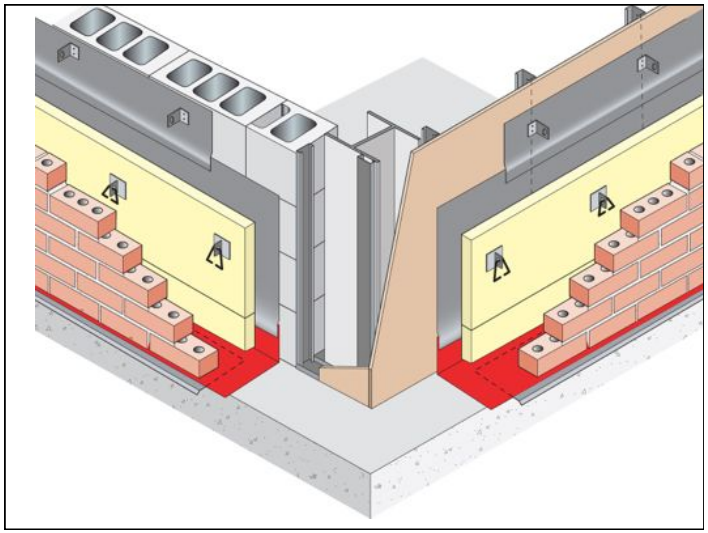
Plan Dimensions



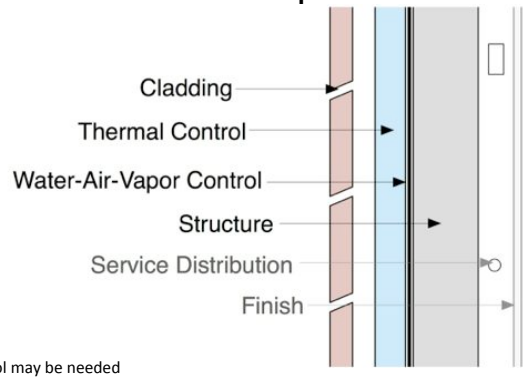


Baseplate usually wider than column at the critical base plate





Perfect Wall expanded



Fire Control may be needed
Sound Control optional

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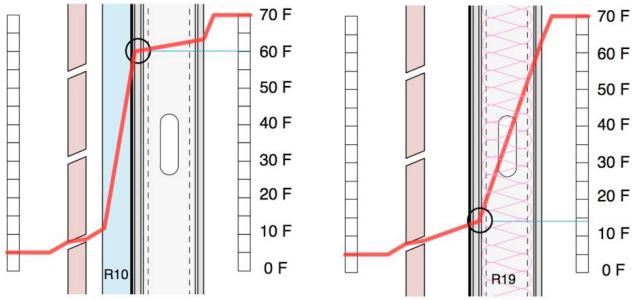
Condensation & Drying



No stud cavity insulation
= perfect wall
= no moisture risk

Cavity insulation
= cold sheathing
= condensation risk
= slow meeting

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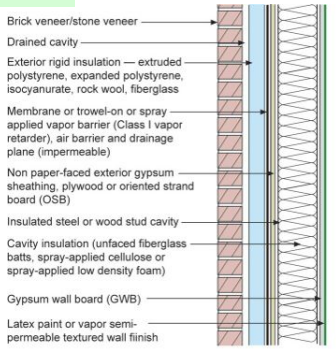
Ratio: $\frac{\text{Exterior R-value}}{\text{Studbay R-value}}$ controls risk of condensation



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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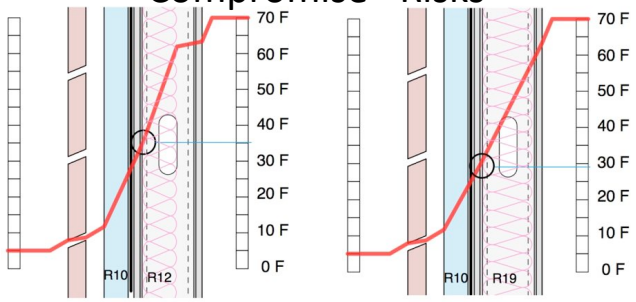
Compromise= Risks



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Rain Control

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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 &concrete to small local points
- Vapor control
  - Not that important to ensure continuity

Energy

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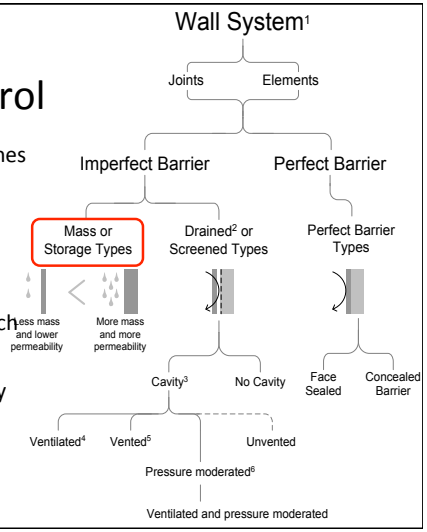
Next Steps

- 1. Rain Control
  - most important
- 2. Air Control
  - Energy, health, humidity
- 3. Thermal Control
  - Solar shading
  - Thermal bridging

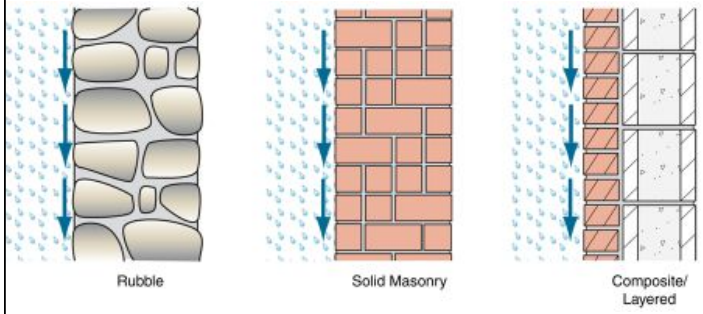
Can be separate Or Combined in same material

1. Rain Control

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



Historic: Mass/Storage Walls



John Straube

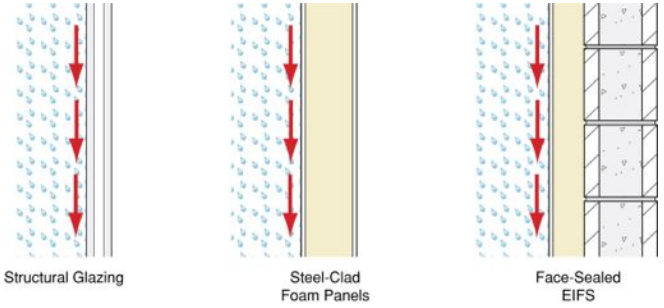
No building paper, flashing, weepholes

Rain Control 67

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

Rain Control 68

Perfect Barrier / Face Sealed



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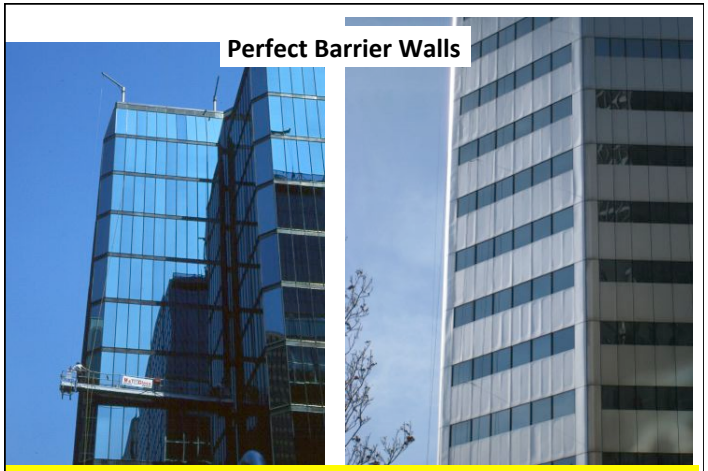
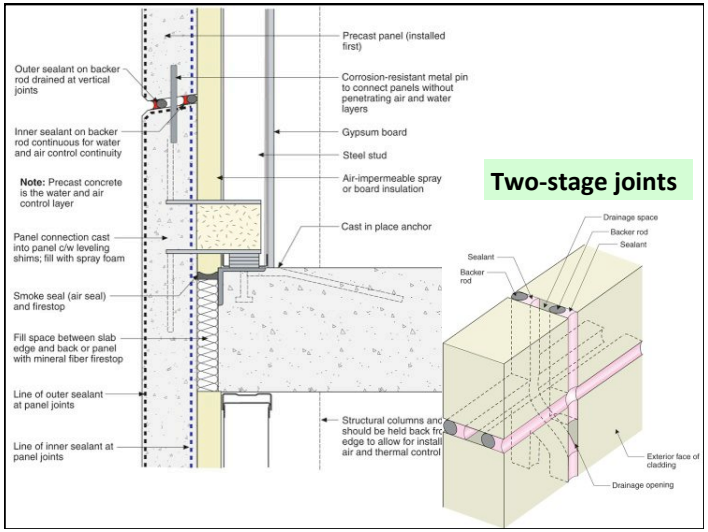
Perfect Barrier Walls



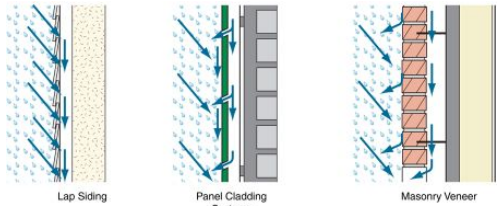
It is all about joints, transitions, penetrations which may not be built, or remain perfect

Precast is often a functional perfect barrier wall .. but the joints leak, exposed sealant fails!



Drained Walls

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



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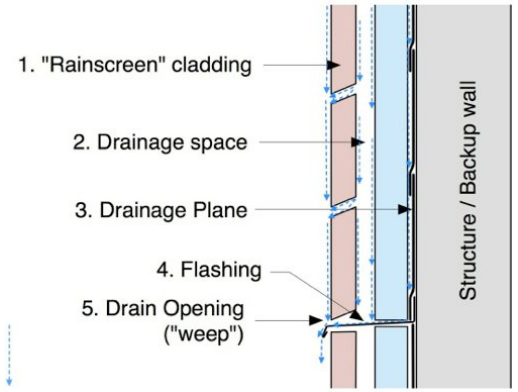
"Rainscreen" or "Drained" System



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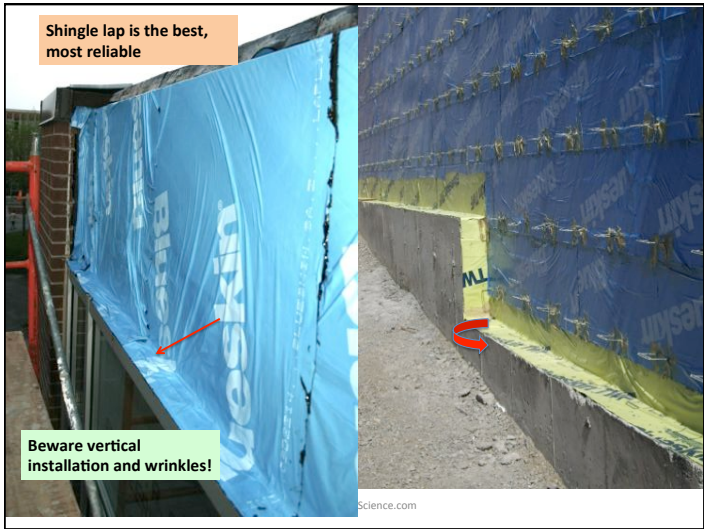
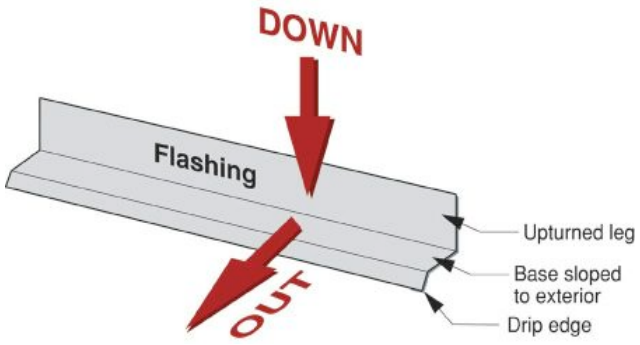


Flashing must be waterproof



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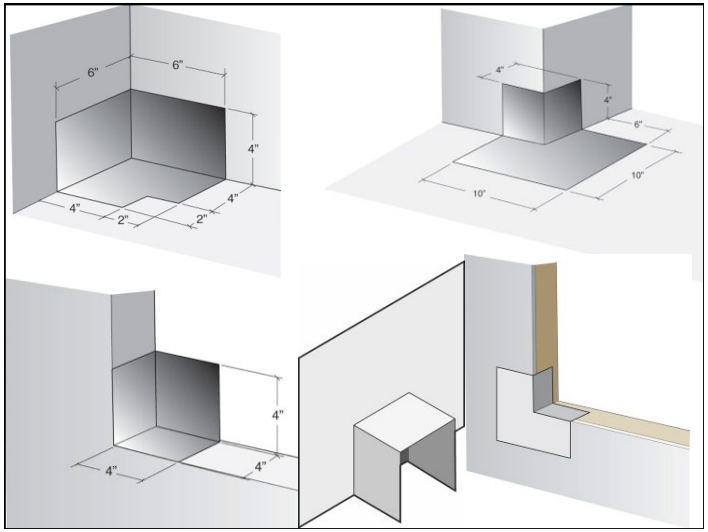
Joseph Lstiburek – Rain Control 77

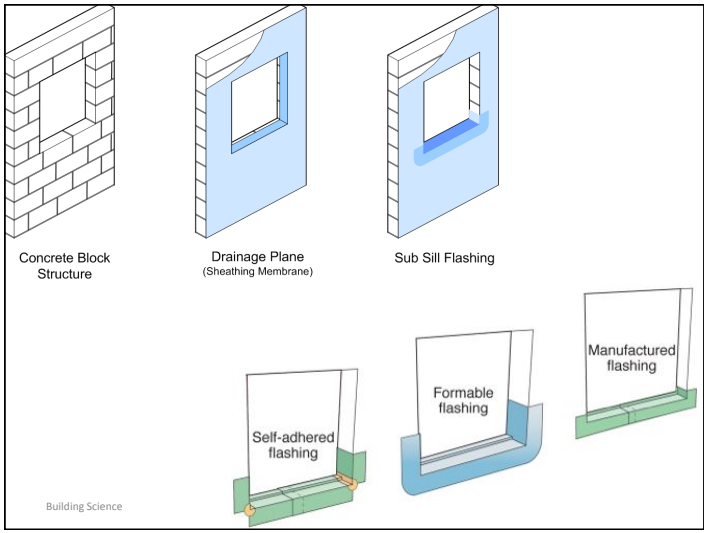


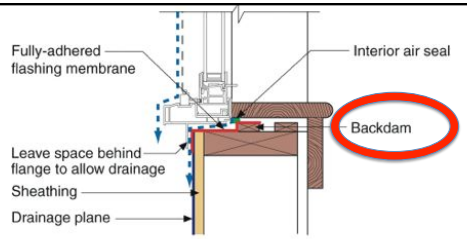
Windows and Doors

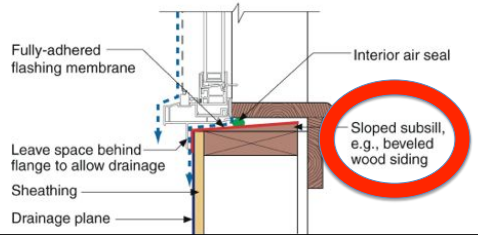
- All penetrations should be drained, regardless of the approach taken to the element
- Windows and doors are the most critical openings to drain
- Rough opening must be drained

Leaky windows

- Studs and sheathing are sensitive to leaks



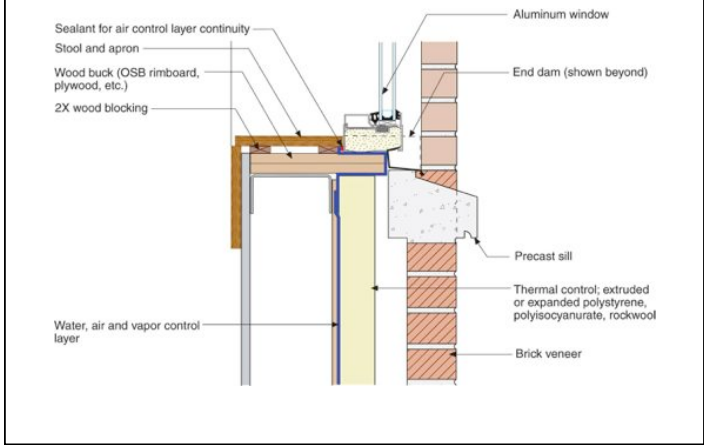


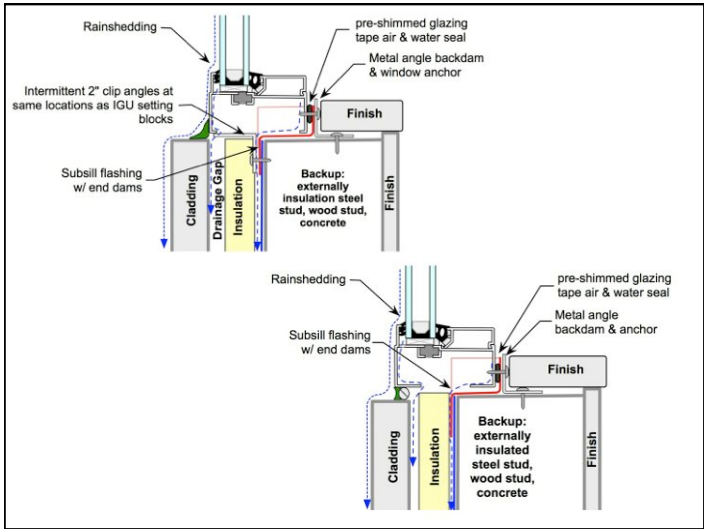


Mixed membrane + liquid

Often use membranes for transitions

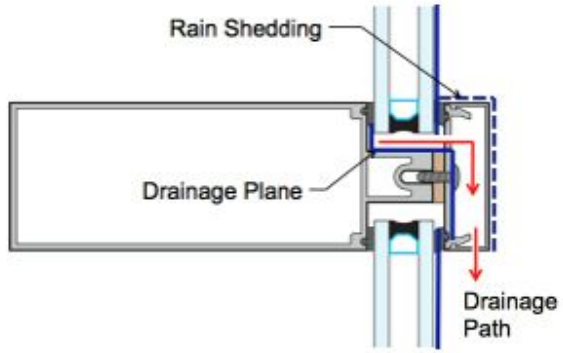
Backdams / Slopes are Important

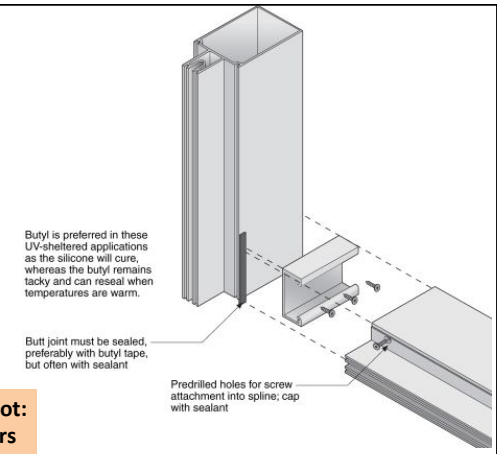




Continuous interior angle provides backdam and airseal continuity

Rain Control





Corners are weak spot:
- **How to drain corners**
- **How to airseal?**

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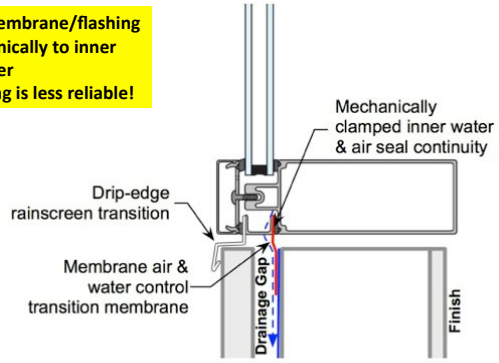
Curtainwall Integration

Seal membrane/flashing mechanically to inner shoulder
Caulking is less reliable!



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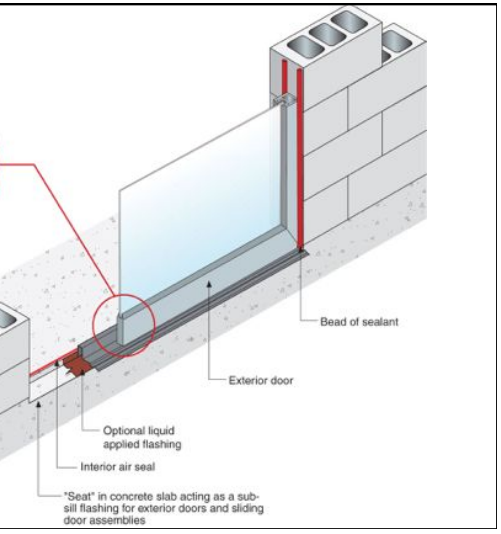
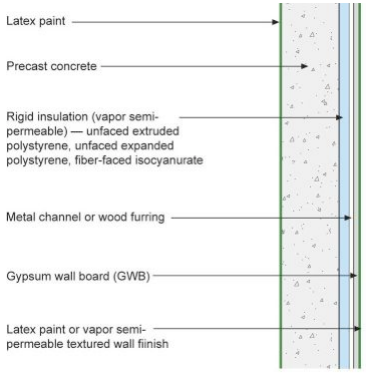
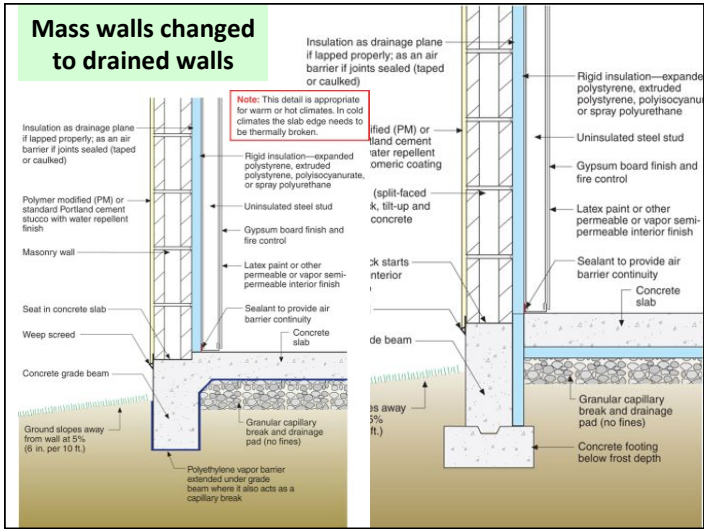


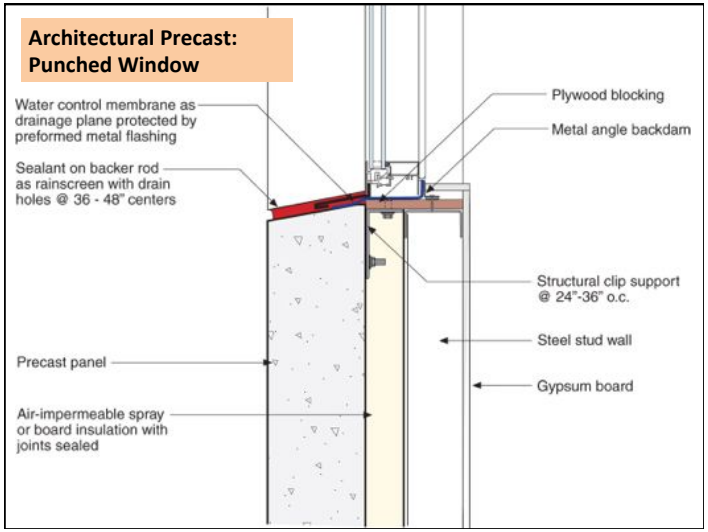
Not "Perfect", But pretty darn good!



Mass walls changed to drained walls

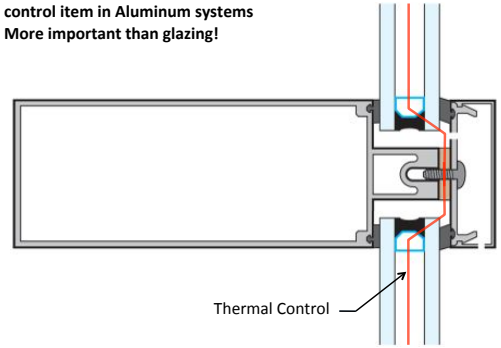


Architectural Precast: Punched Window



Thermal Control

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



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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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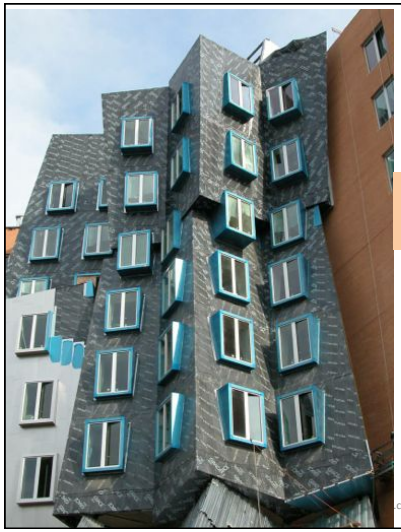

Air-Water Control Layers

Sloped and complex surfaces demand very high performance

Fully-adhered air-water barrier

Vapor Permeable!

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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

Non-adhered, vapor permeable =modest performance

Supported **flexible membrane is better**

Air Flow Control

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Airflow control

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

104/175

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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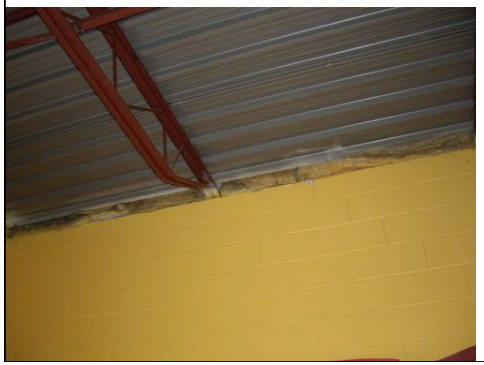
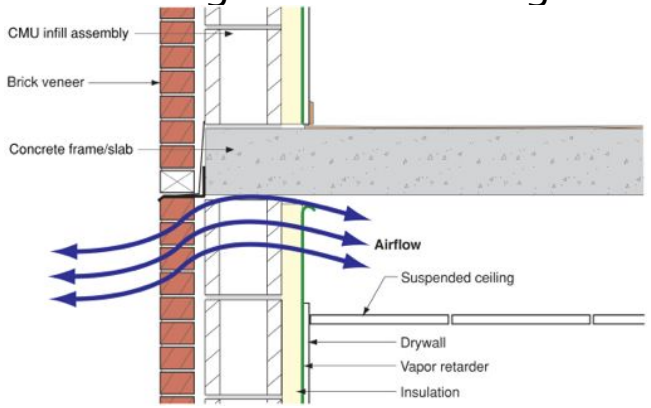
Air + Water Barrier

- Beware:
- Around windows
- Canopies
- Parapets

Find the air leak

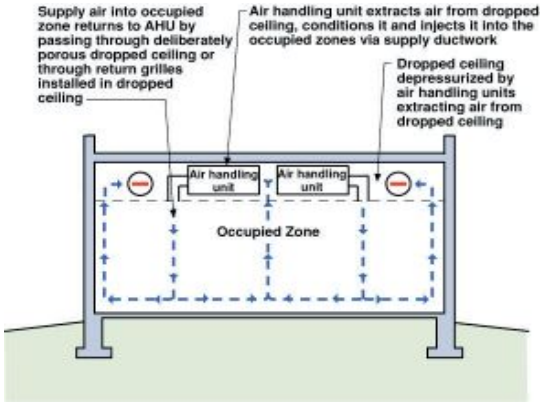


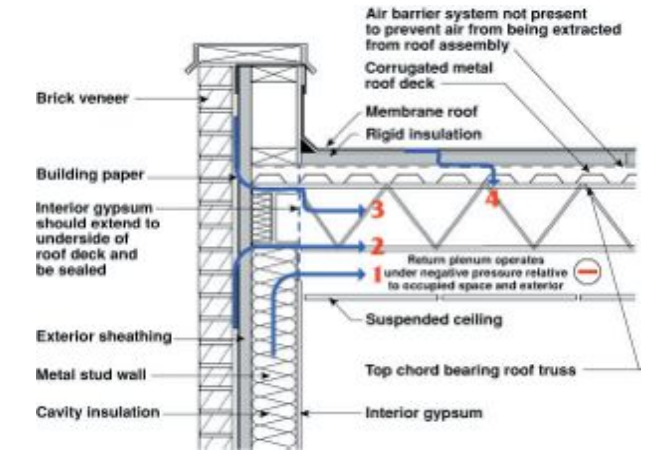
Leakage above ceilings



Building Science.com Airflow Control No. 110/79

Dropped-Ceiling Return Plenum





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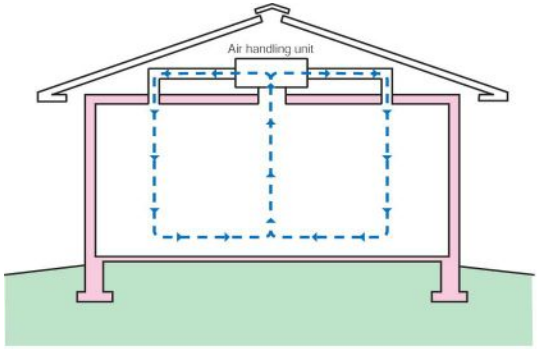
Ducts in Un-conditioned Attic



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

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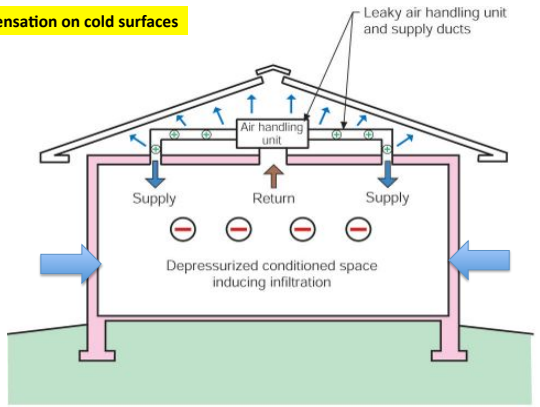
Condensation on cold surfaces



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

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Details

- Air & water & vapor transition membranes

Commercial Buildings: Often exterior air barrier is only practical solution

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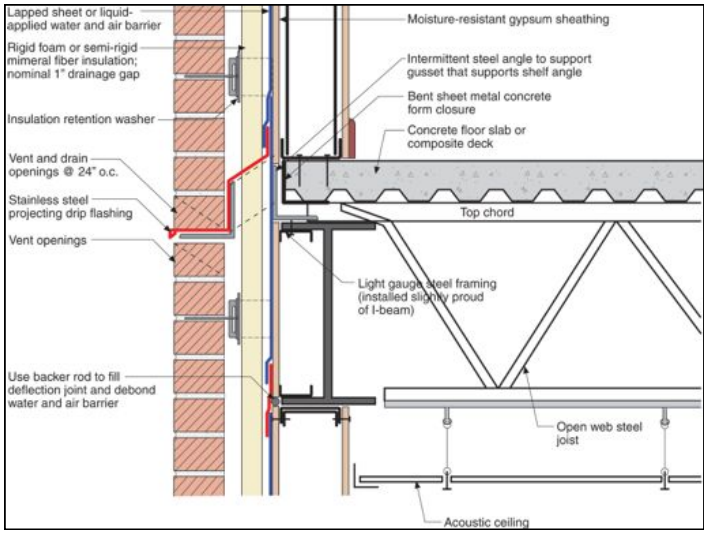


Rigid Exterior Air Barrier

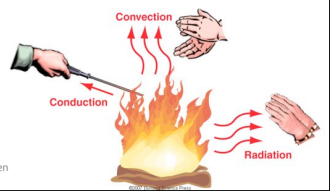
3. Thermal control

- Ensure Comfort
  - Avoid hot/cold interior surfaces
- Warms surfaces = durability
  - Avoids condensation in hot and cold weather
  - hence, a durability and health strategy
  - Keep structure warm and dry and stable
- Save Energy
  - Reduce heat flow

12-03-21

Thermal Control

- Insulation (conduction)
  - Slows heat flow in and out
- Windows (conduction, radiation)
  - Slow heat flow in and out
  - Control solar gain : allow or reject?
- "cool" roofs
  - Reduce solar gain
- Radiant barriers



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Solar Shading

- Reduce window area
- Provide shading (do analysis
- Low-solar gain

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
- "True" R-value is what matters
  - Control thermal bridging!
- Increased insulation should reduce HVAC capital as well as operating!

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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

Thermal Continuity / Thermal Bridges

- Some short circuiting is normally tolerated.
- High-performance walls tolerate few bridges
- Major offenders / weak spots
  - Penetrating slabs (<R1)
  - Steel studs (<<R1)
  - Windows (R2-R3)
- *Product* of **Area** and **U-value** defines significance to energy and condensation

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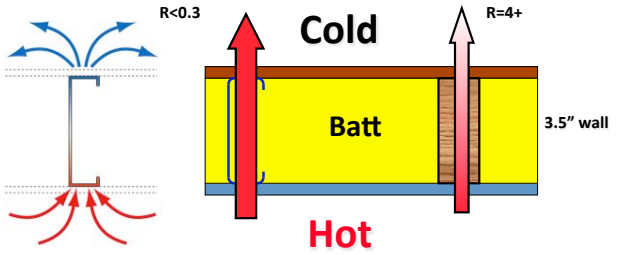
Thermal Bridging

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



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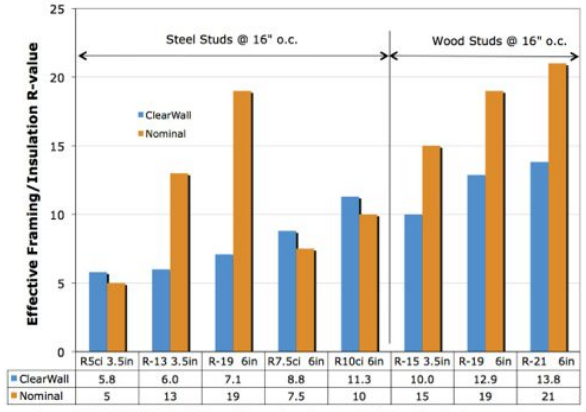
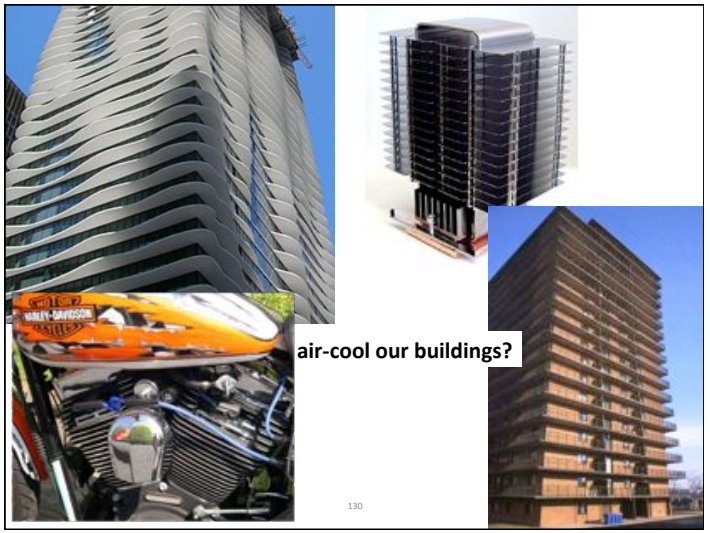
Insulation and Thermal Bridges No. 128/65

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

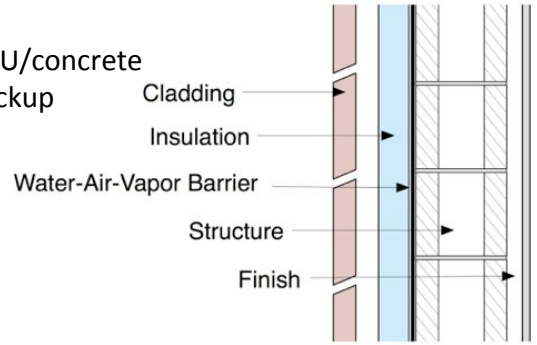


Thermal Bridge Examples

- Aluminum framed
- Balconies, Exposed slab edges

Perfect Wall

- CMU/concrete backup



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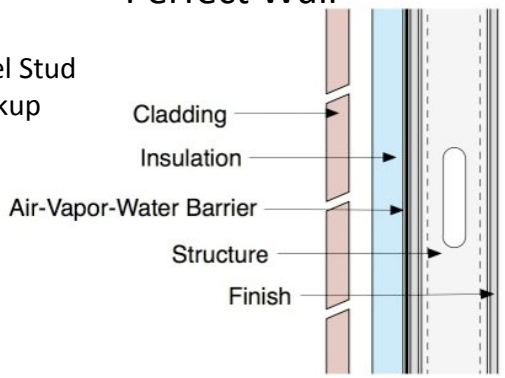
Perfect Wall

- Steel Stud Backup



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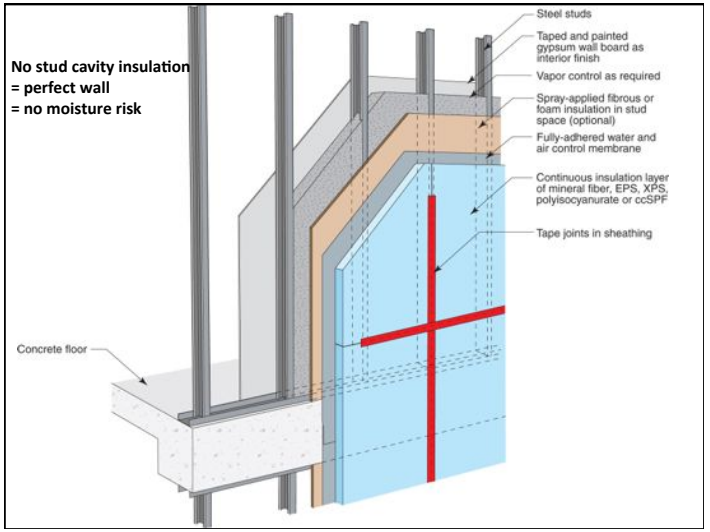
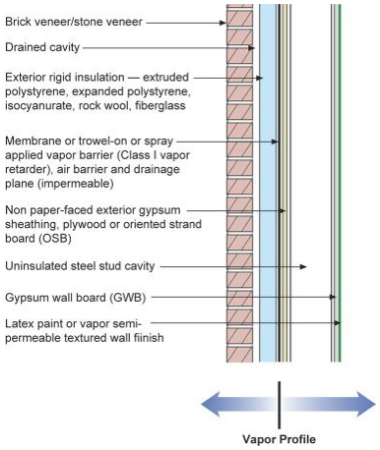


Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



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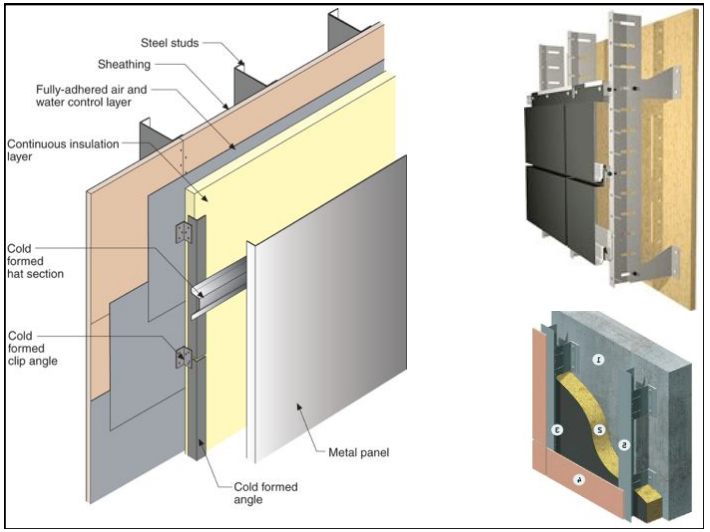
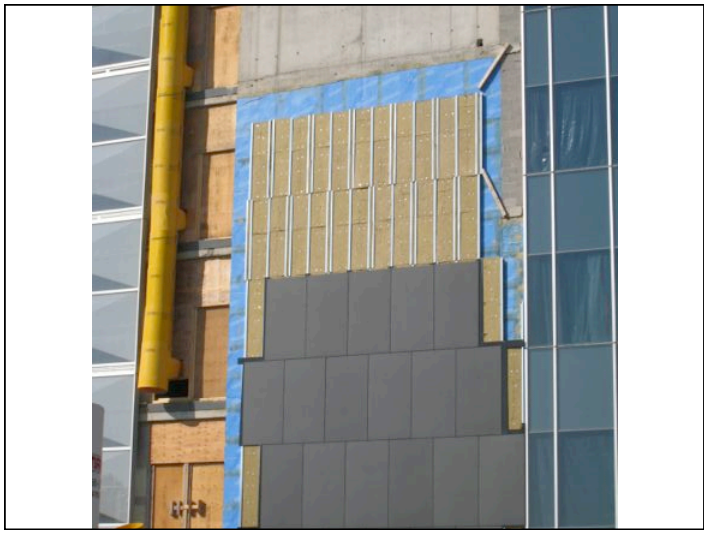
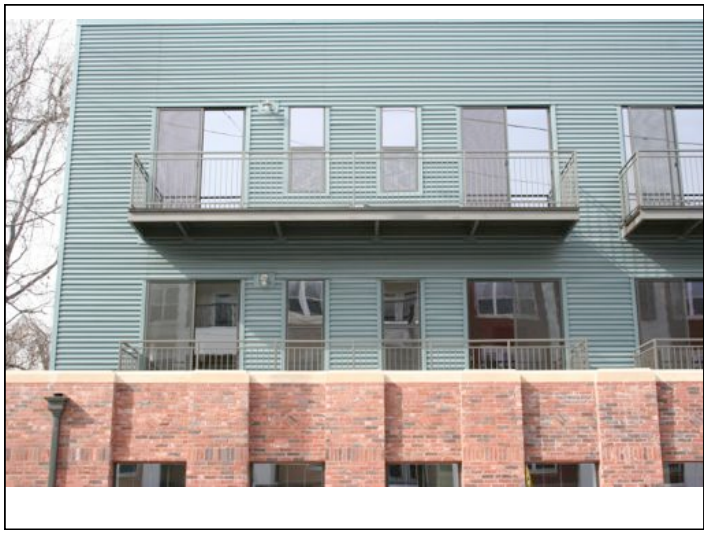
Blueskin


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



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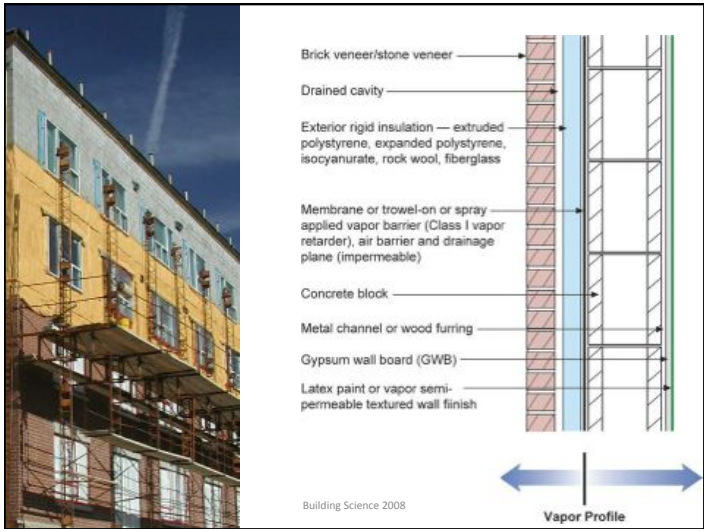
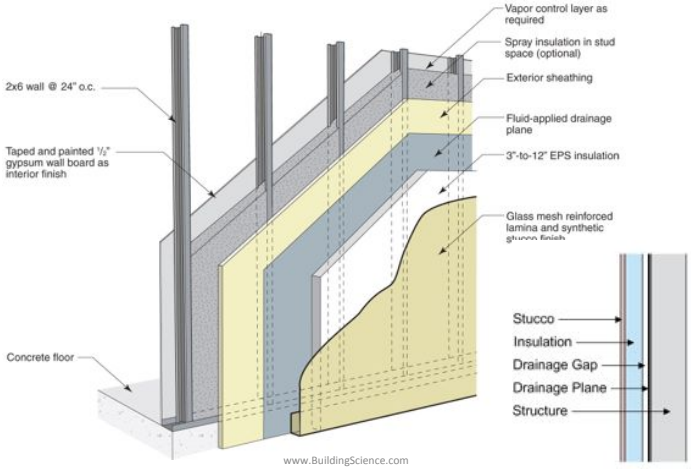
Hartford

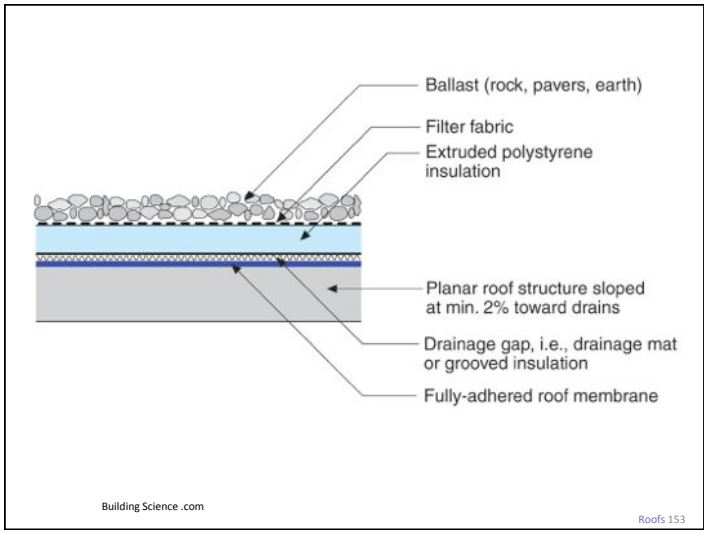

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel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

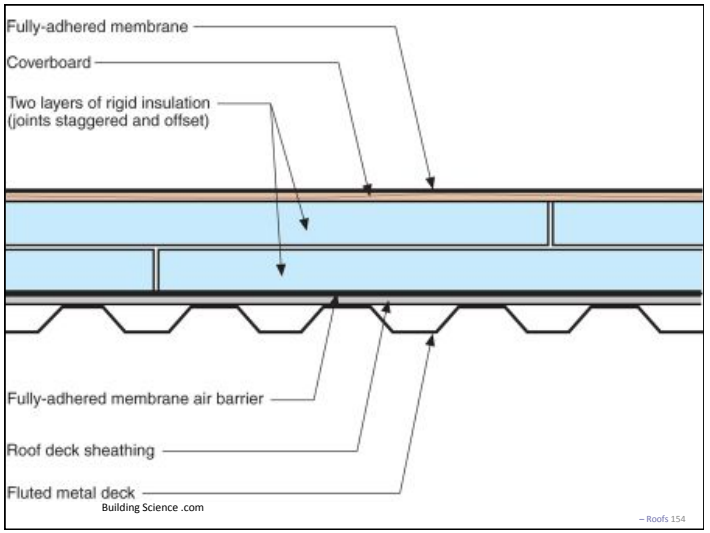
Closed-cell spray polyurethane foam: ccSPF
-Rain control
-Air Control
-Thermal Control
- Vapor Control

EIFS: no longer a four letter word



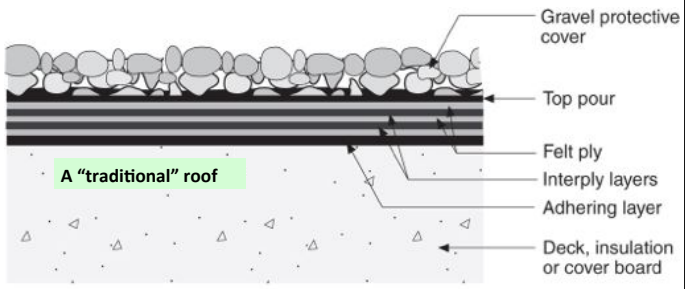
Drained EIFS is HP





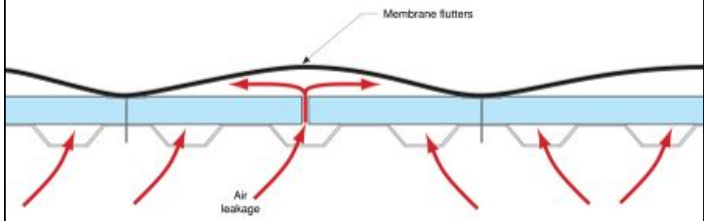
Best UV Protection: rocks

- But, you need to hold down to resist wind
- Light color stones = reflective roof performance



From Baker, M.; Roofs, 1980

- What an air barrier?
- Why fully adhered?



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Conclusions

- Continuous drainage and rain control layer
- Continuous air control layer (air barrier)
- Continuous thermal control layer
  - Limit the thermal bridges

Good Mechnicals

The other half of the pie

Functions

Five Critical functions are needed

- Ventilation
  - "fresh air"
  - Dilute / flush pollutants
- Heating
- Cooling
- Humidity Control
- Air filtration / pollutant Removal
  - Remove particles from inside and outside air
  - Remove pollutants in special systems

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What do you need to deliver?

Type	Temperature	Humidity	Pressure	Examples
I a	●			Heated house, warehouse
I b	●	○		Heating and normal A/C
I c	●		○	Heating + exhaust fans
I d	●	○	○	Heating+ A/C + exhaust fans
II a	●	●		Museum, fruit storage
II b	●	●	○	Pressurized + controlled
III	●	●	●	Special labs, chip fabrication
IV	●		●	Dust controlled manufacturing
V		●	●	
VI			●	

Note: ● Directly controlled ○ - Incidental Implicit

All require metered deliver of fresh air, and some exhaust of polluted air

Common Air-based Sysems

- CAV systems
  - high energy consumers but provide outdoor air
- VAV
  - decent energy performance, but rarely supply desired ventilation (fresh) air rates
- DOAS: Dedicated Outdoor Air Systems
  - provide Ventilation (+ almost always dehumidification) only
  - separate terminal equipment does heating and cooling
  - Highest performance, easy to design & fix

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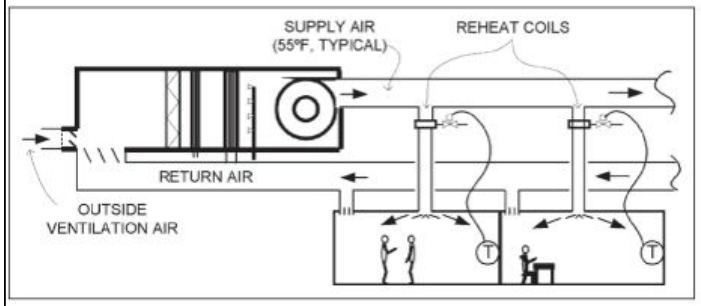
Constant Air Volume



Great RH & T control (Dewpoint of 55 all the time)
Terrible energy performance (reheating almost all the air, all the time)
Often no designed exhaust air: "pressurize" building

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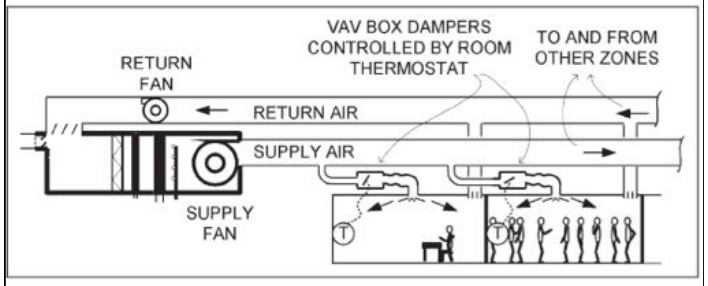
Variable Air Volume



Poor IAQ: ventilation controlled by thermostat
Poor/no RH control: depends on cooling coil operation
Either good energy performance /poor RH, or good RH / poor energy
Often no designed exhaust air: "pressurize" building

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VAV: Fixing How it works

- Pre-treat all outdoor air to reduce humidity
  - Target leaving air dewpoint of <50F
  - Cannot use "cooling" only, need dehumidification
- Ventilation air still is uncertain
  - Thermostat controls ventilation!
    - Require reheating to avoid cold rooms at min. flow
  - In multi-zone system, one zone's ventilation needs are different than an others'
    - Hence, either over-ventilation or under-ventilate

Designer's Question

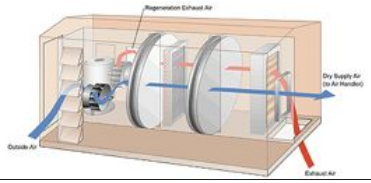
- How is indoor humidity controlled when it is 65-80F outdoors and raining (100%RH)?
  - Sensible load is very low (lights+people)
  - Latent load high (ventilation + people)
  - AC does not run, or does not run much
- Answer usually is "not"
  - Reheat is energy intensive but works
  - ERVs reduce humidity load, they don't eliminate it

DOAS

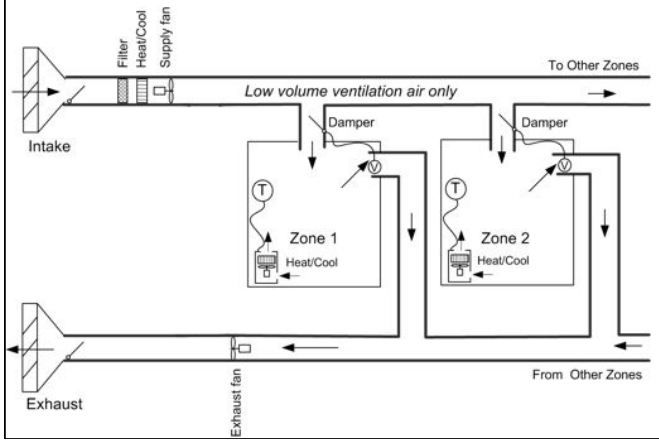
- Dedicated Outdoor Supply
  - Supplies all required dry air and fresh air
- All ventilation air can be pretreated
  - Air should be dried to <50F Dewpoint
  - Supply of dry air to each space controlled *independent of thermostat*
- Key is to decouple humidity control/ ventilation from temperature control

Energy recovery ventilation

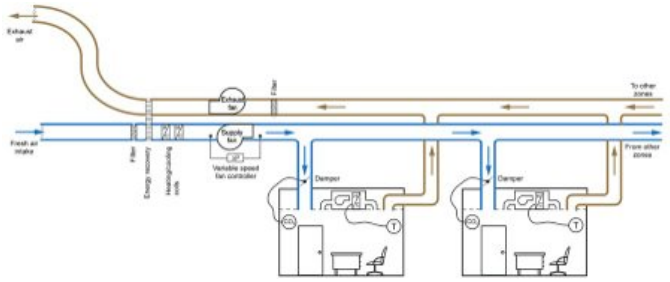
- Reduces equipment peak capacity (saves capital $)
- Reduces load on heating/cooling/ dehumidification (saves energy/operating $)
- Usually makes sense for any large mechanical ventilation flow



DOAS



BSI-022 Perfect HVAC



Thermostat controls heating/cooling by zone
Ventilation controlled by occupancy (CO_2)
All air is delivered dry (humidity control)
No re-circulated air (improved IAQ)

Conclusions

- Key to good mechanicals is to separate ventilation from heating/cooling
- Consider humidity control in climates where it is needed