High-performance Buildings

For: Association of Jesuit Colleges and Universities (AJCU)

Presented by:
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University of Waterloo / Building Science Corporation

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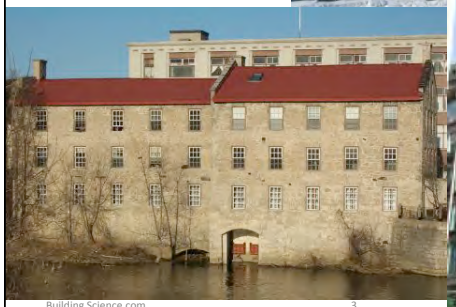
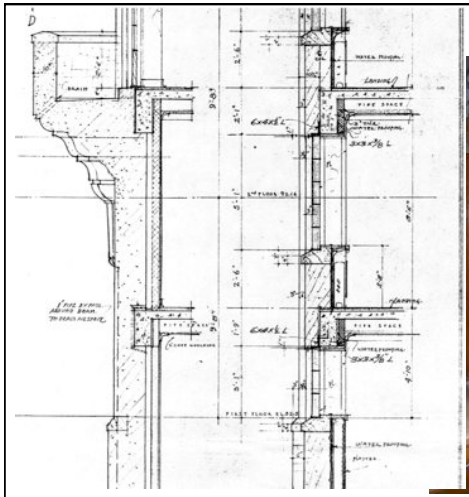
Solid masonry





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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Changes …

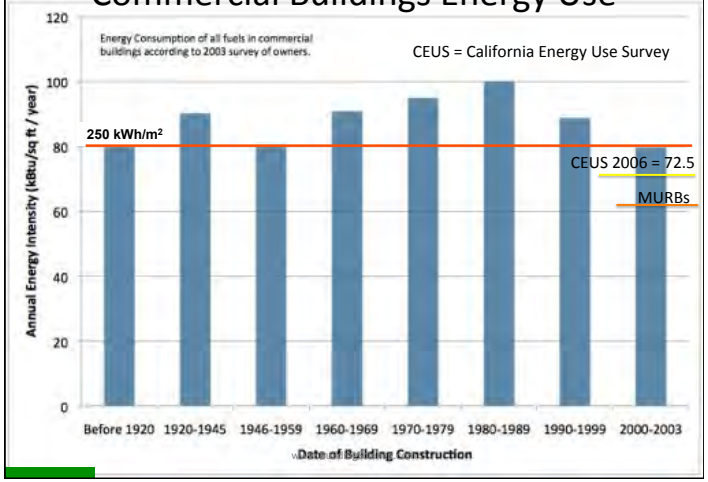
- Expectations are rising
  - Faster design and construction
  - Lower risk of delays / cost over runs
  - Lower operating costs
  - less energy consumption (Codes)
  - more comfort and IAQ
- In short …

  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

Commercial Buildings Energy Use



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R2
R4
R6
R8
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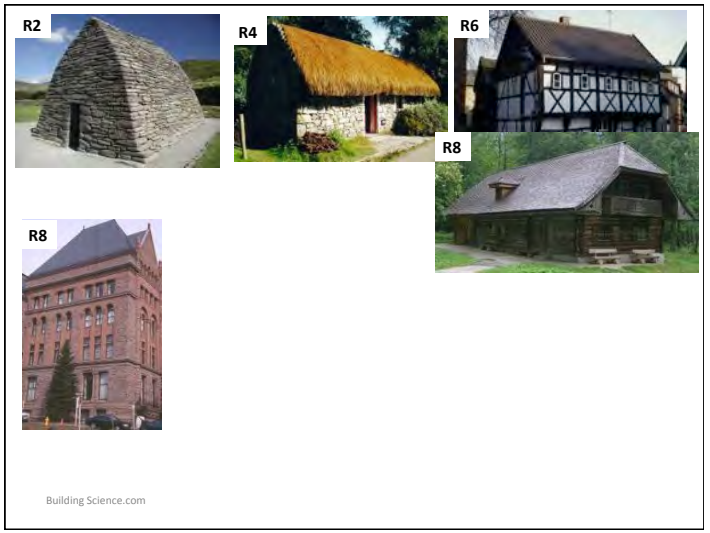
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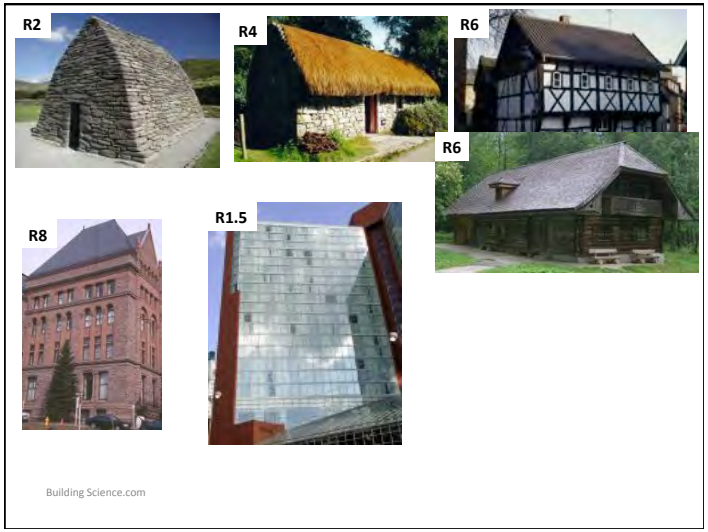
R2
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R1.5
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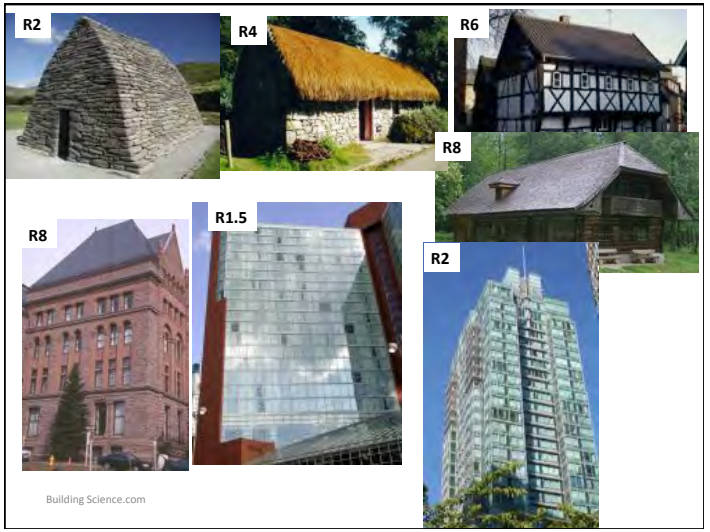
R2
R4
R6
R8
R8
R1.5
R2
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Why such poor performance?

- 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 HVAC & control systems
  - HVAC systems no one understands

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

This seminar

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

Enclosure Design Principles

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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**

The Enclosure: An Environmental Separator

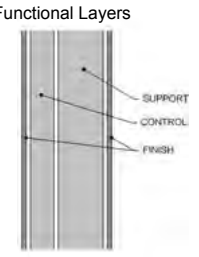
- The part of the building that physically ***separates*** the ***interior*** and ***exterior*** environments.
- Includes all of the parts that make up the wall, window, roof, floor, caulked joint etc.
- Sometimes, interior partitions also are environmental separators (pools, rinks, etc.)

Climate Load Modification

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

Basic Functions of the Enclosure

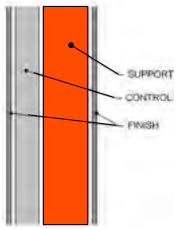
- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people
- Distribution – a building function



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

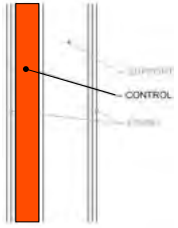
Functional Layers



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

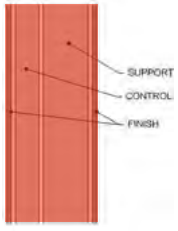
Functional Layers



Other Control . . .

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

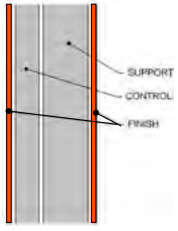
Functional Layers



Basic Enclosure Functions

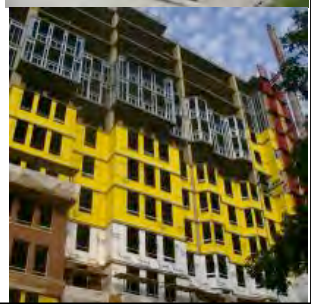
- Support
  - Resist & transfer physical forces from inside and out
- Control
  - Control mass and energy flows
- **Finish**
  - **Interior & exterior surfaces for people**
    - Color, speculance
    - Pattern, texture

Functional Layers



History of Control Functions

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



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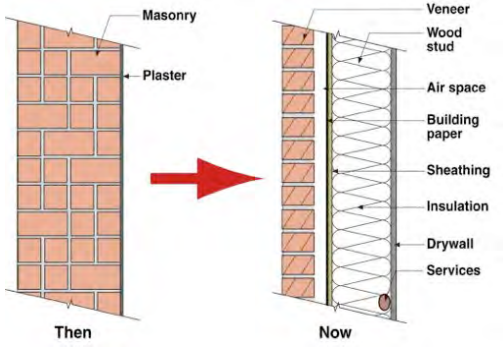
Changes



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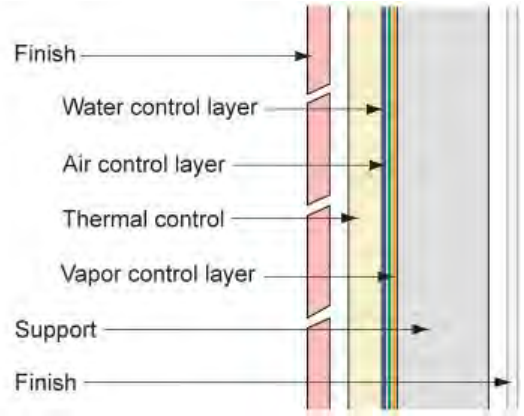
The Perfect Wall



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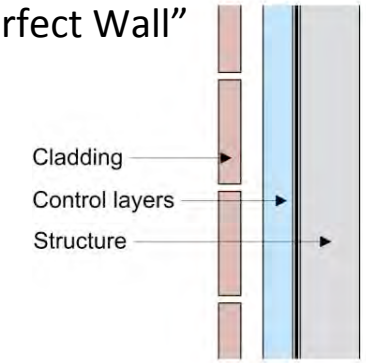
The "Perfect Wall"

- Finish of whatever
- Control continuity
  - Rain control layer
  - 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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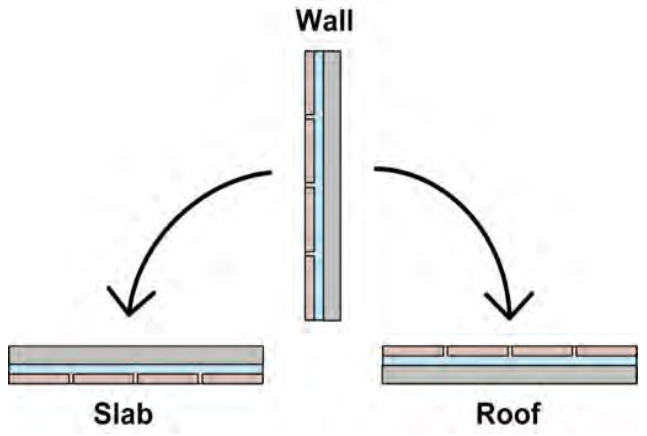

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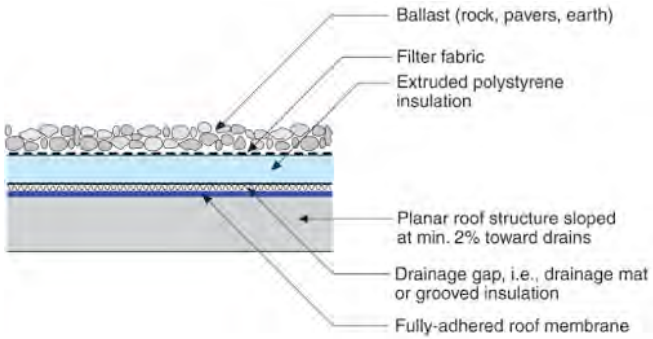

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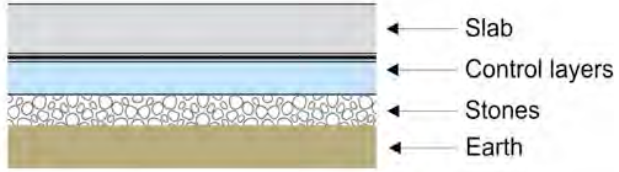

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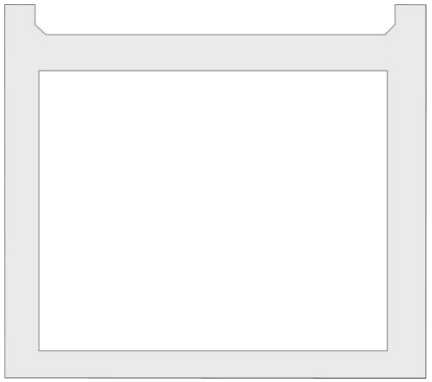

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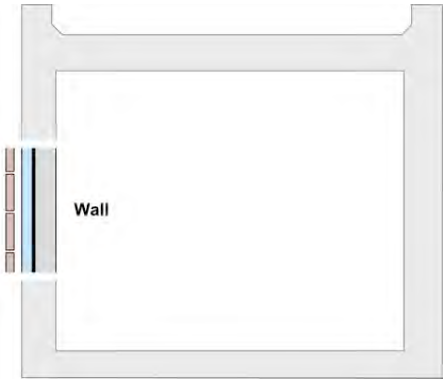

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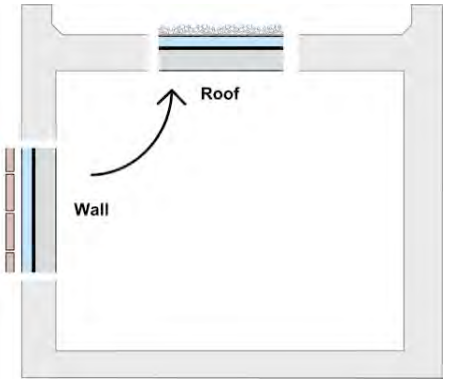

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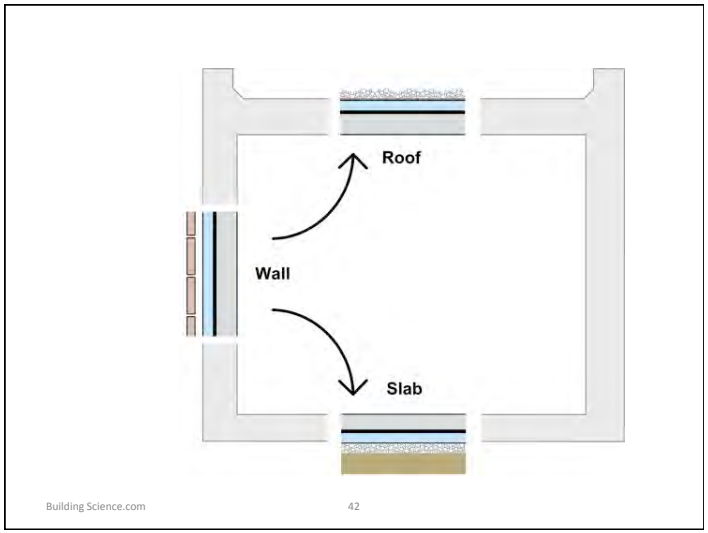
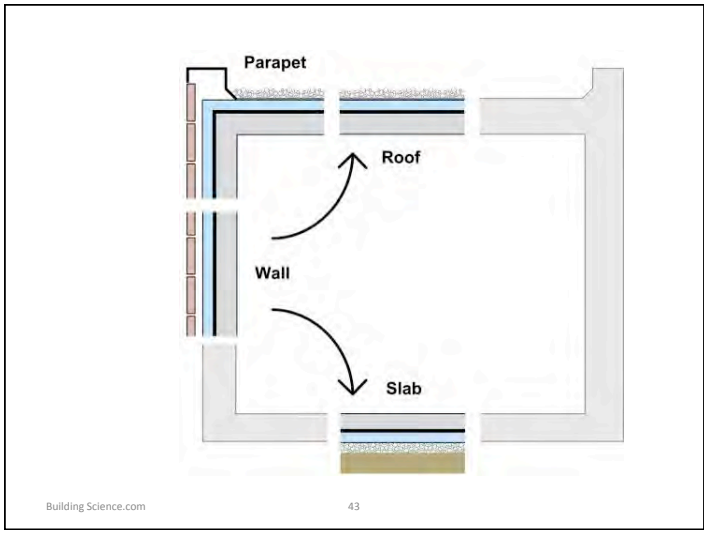
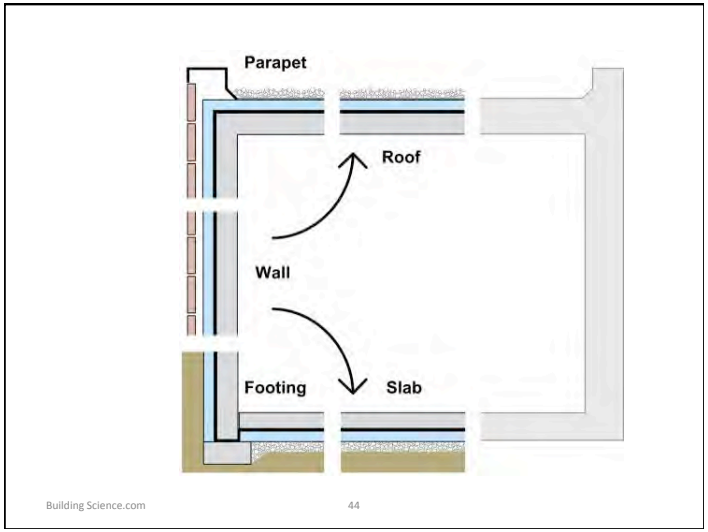
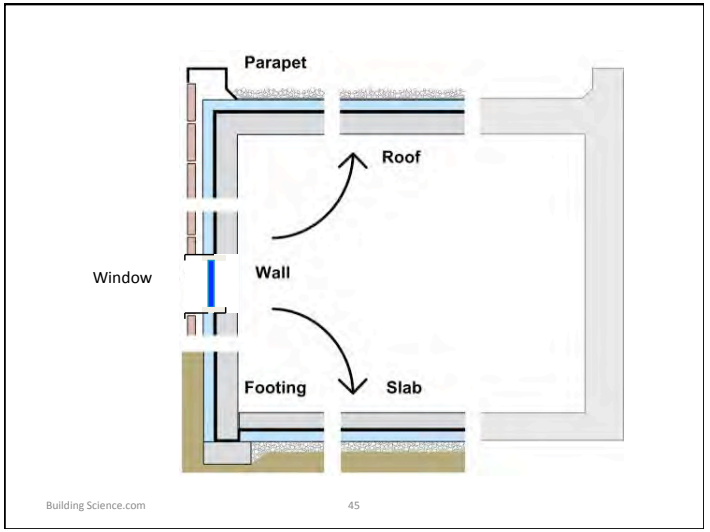

Roof
Wall
Slab
Building Science.com
42


Parapet
Roof
Wall
Slab
Building Science.com
43


Parapet
Roof
Wall
Footing
Slab
Building Science.com
44


Parapet
Roof
Window
Wall
Footing
Slab
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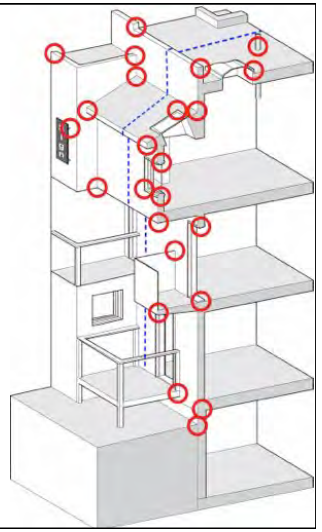
45

Enclosure Design: Details

- Details demand the same approach as the enclosure.
- Scaled drawings required at
  - change in plane
  - change in material
  - change in trade



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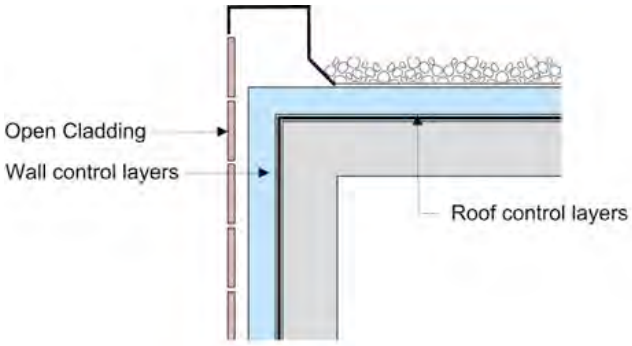
Connections: Who is in charge



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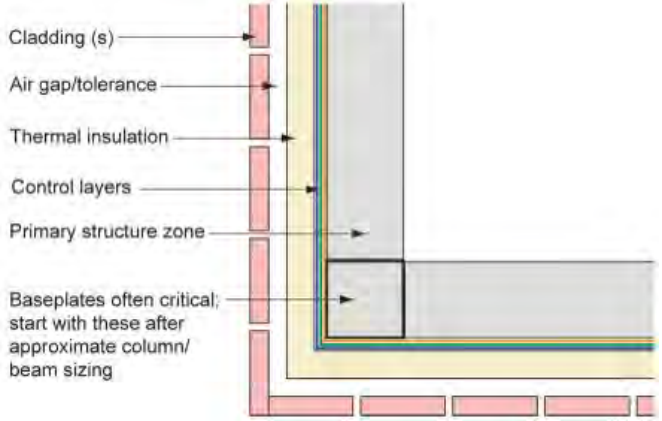
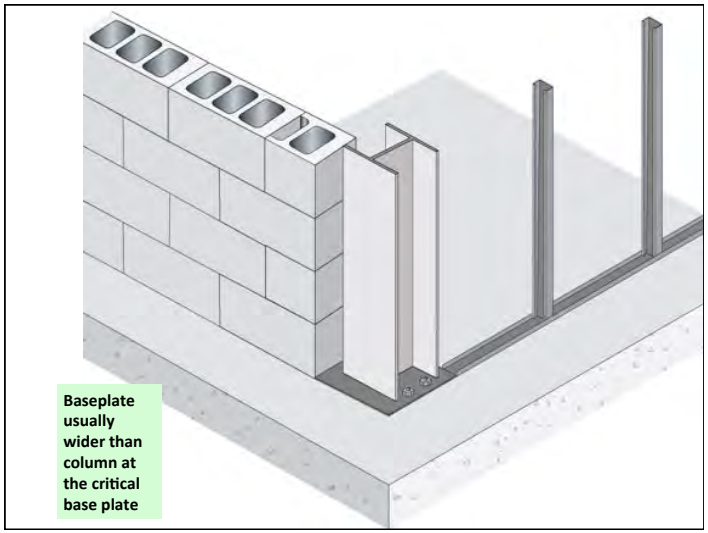
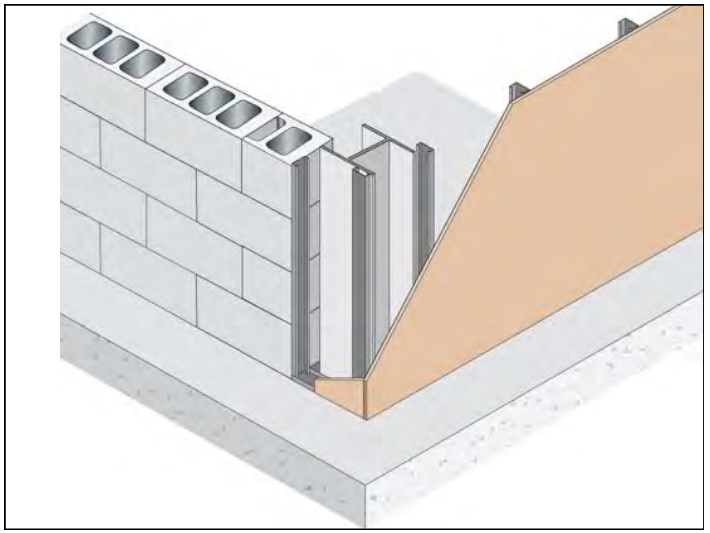
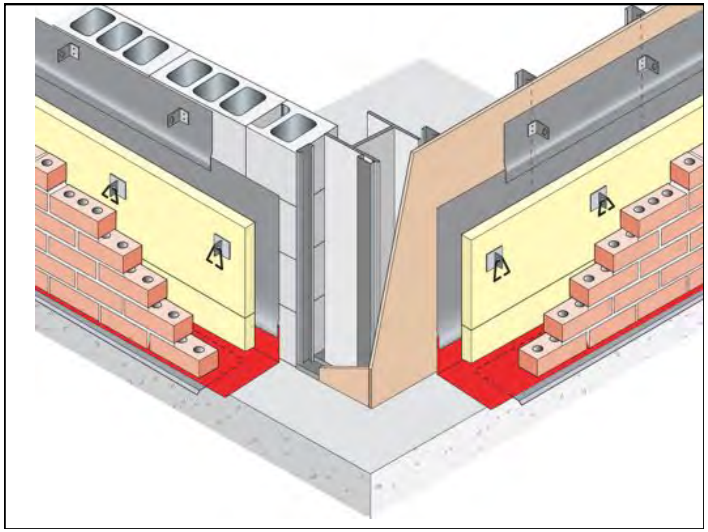
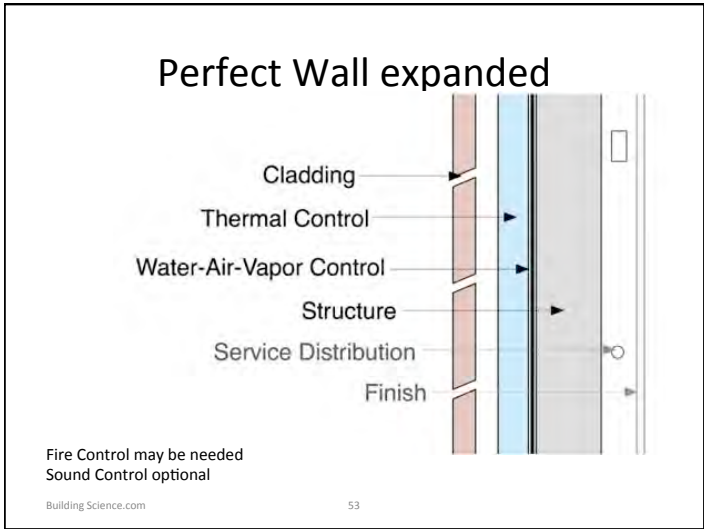
Plan Dimensions




Baseplate usually wider than column at the critical base plate






Perfect Wall expanded
Cladding
Thermal Control
Water-Air-Vapor Control
Structure
Service Distribution
Finish
Fire Control may be needed
Sound Control optional
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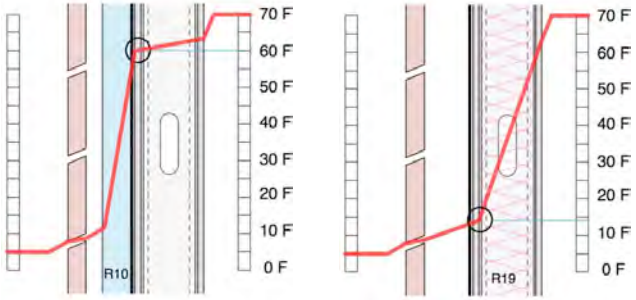
53

Perfect: Condensation & Drying



No stud cavity insulation
= perfect wall
= no moisture risk

Cavity insulation
= cold sheathing
= condensation risk
= slow meeting

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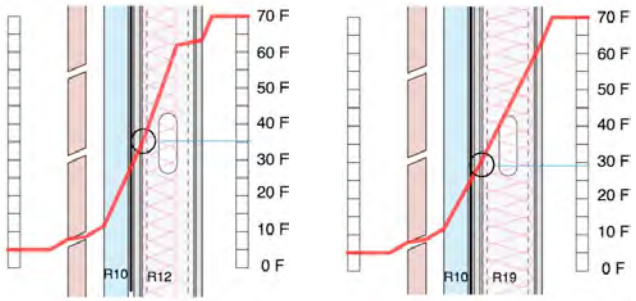
Compromise= Risks

ASHRAE 90.1 now requires SOME exterior insulation just to meet code
Hybrid systems: Batt + exterior, have more risk than all exterior insulation



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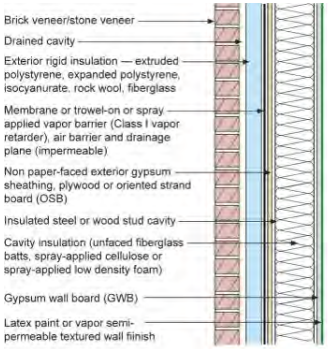
Compromise: walls

Can limit risk with large fraction of R-value on exterior

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

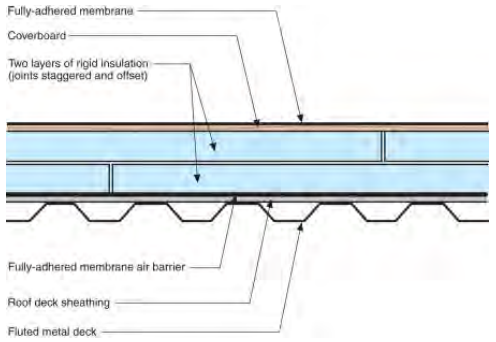


Vapor Profile

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

Compromise: roofs

Deck level **air** barrier
Replace membrane every 15-25 years



– Roofs 57

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 / assembly

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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1. Rain Control

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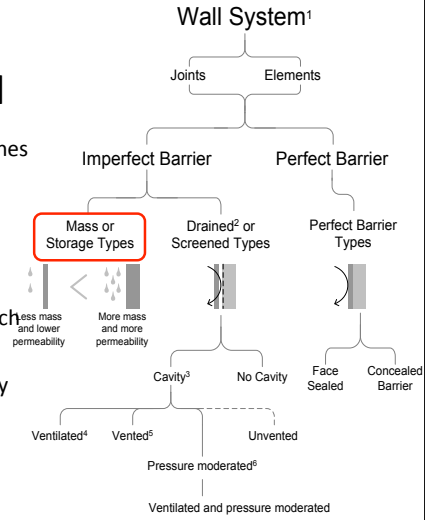
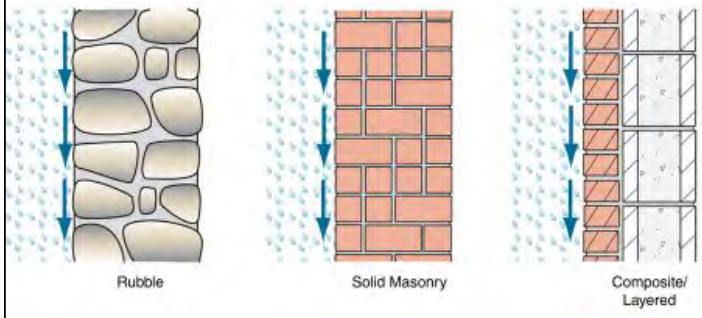
Rain Control

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



Historic: Mass/Storage Walls



John Straube

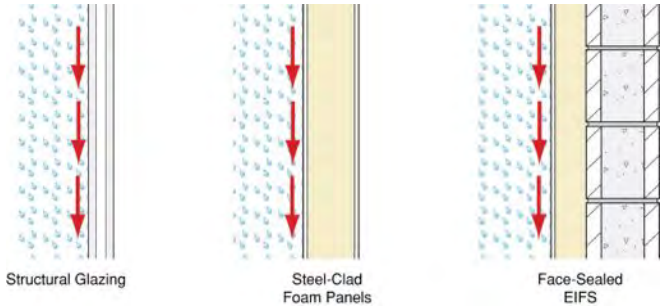
No building paper, flashing, weepholes

Rain Control 63

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

Rain Control 64

Perfect Barrier / Face Sealed



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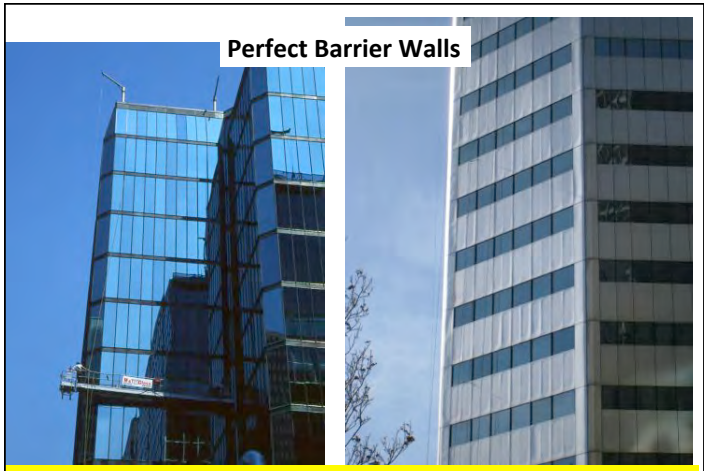
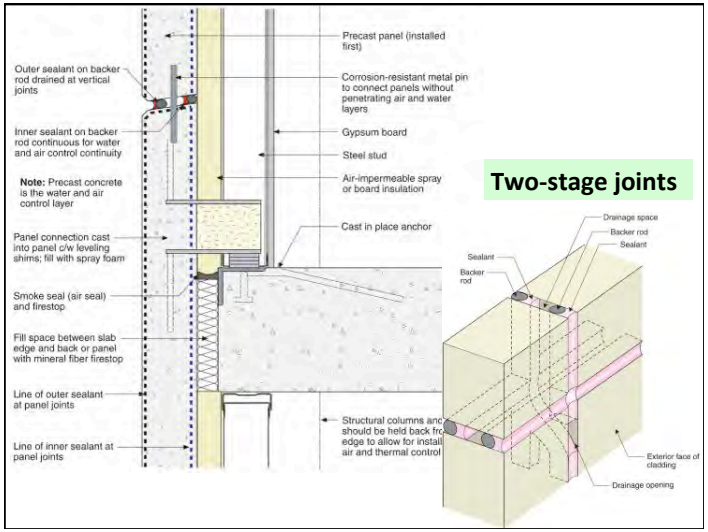
Perfect Barrier Walls



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

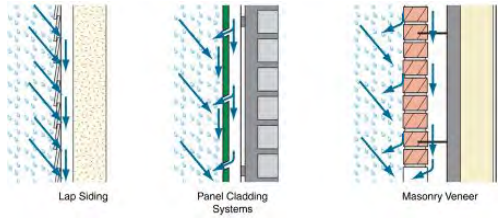
Precast is often a functional perfect barrier wall .. but the joints leak, exposed sealant fails!



Two-stage joints

Drained Walls

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



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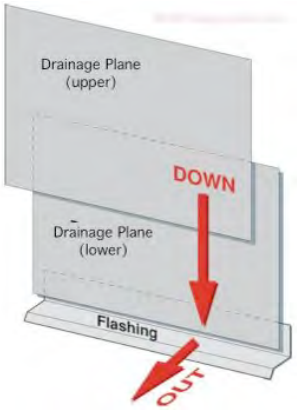
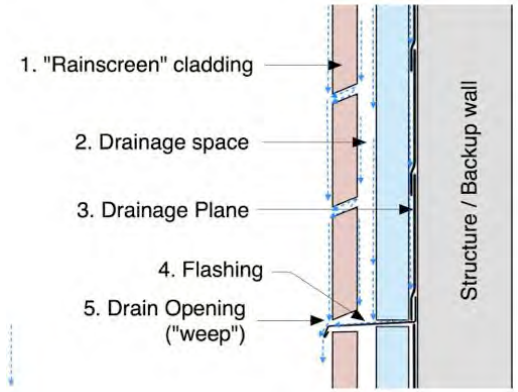
"shingle fashion" lapping



Five parts of a "Rainscreen" or "Drained" System



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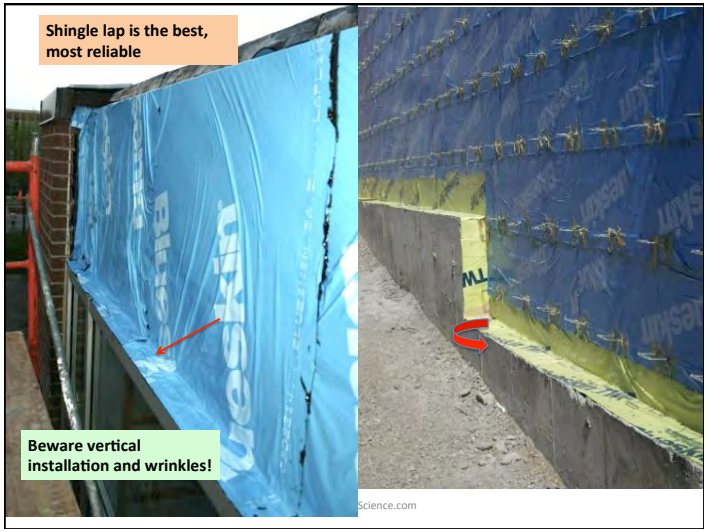
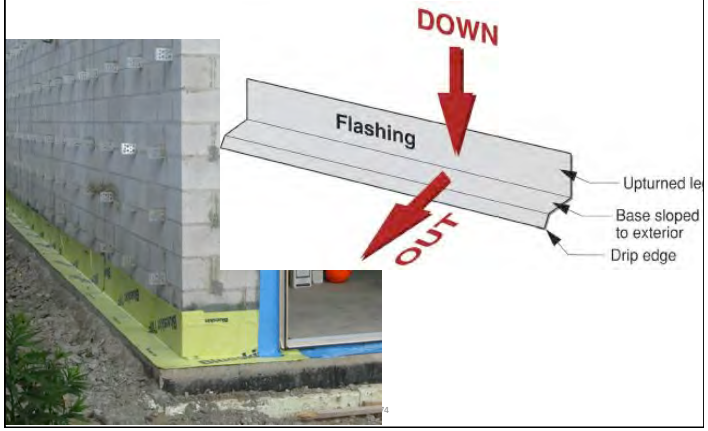
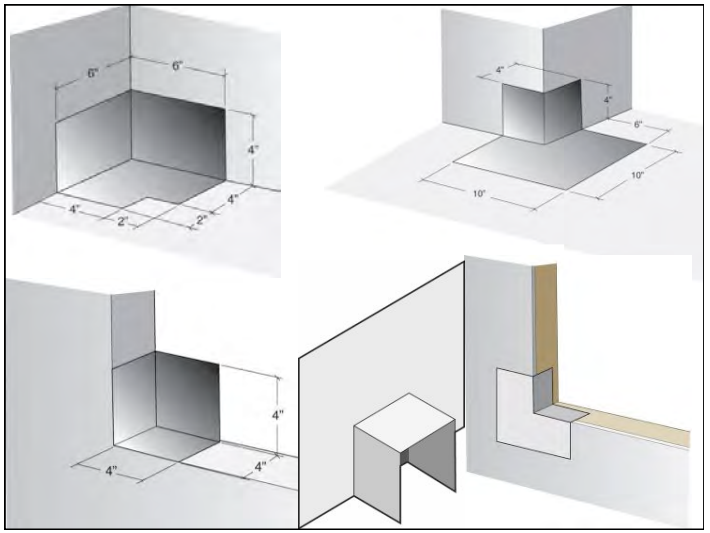


Flashing must be waterproof



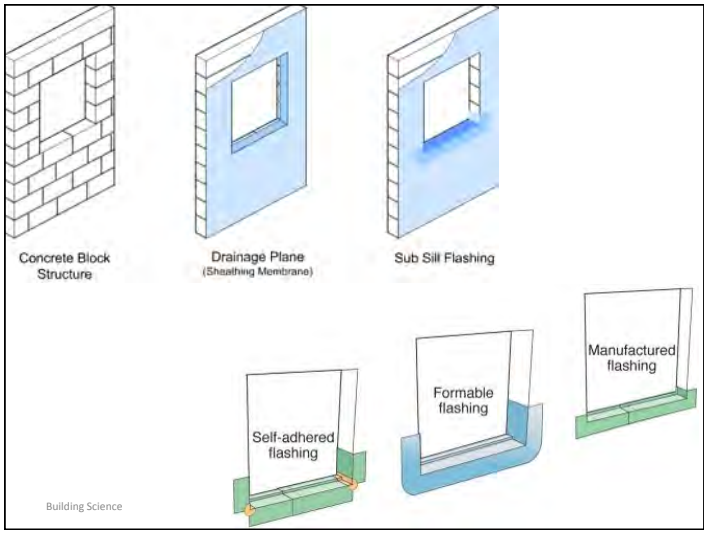


Windows and Doors

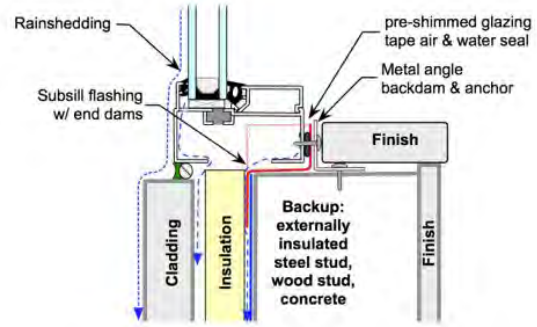
- All penetrations should be drained, regardless of the approach taken to the element
- Windows and doors are the most critical openings to drain
- Rough opening must be drained

Leaky windows

- Studs and sheathing are sensitive to leaks



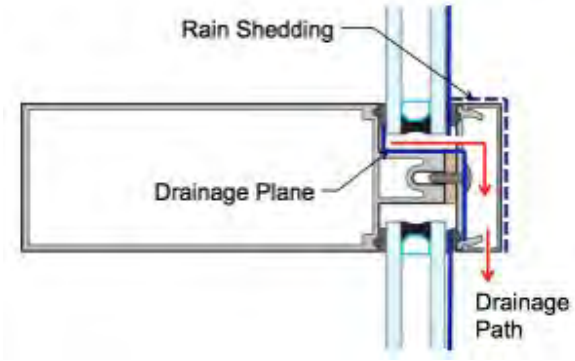
Window Install

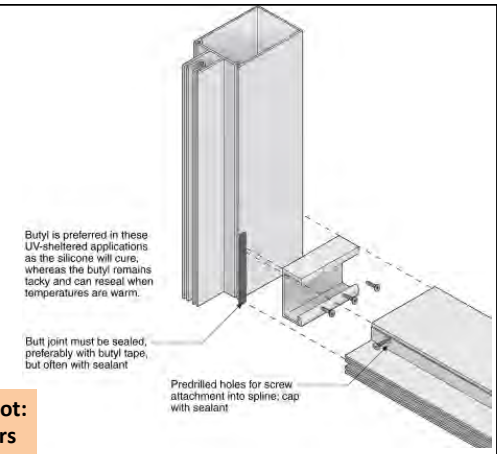


Continuous interior angle provides backdam and airseal continuity

Backdams / Slopes are Important

Curtainwall: Rain Control





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

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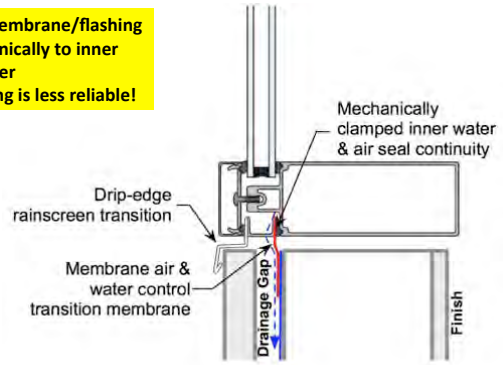
Curtainwall Integration

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



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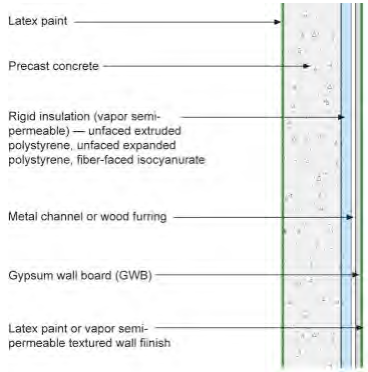
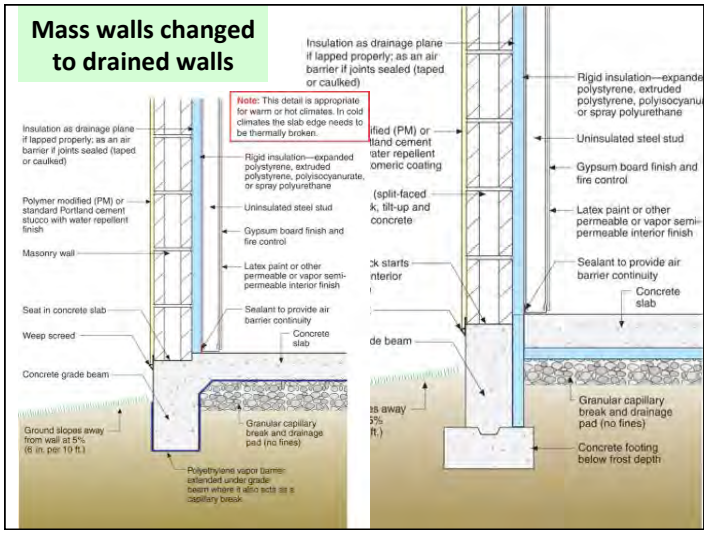
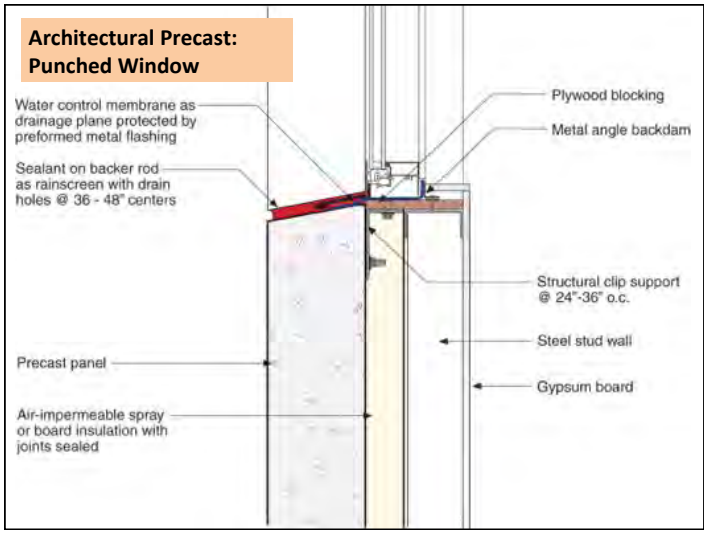
Not "Perfect", But pretty darn good!



Mass walls changed to drained walls



Architectural Precast: Punched Window



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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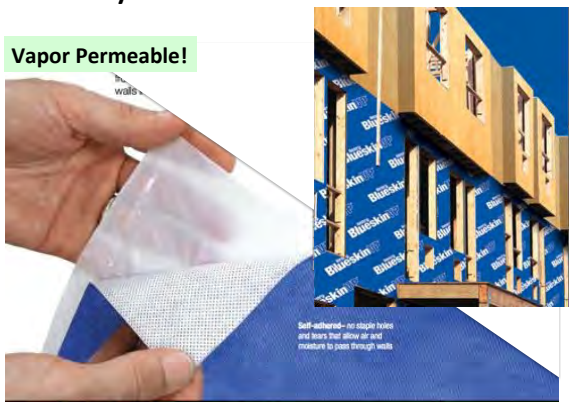
Air-Water Control Layers

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 =modest performance

Supported **flexible membrane is better**

Fully-adhered is best

2. 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

95/175

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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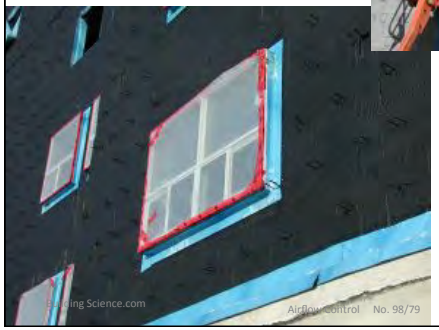
Air + Water Barrier

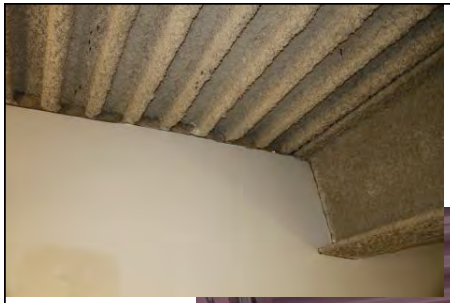
- Beware:
- Around windows
- Canopies
- Parapets

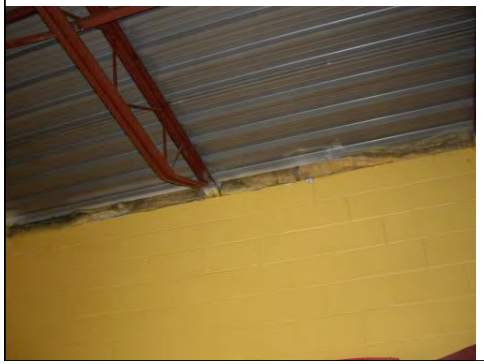
Details

- Air & water & vapor transition membranes

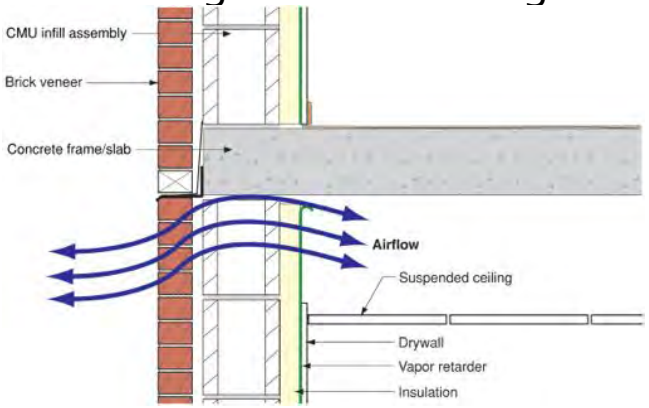


Find the air leak



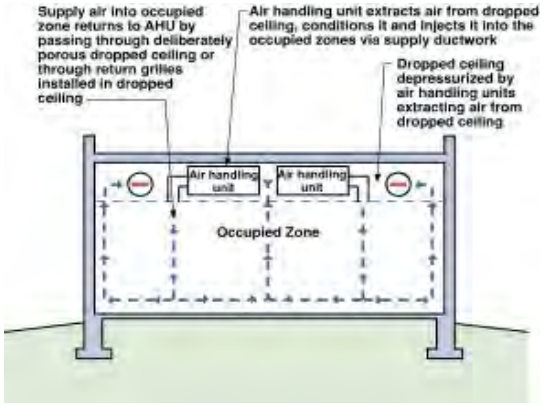


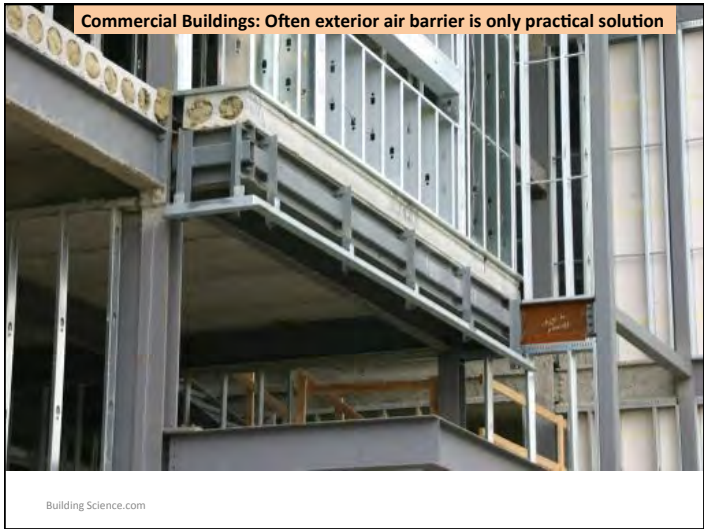
Leakage above ceilings

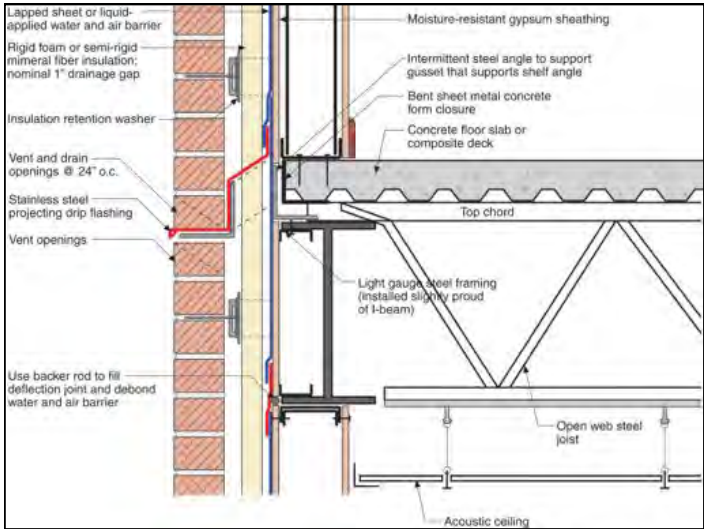


Building Science.com Airflow Control No. 102/79

Dropped-Ceiling Return Plenum



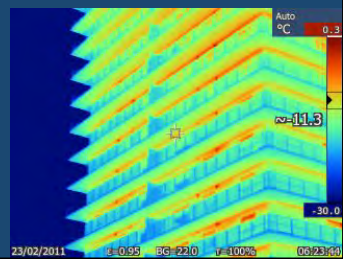




Air Barriers are coming

- More stringent numerical targets
  - GSA 0.4 cfm/sf @0.3 in w.c.
  - Army Corp 0.25
- Testing of whole buildings becoming common

3. Thermal Control



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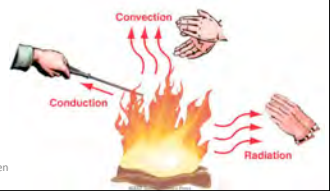
Thermal control

- 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

12-04-03

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
- Shading (radiation)



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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 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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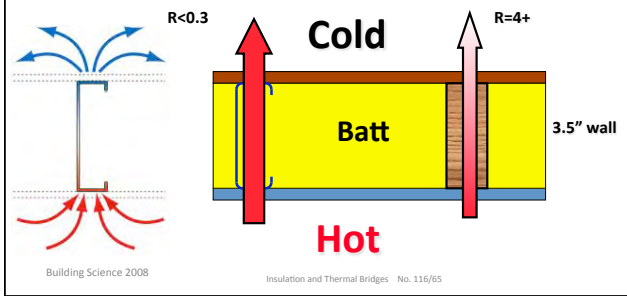
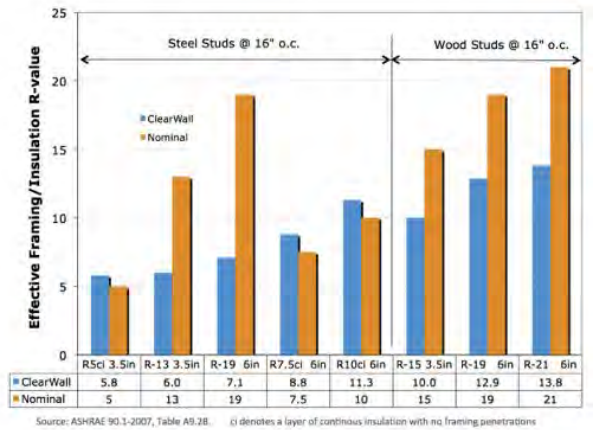
Thermal Bridging

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

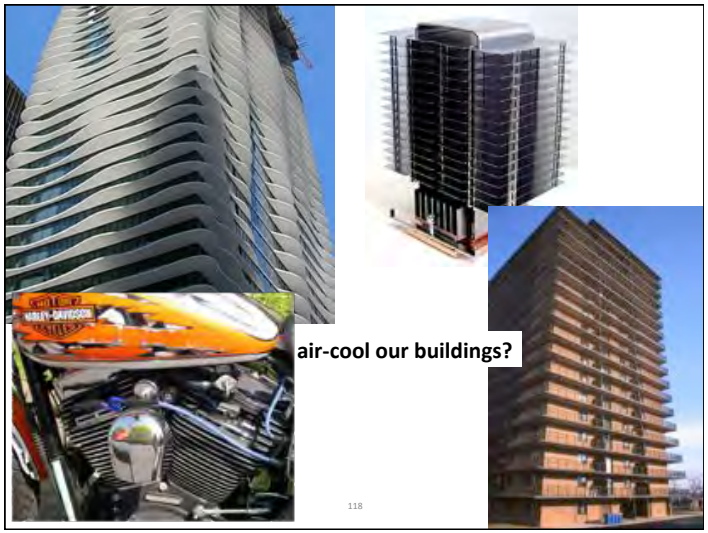


Best-case R-values for stud walls



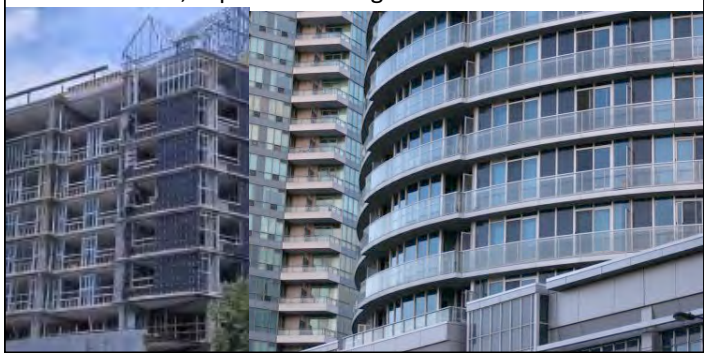
	R5ci 3.5in	R-13 3.5in	R-19 6in	R7.5ci 6in	R10ci 6in	R-15 3.5in	R-19 6in	R-21 6in
ClearWall	5.8	6.0	7.1	8.8	11.3	10.0	12.9	13.8
Nominal	5	13	19	7.5	10	15	19	21

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

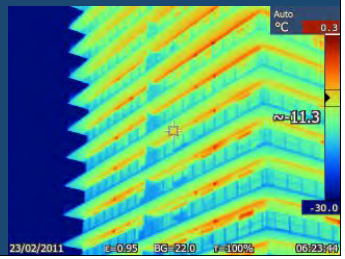


Thermal Bridge Examples

- Aluminum framed
- Balconies, Exposed slab edges



Examples



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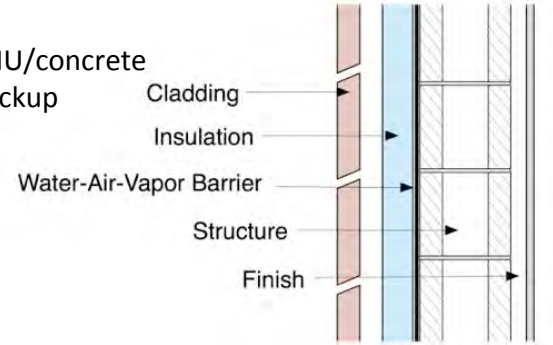
Perfect Wall

- CMU/concrete backup



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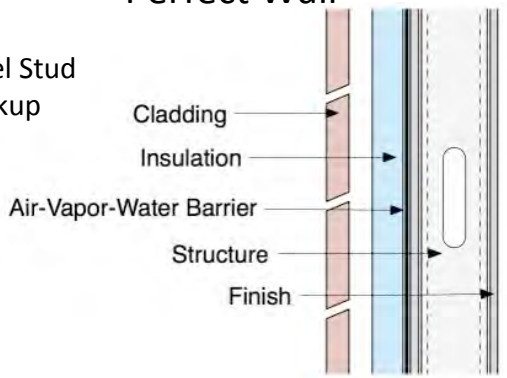
Perfect Wall

- Steel Stud Backup



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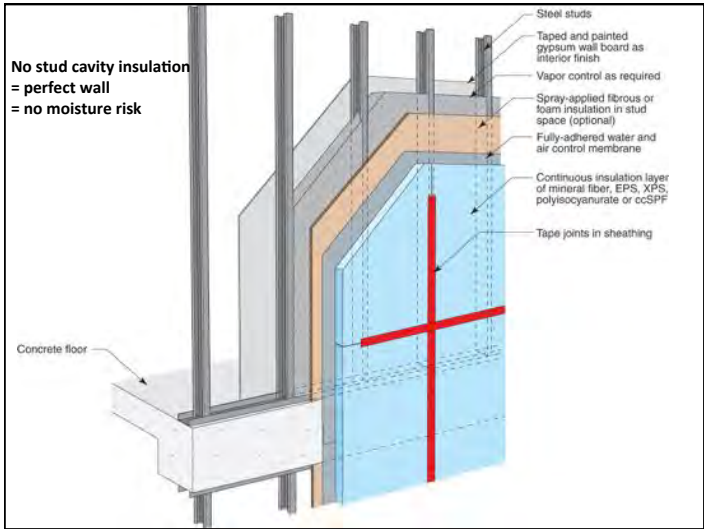
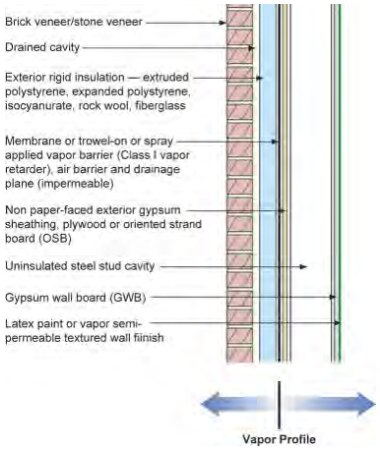


Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



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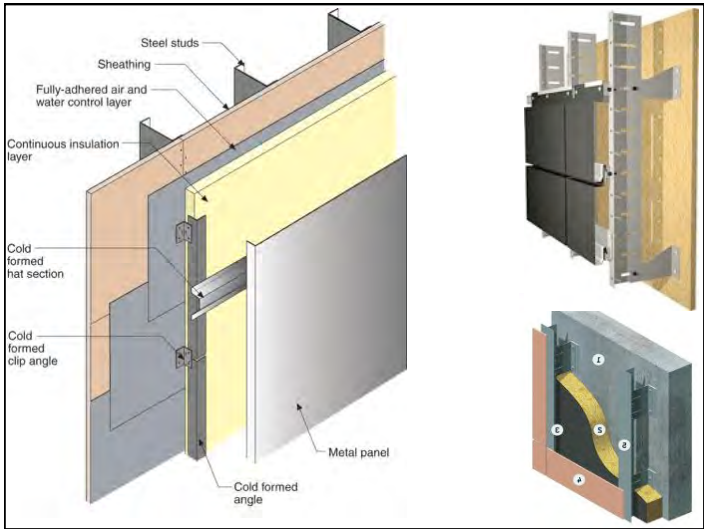
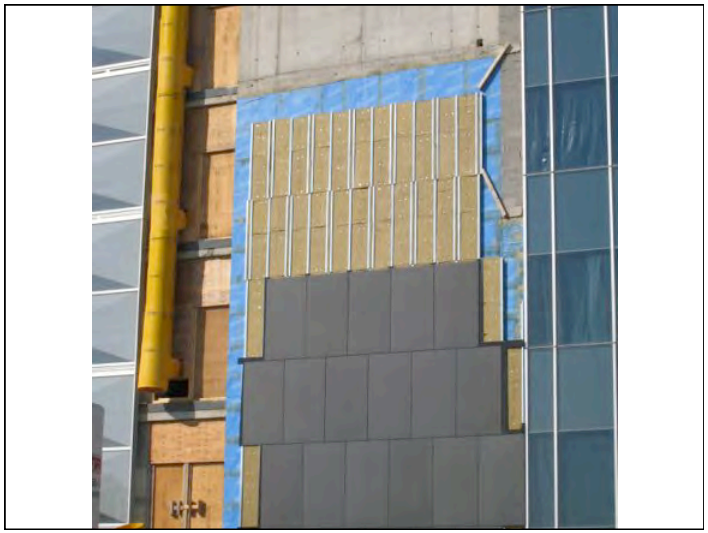
Blueskin


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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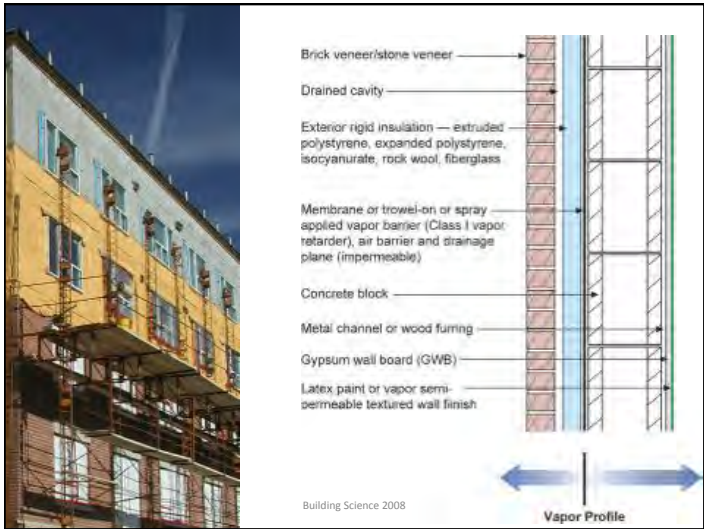
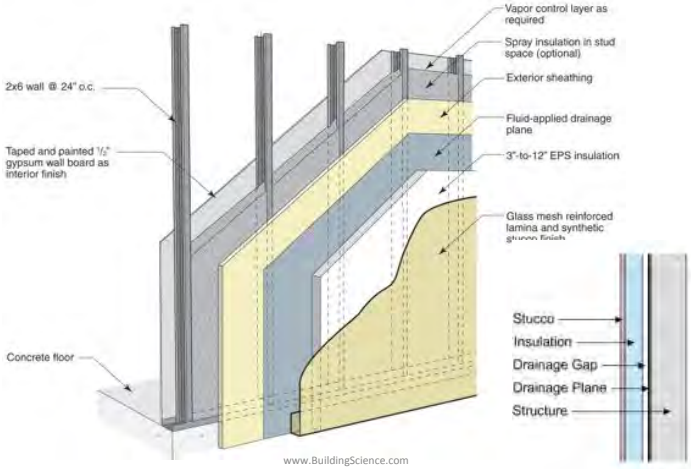
Hartford

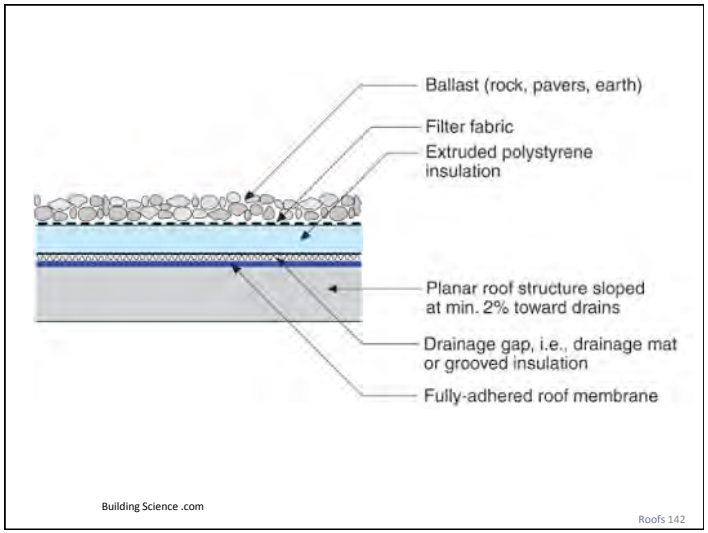

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel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

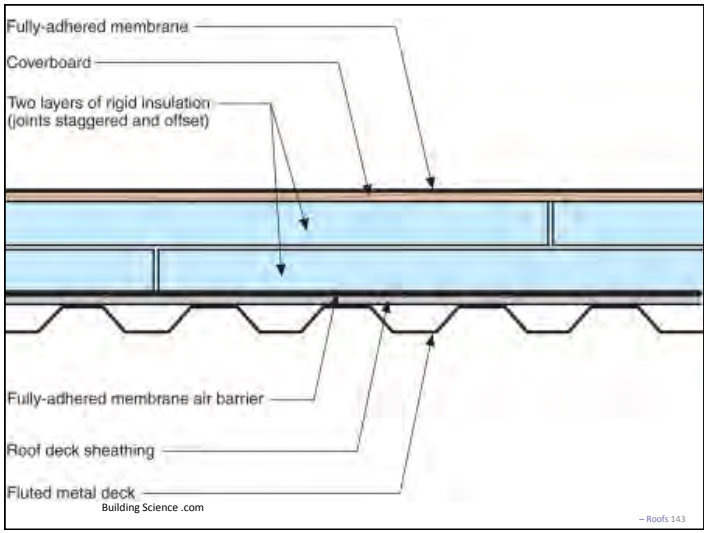
Closed-cell spray polyurethane foam: ccSPF
-Rain control
-Air Control
-Thermal Control
- Vapor Control

EIFS: no longer a four letter word



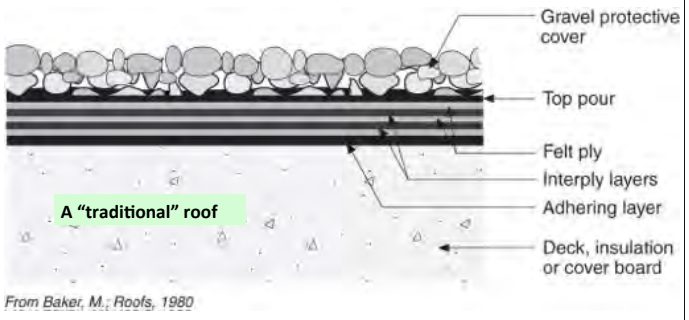
Drained EIFS is HP





Best UV Protection: rocks

- But, you need to hold down to resist wind



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– Roofs 144

White roofs

- Lower heat gain: great!
- Reduce stress on exposed roof membranes
- **But**: Reduces drying out of roof
- **Thus**: Require better moisture control!
  - Air barrier
  - Construction moisture

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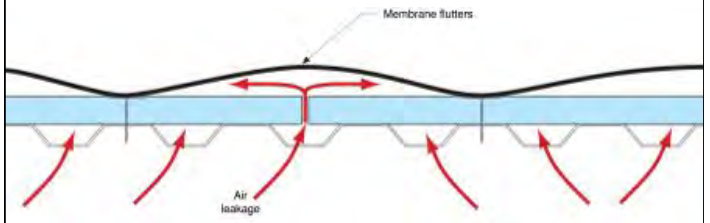
- What an air barrier?
- Why fully adhered?



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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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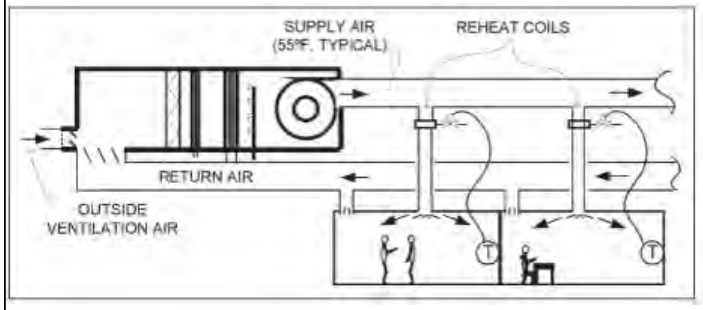
Constant Air Volume



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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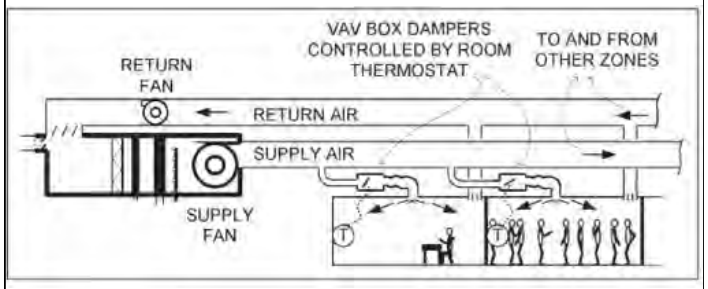
Variable Air Volume



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

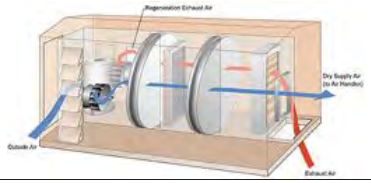
- How is indoor humidity controlled when it is 65-80F outdoors and raining (100%RH)?
  - Sensible load is very low (lights+people)
  - Latent load high (ventilation + people)
  - AC does not run, or does not run much
- Answer usually is "not"
  - Reheat is energy intensive but works
  - ERVs reduce humidity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

DOAS

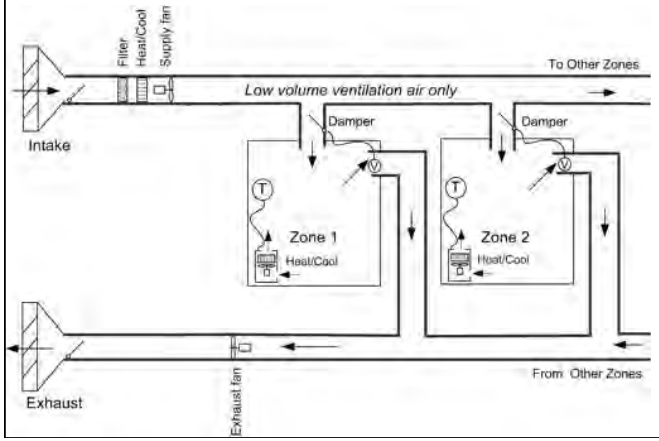
- Dedicated Outdoor Supply
  - Supplies all required dry air and fresh air
- All ventilation air can be pretreated
  - Air should be dried to <50F Dewpoint
  - Supply of dry air to each space controlled *independent of thermostat*
- Key is to decouple humidity control/ ventilation from temperature control

Energy recovery ventilation

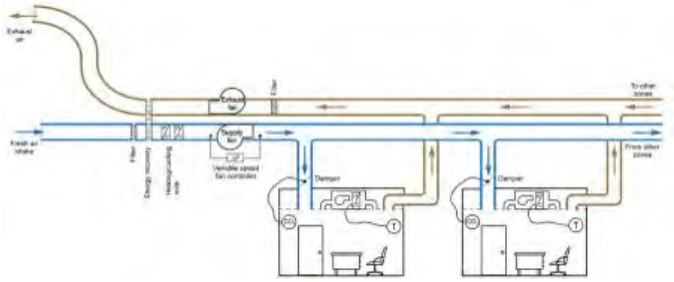
- Reduces equipment peak capacity (saves capital $)
- Reduces load on heating/cooling/ dehumidification (saves energy/operating $)
- Usually makes sense for any large mechanical ventilation flow



DOAS



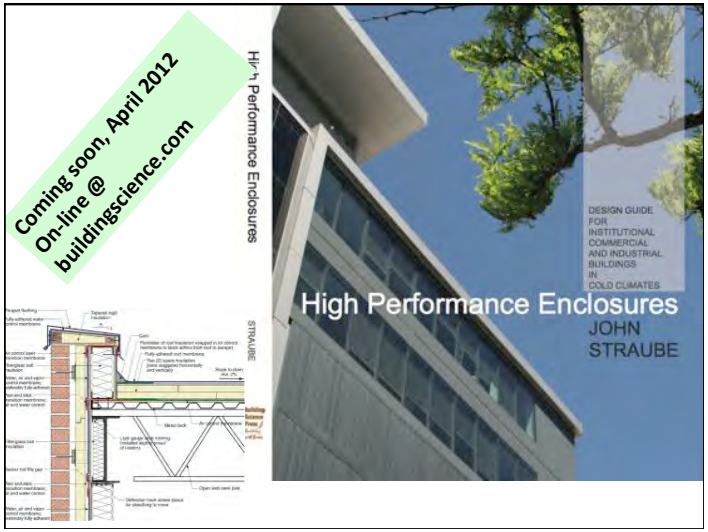
BSI-022 Perfect HVAC



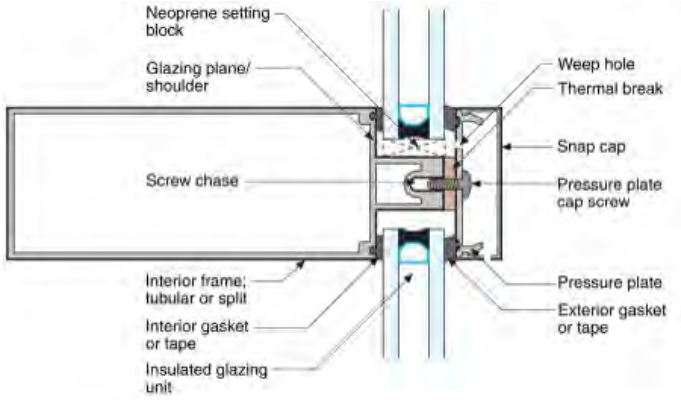
Thermostat controls heating/cooling by zone
Ventilation controlled by occupancy (CO_2)
All air is delivered dry (humidity control)
No re-circulated air (improved IAQ)

Conclusions

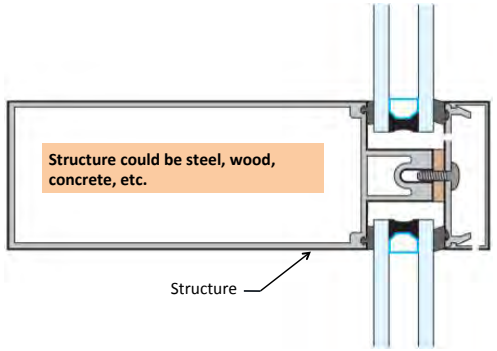
- Key to good mechanicals is to separate ventilation from heating/cooling
- Consider humidity control in climates where it is needed



Curtainwall: Anatomy & Jargon



Structure



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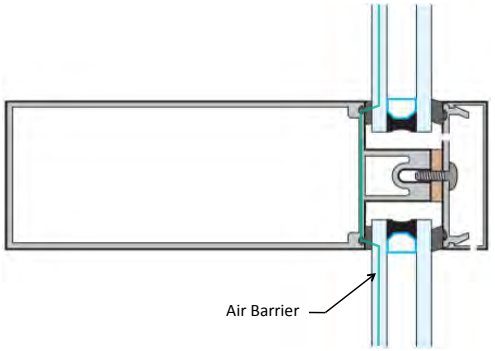
Air Flow Control



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