AIM HIGH

A seminar.

CREATING HIGH PERFORMANCE BUILDINGS

Presented by:
John Straube Ph.D. P.Eng.

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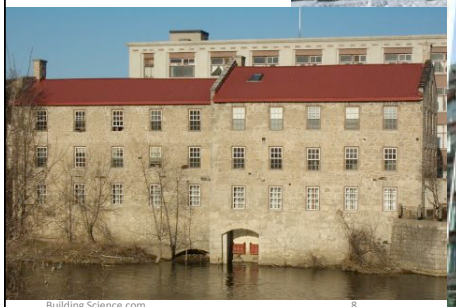
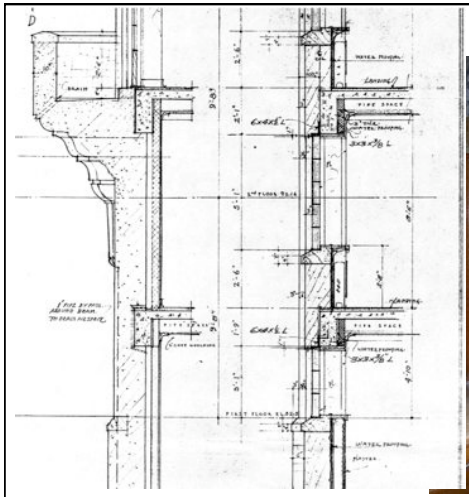
Solid masonry





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 …

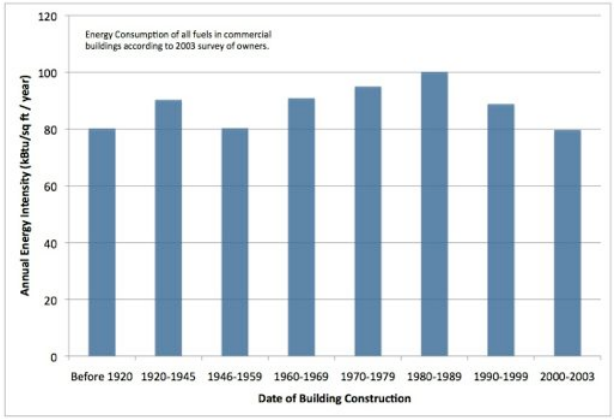
  better buildings at less total cost

Measuring Performance

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

How do we measure these?

Energy: How have we been doing?



R2

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R2

R4

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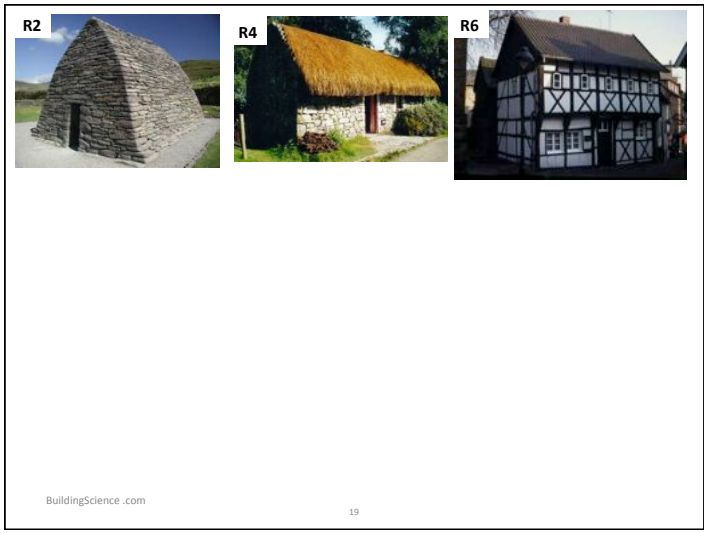
R2
R4
R6
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R2
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R8
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R2
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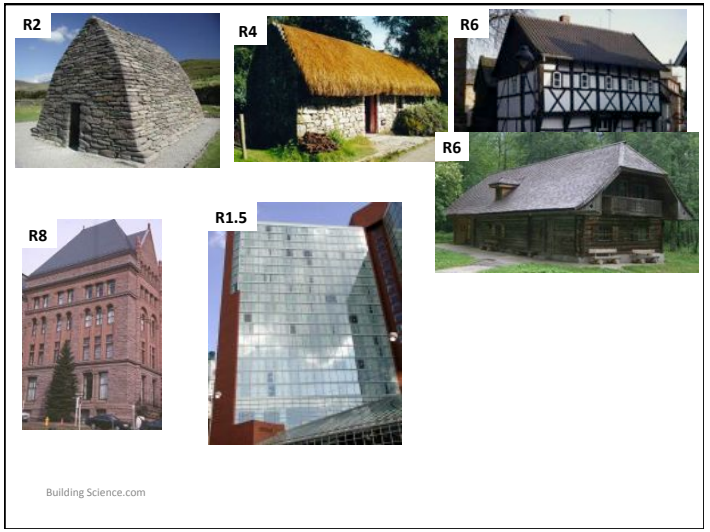
R2
R4
R6
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Why such poor performance?

- Not enough insulation
  - Thermal bridges
- Not enough solar control
  - Windows!
- 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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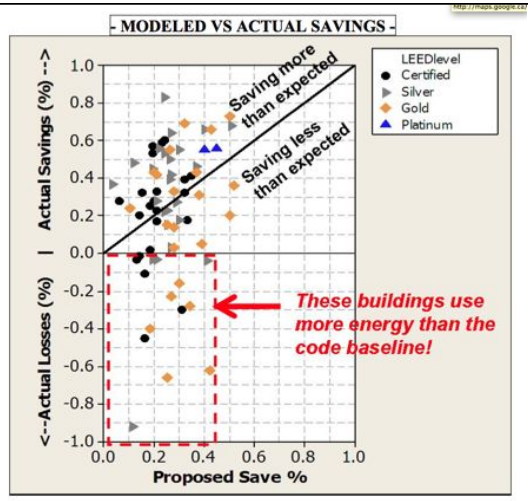
New Solutions

- 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



From: New Buildings Institute Study

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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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
  - Humidity
  - Ventilation
  - Energy

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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Enclosures No. 33 /

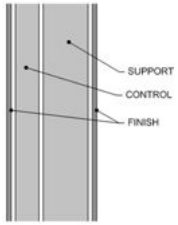
Climate Load Modification

- 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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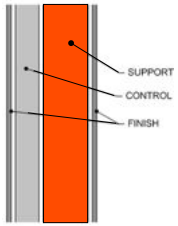
Basic Enclosure Functions

- **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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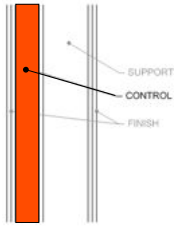
Enclosures No. 36 /

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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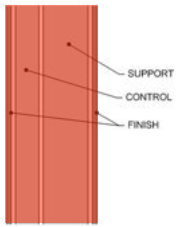
Other Control . . .

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

Functional Layers



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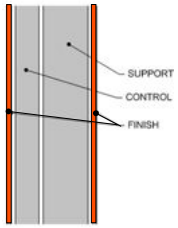
Enclosures No. 38 /

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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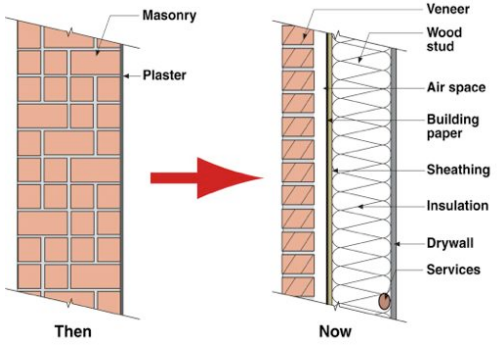
Changes



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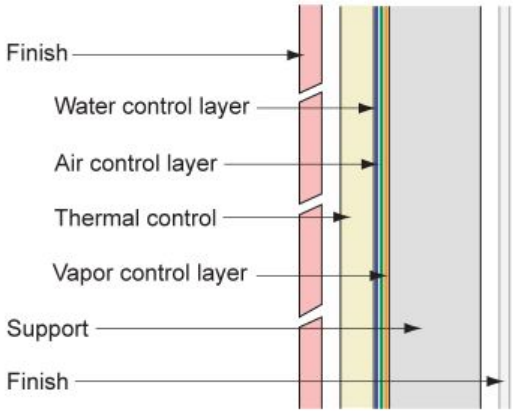
The Perfect Wall



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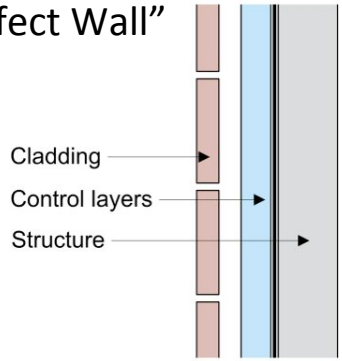
The "Perfect Wall"

- 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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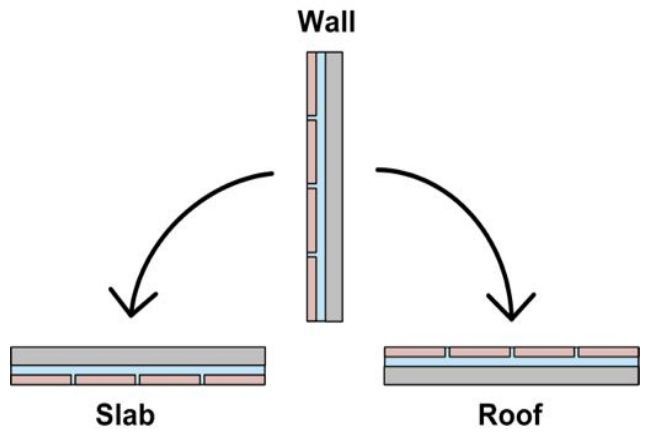

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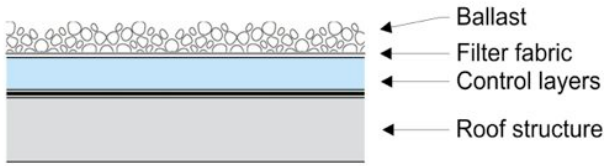

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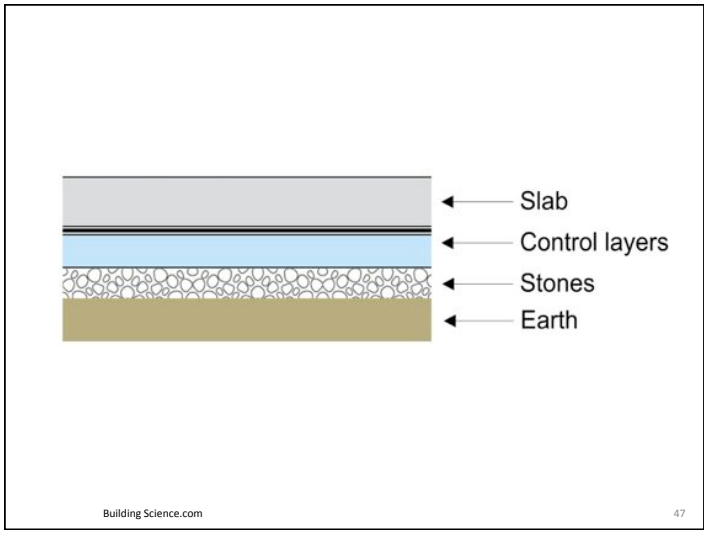
Slab
Control layers
Stones
Earth
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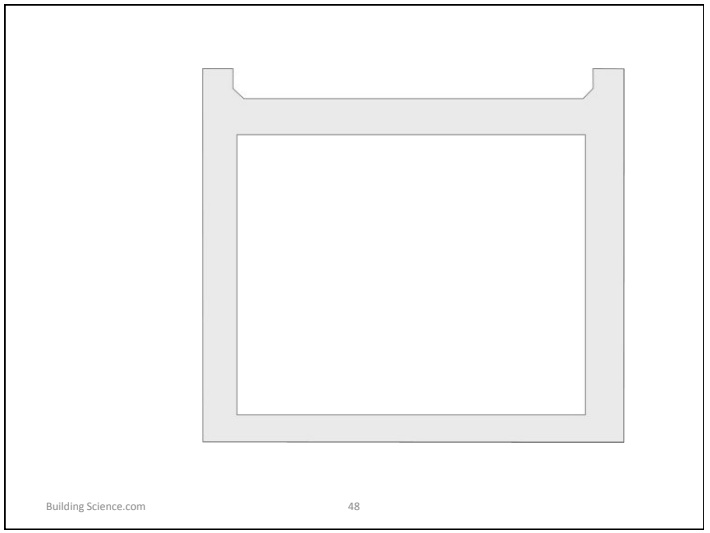
47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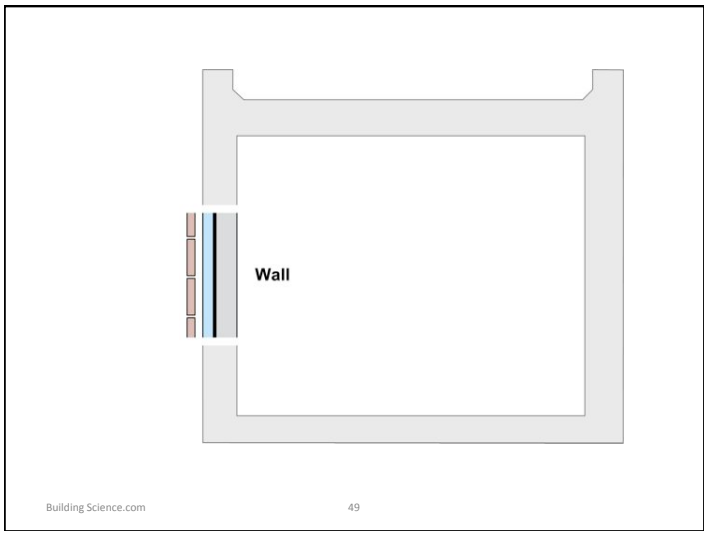
Wall
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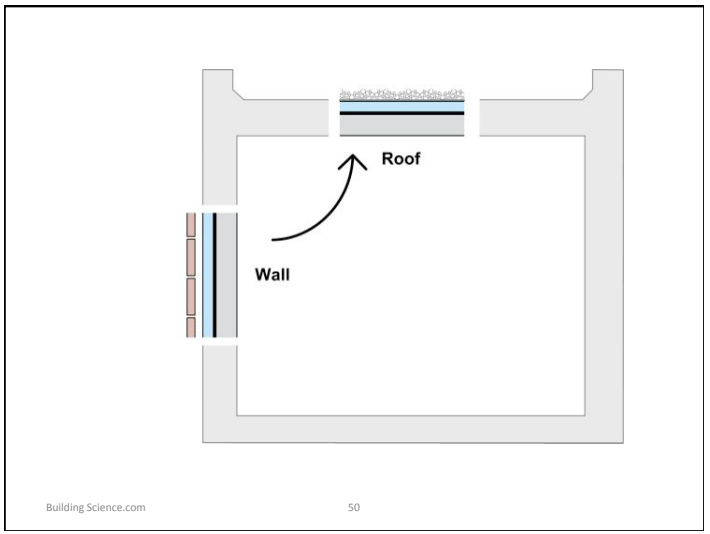
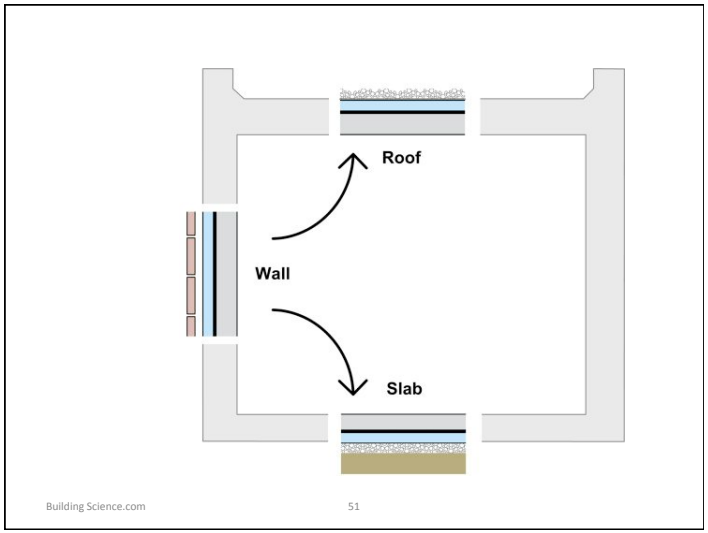
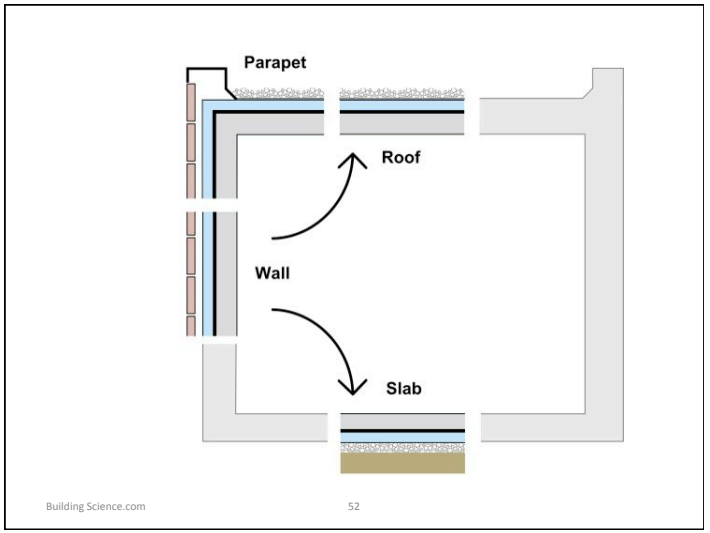
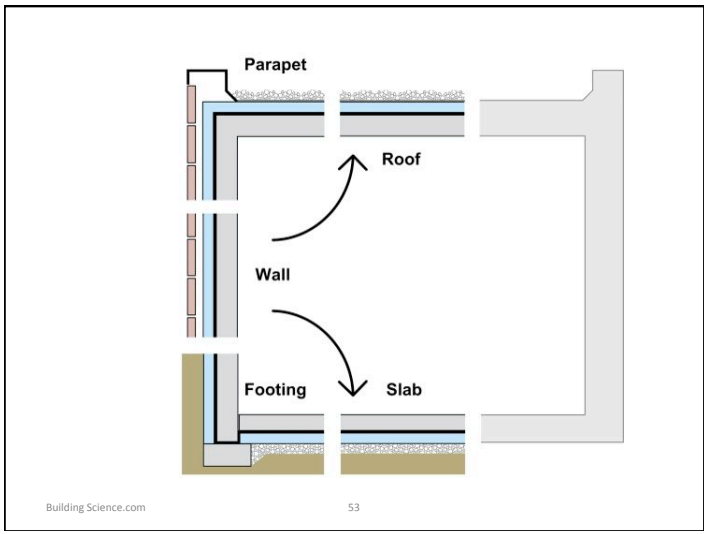
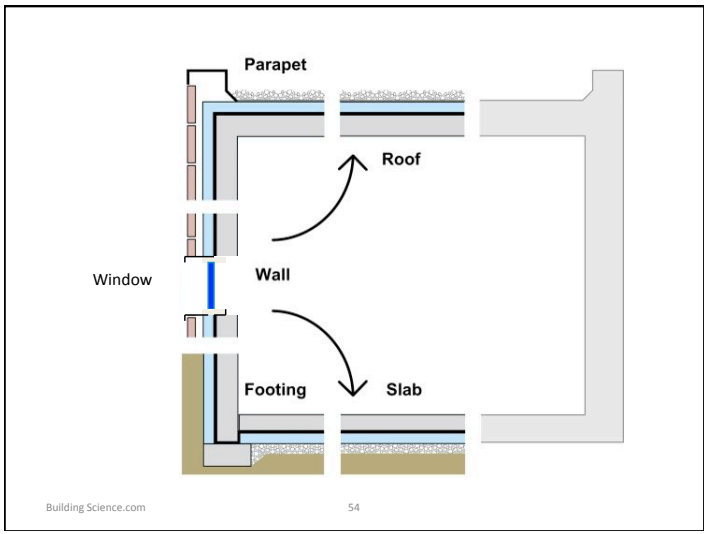

Roof
Wall
Building Science.com
50


Roof
Wall
Slab
Building Science.com
51


Parapet
Roof
Wall
Slab
Building Science.com
52


Parapet
Roof
Wall
Footing
Slab
Building Science.com
53


Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
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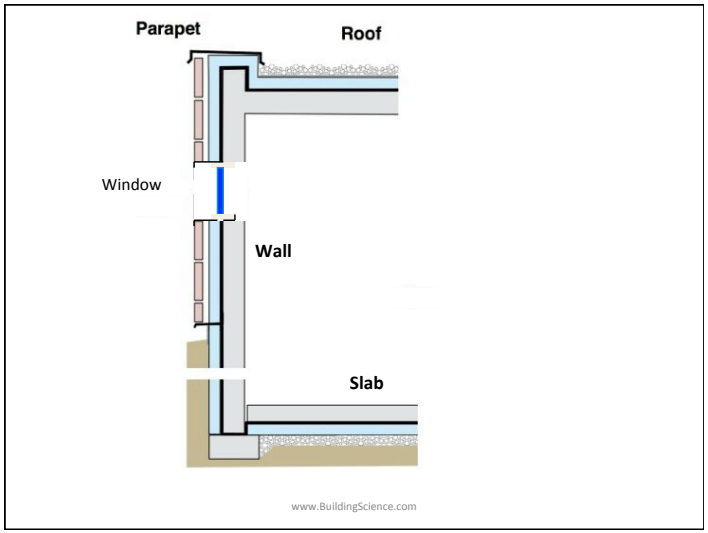
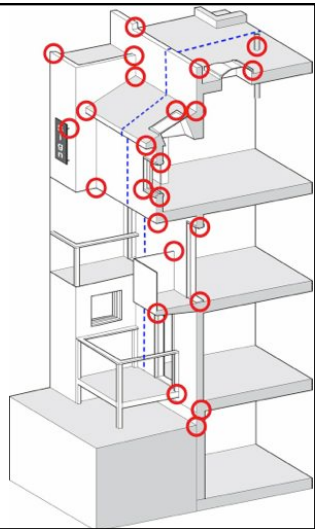


Enclosure Design: Details

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



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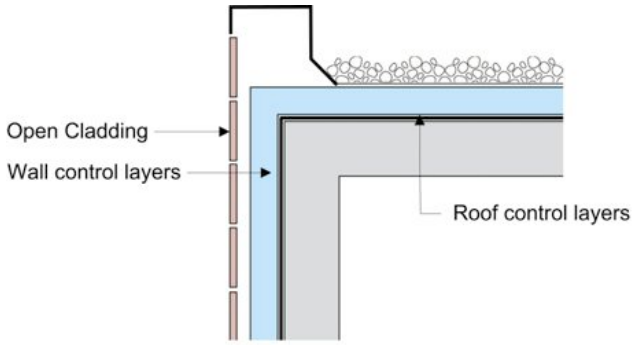
Connections: Who is in charge



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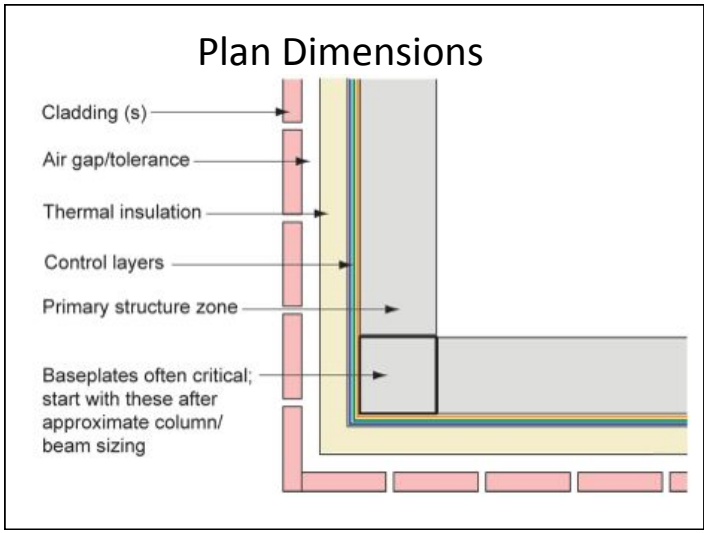
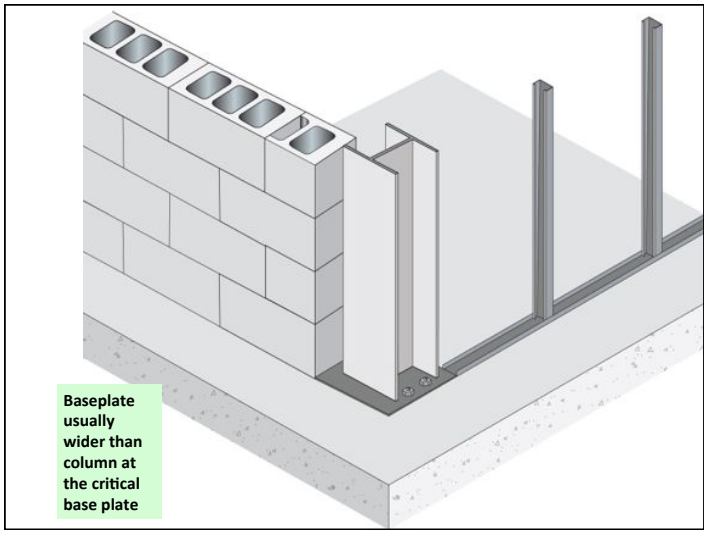
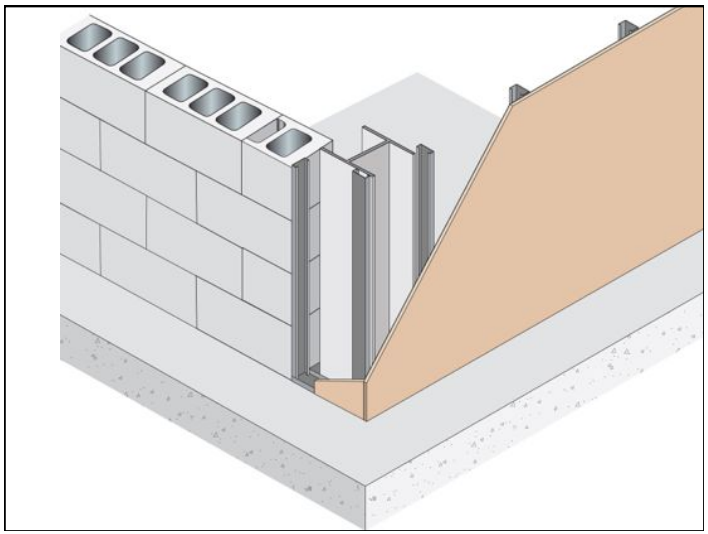
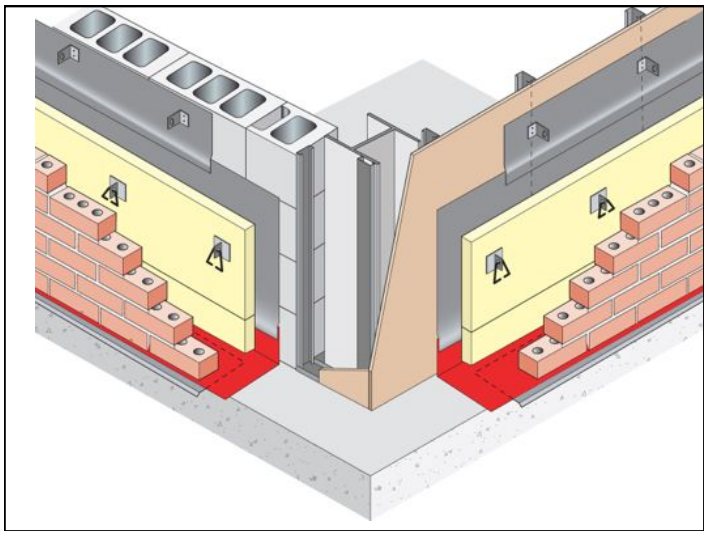
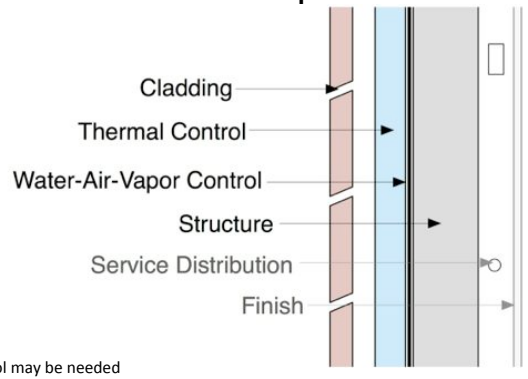

Plan Dimensions
Cladding (s)
Air gap/tolerance
Thermal insulation
Control layers
Primary structure zone
Baseplates often critical; start with these after approximate column/ beam sizing


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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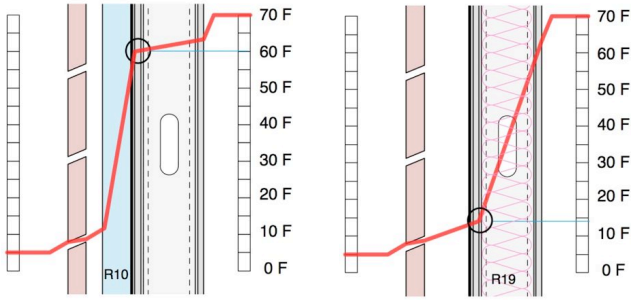
Condensation & Drying



No stud cavity insulation
= perfect wall
= no moisture risk

Cavity insulation
= cold sheathing
= condensation risk
= slow meeting

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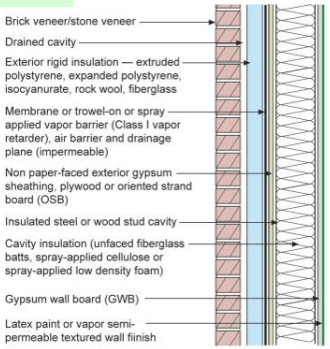
Ratio: $\frac{\text{Exterior R-value}}{\text{Studbay R-value}}$ controls risk of condensation



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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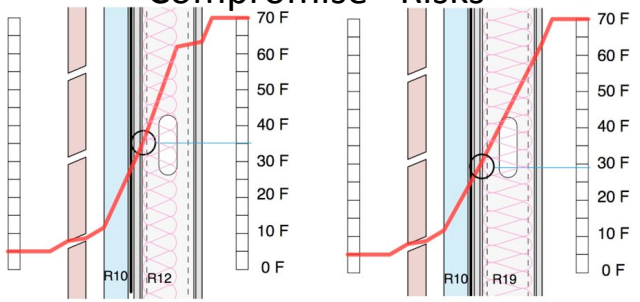
Compromise= Risks



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

Energy

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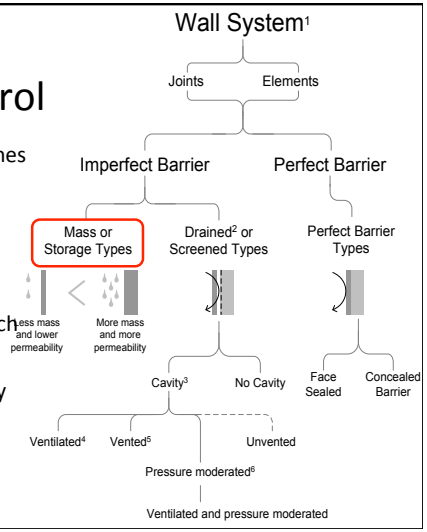
Next Steps

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

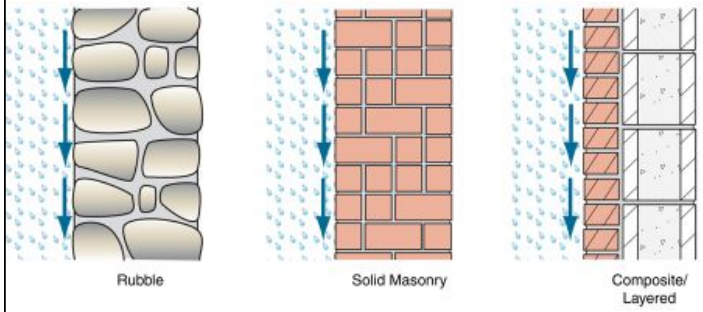
Can be separate
Or
Combined in same material

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

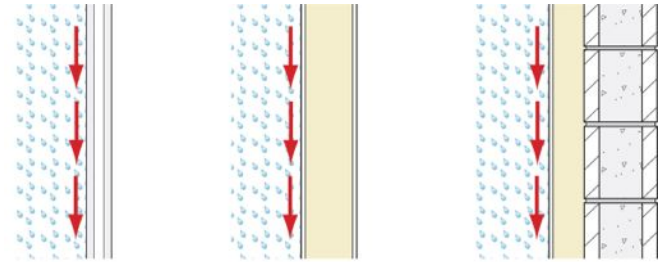


John Straube

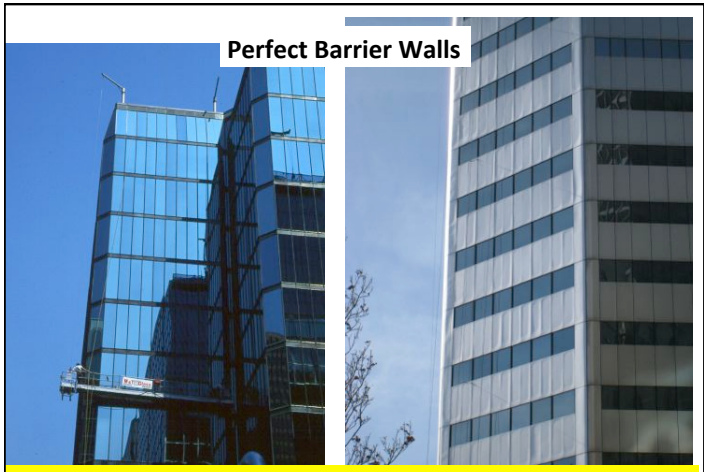
No building paper, flashing, weepholes

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

Perfect Barrier / Face Sealed

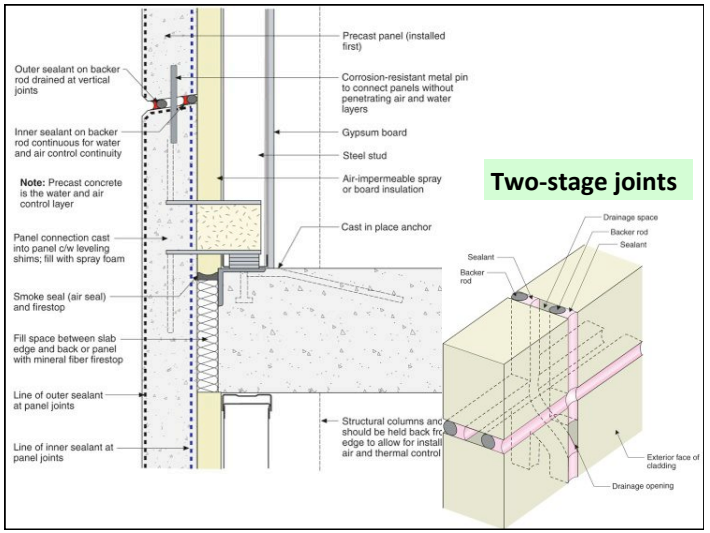


Perfect Barrier Walls



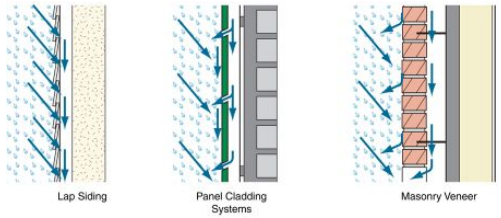
It is all about joints, transitions, penetrations which may not be built, or remain perfect

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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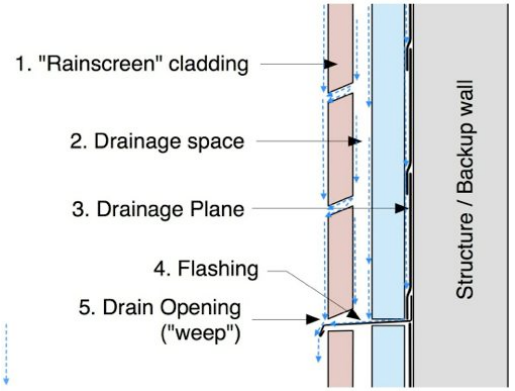
"Rainscreen" or "Drained" System



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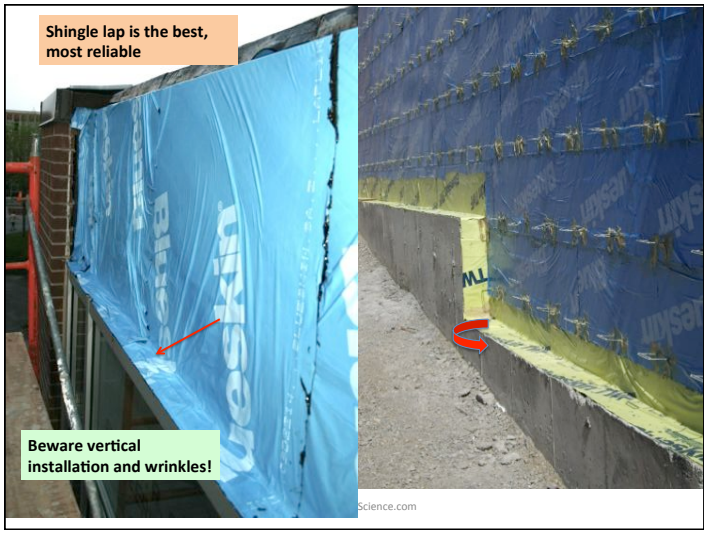
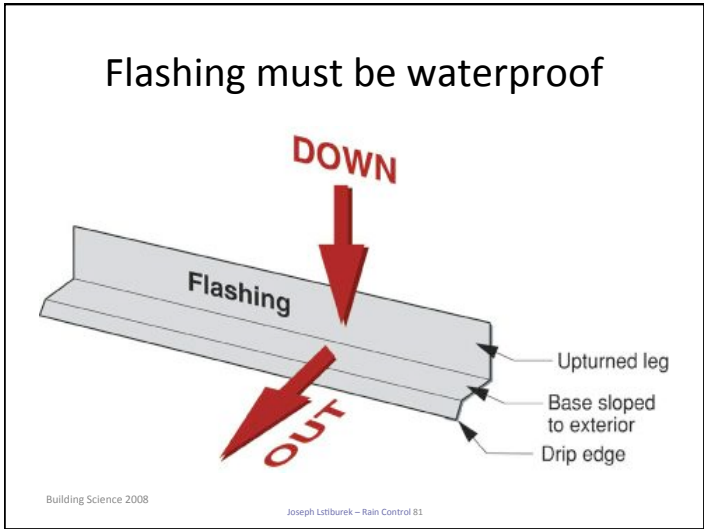
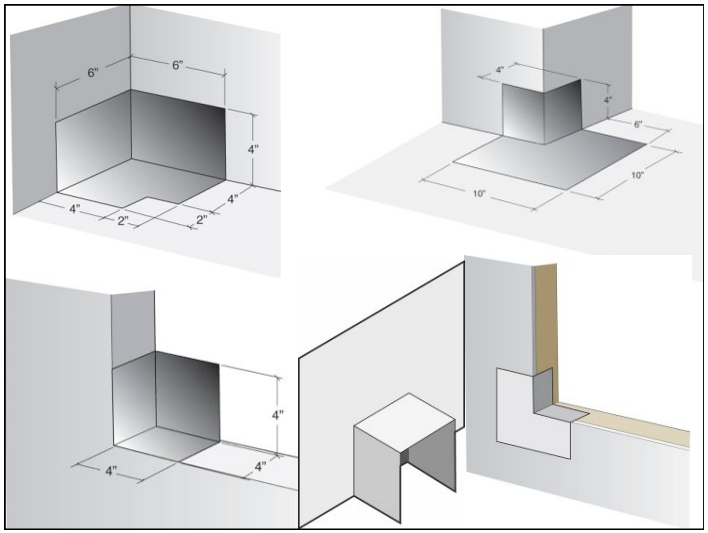
Fluid-applied products avoids laps


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


Flashing must be waterproof
DOWN
Flashing
OUT
Upturned leg
Base sloped to exterior
Drip edge
Building Science 2008
Joseph Lstiburek – Rain Control 81

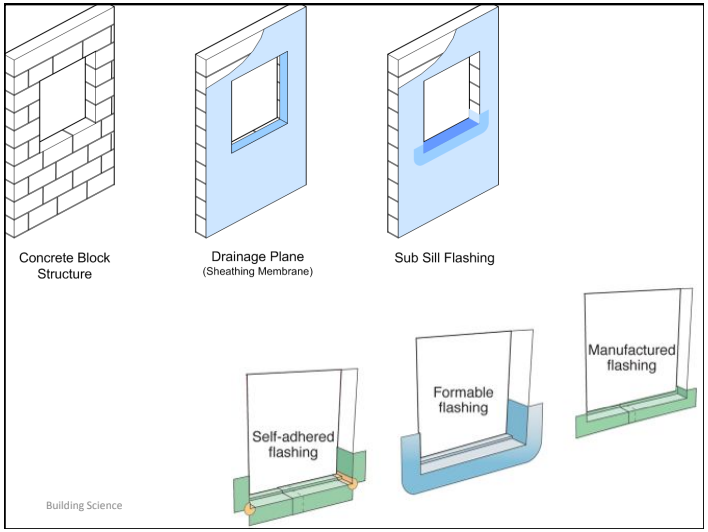


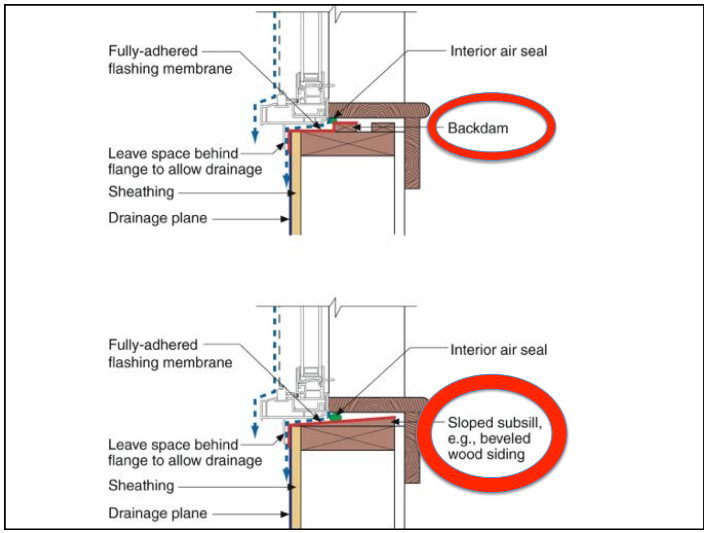
Windows and Doors

- 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

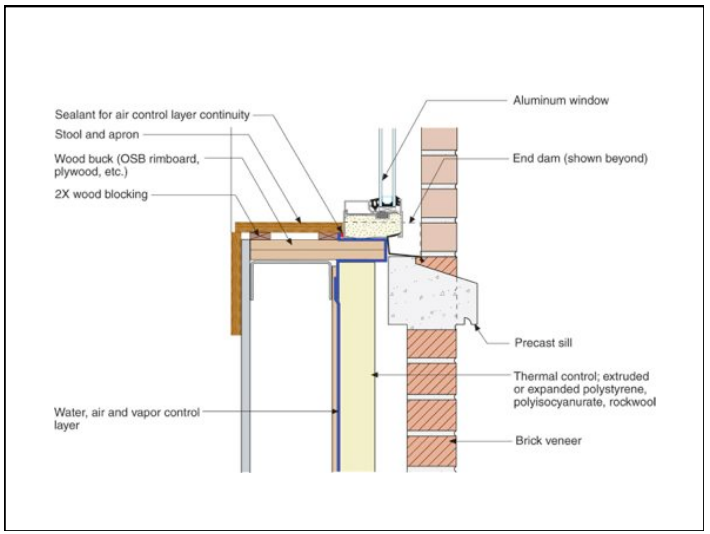


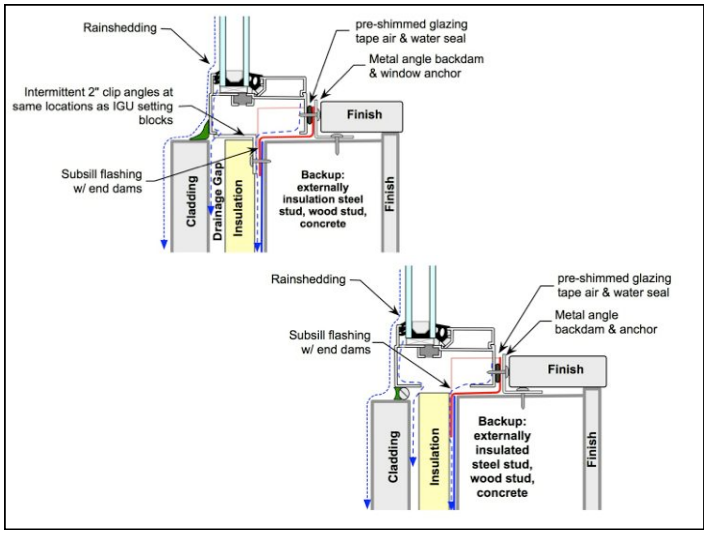


Mixed membrane + liquid

Often use membranes for transitions

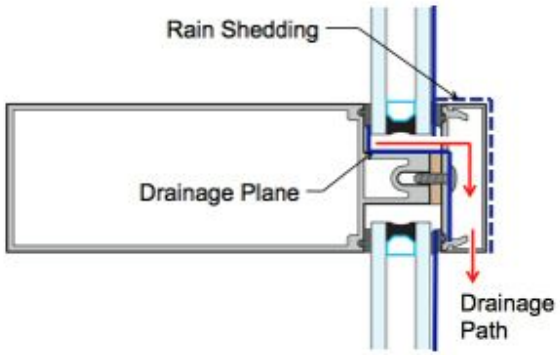
Backdams / Slopes are Important

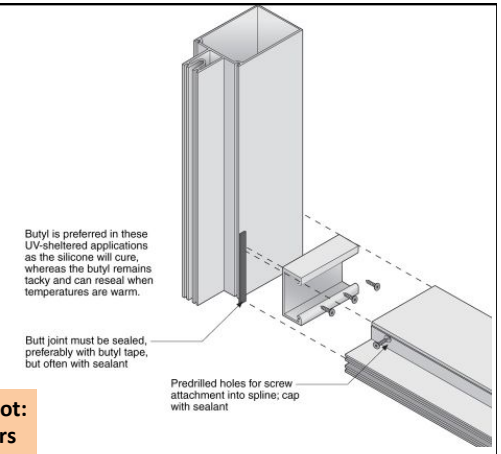




Continuous interior angle provides backdam and airseal continuity

Rain Control





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

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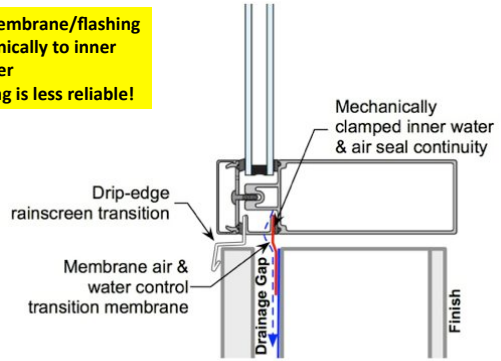
Curtainwall Integration

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



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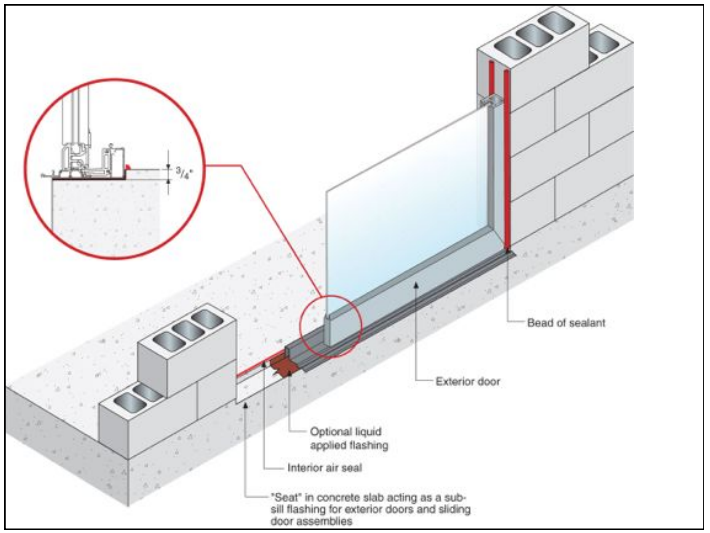
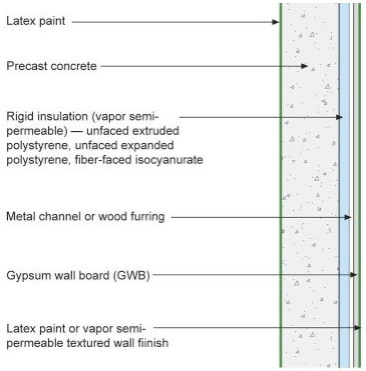
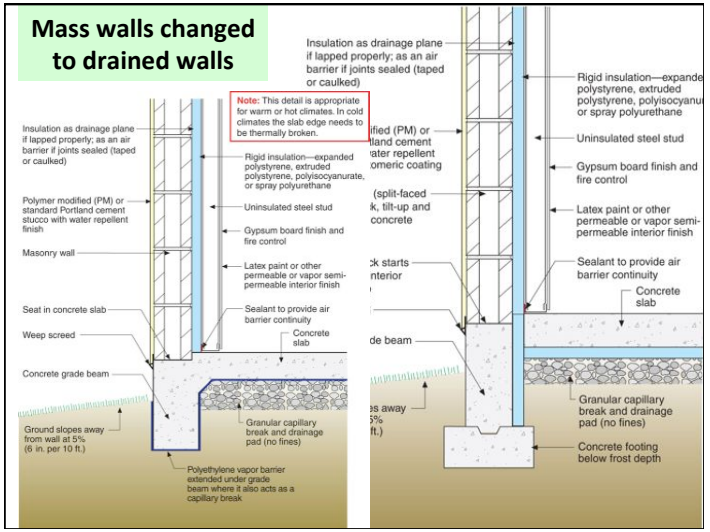
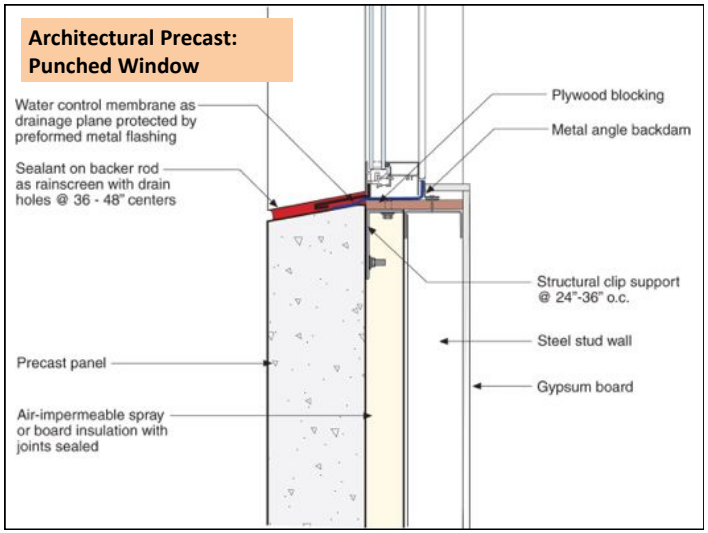


Not "Perfect", But pretty darn good!



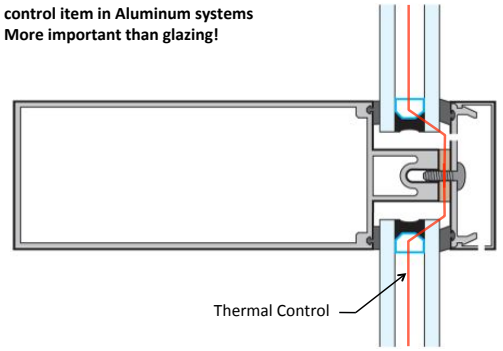
Mass walls changed to drained walls





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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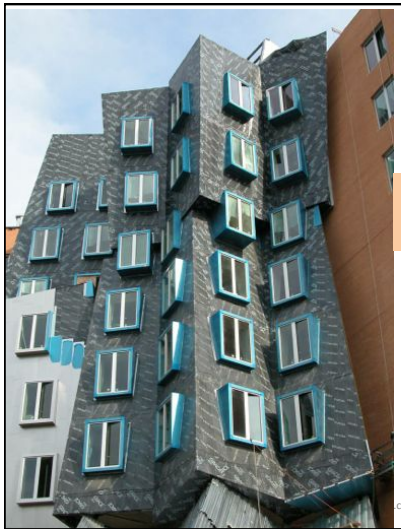
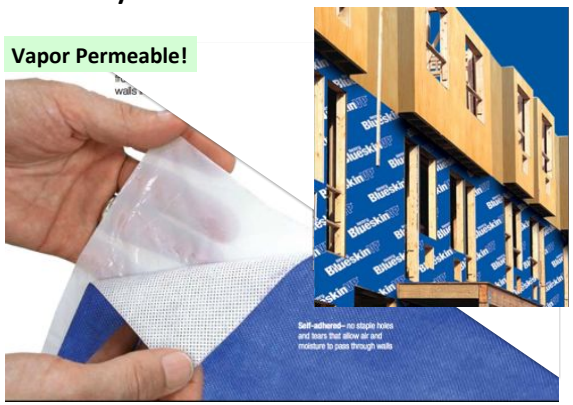


Air-Water Control Layers

Sloped and complex surfaces demand very high performance

.com

Fully-adhered air-water barrier



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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**

2. 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

107/175

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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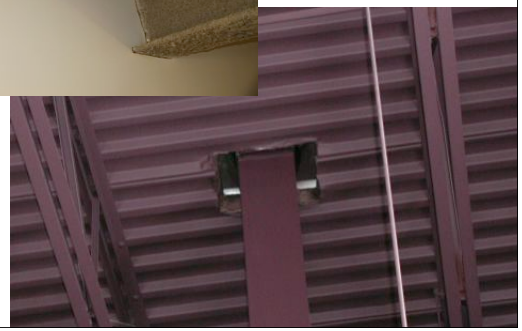
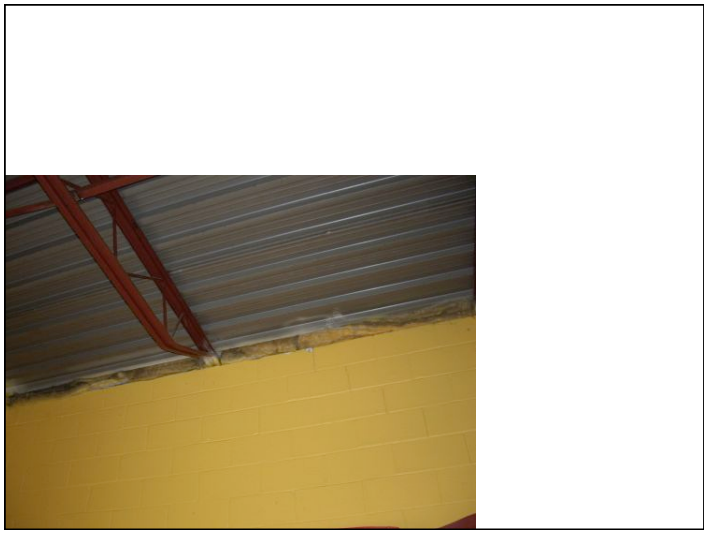
Air + Water Barrier

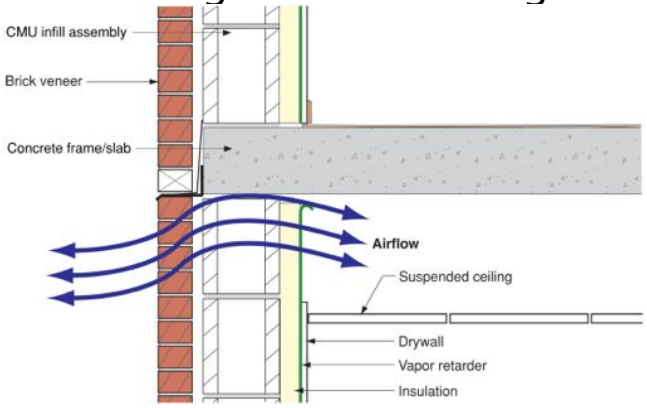
- Beware:
- Around windows
- Canopies
- Parapets

Find the air leak



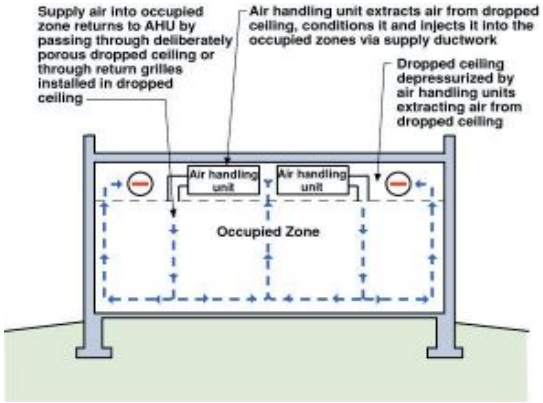


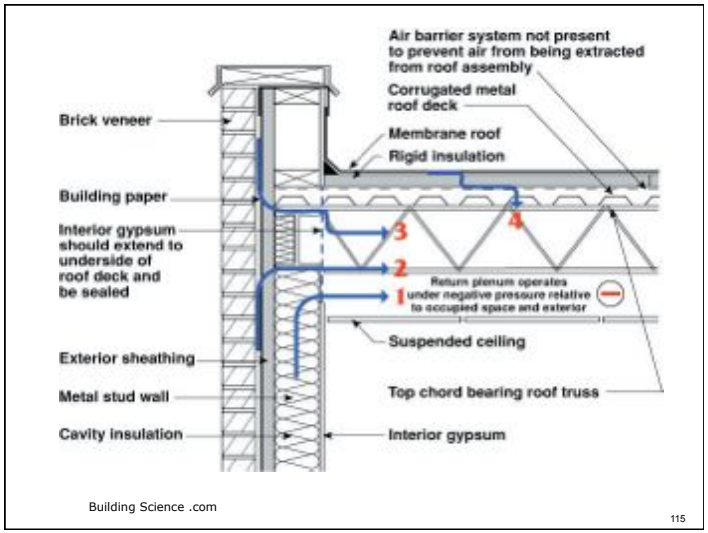
Leakage above ceilings



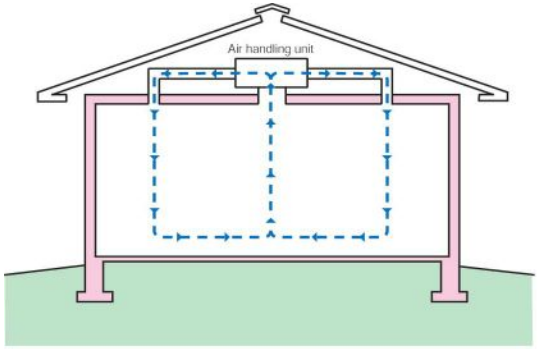
Building Science.com Airflow Control No. 113/79

Dropped-Ceiling Return Plenum





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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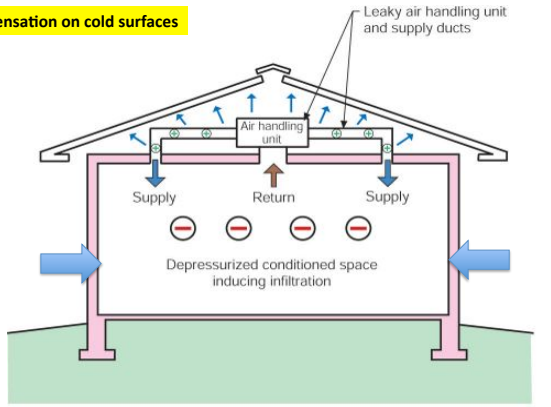
Condensation on cold surfaces



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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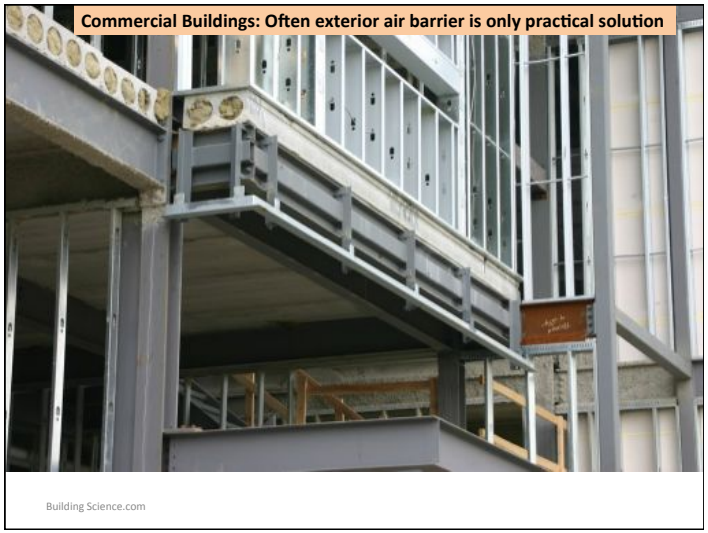
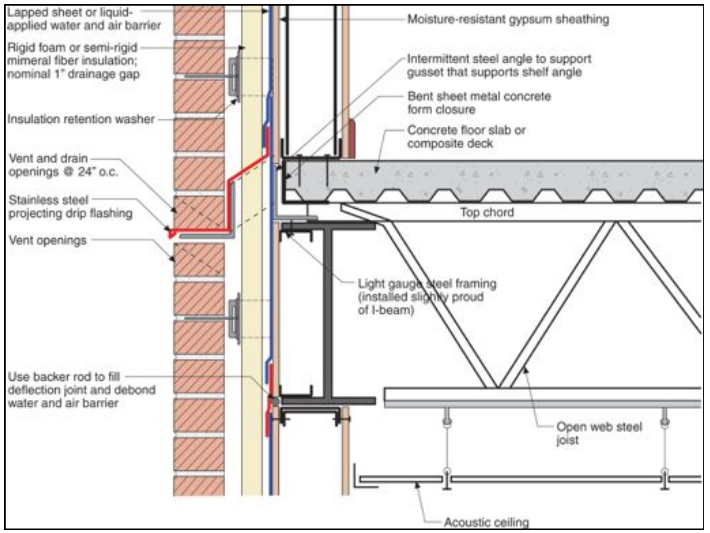
Details

- Air & water & vapor transition membranes





Rigid Exterior Air Barrier

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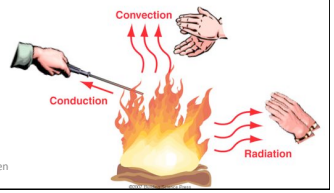
3. Thermal control

- 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

12-02-28

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



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!

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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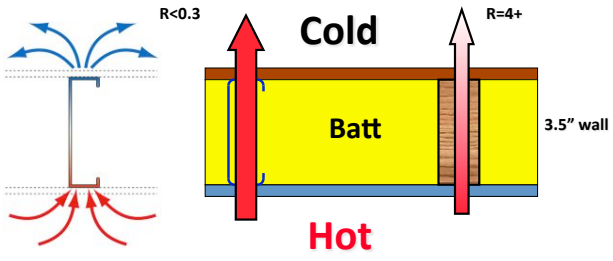
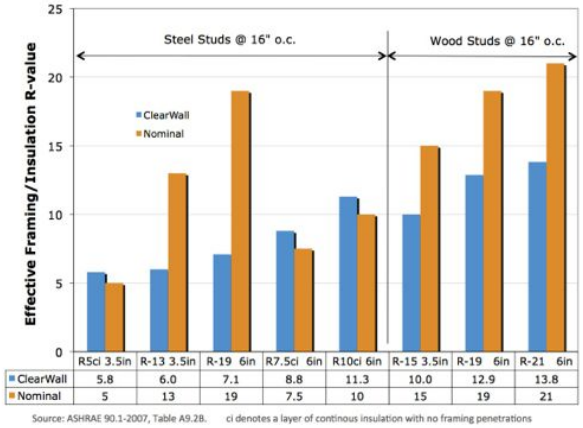
Thermal Bridging

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

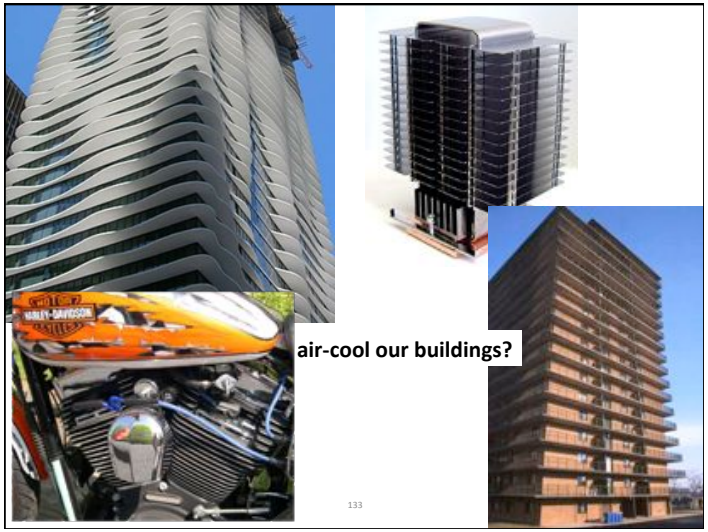


Best-case R-values for stud walls



	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

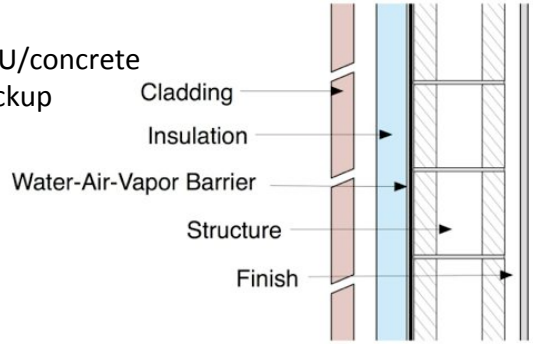


Thermal Bridge Examples

- Aluminum framed
- Balconies, Exposed slab edges

Perfect Wall

- CMU/concrete backup



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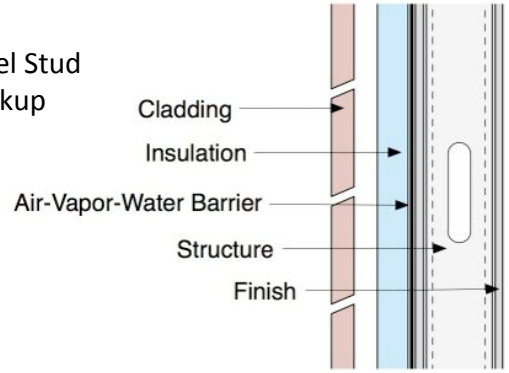
Perfect Wall

- Steel Stud Backup



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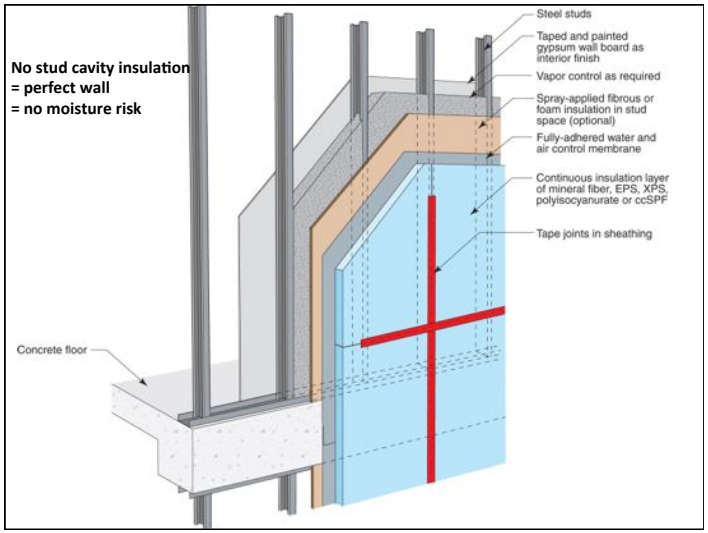
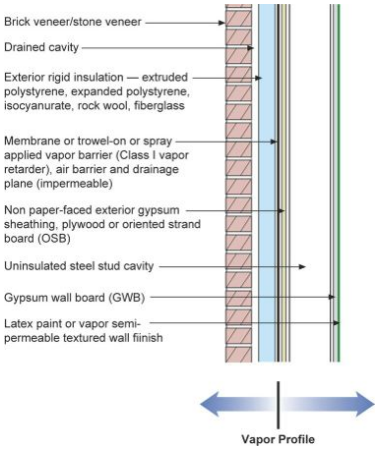
No stud cavity insulation
= perfect wall
= no moisture risk



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



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Joseph Lstiburek 141

Building Science Corporation
2010

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DENSGLASS GOLD
DENSGLASS GOLD
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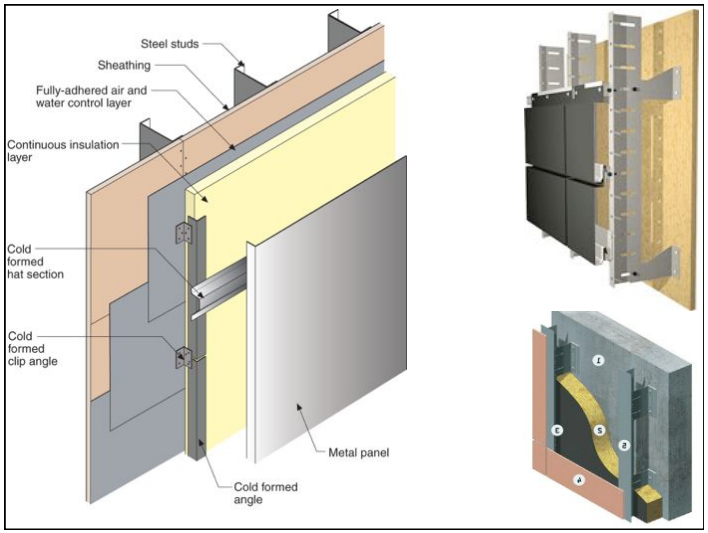
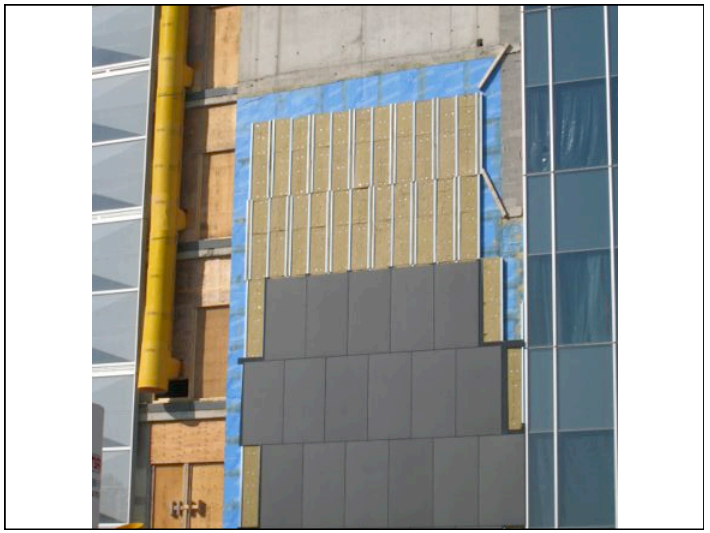
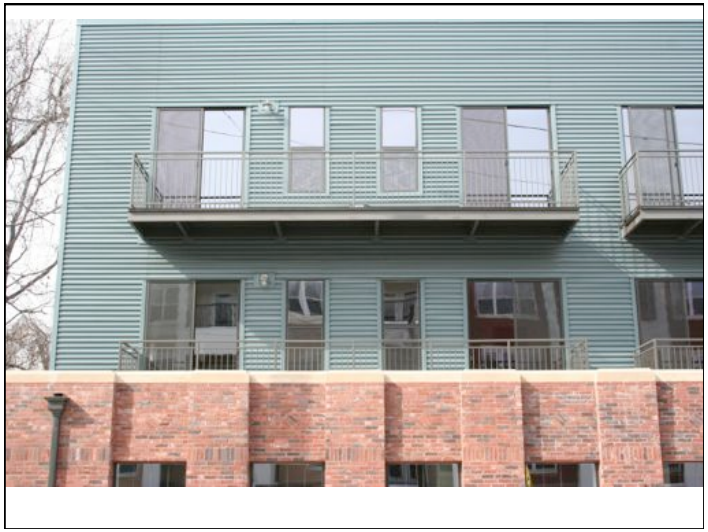
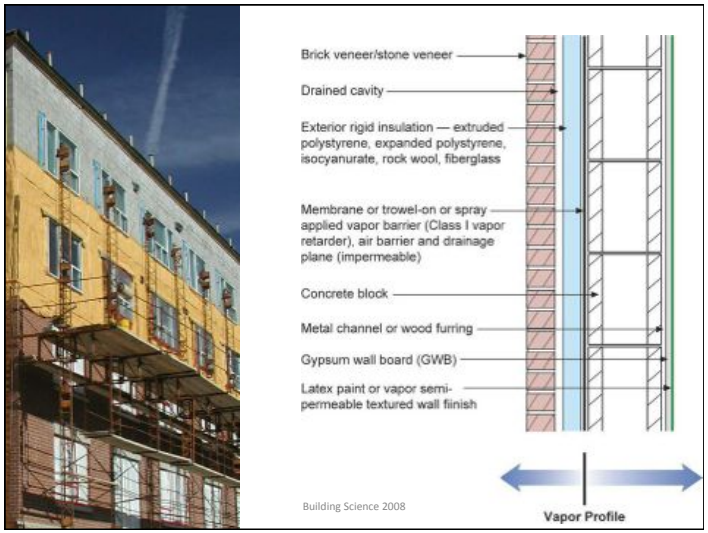
Blueskin


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

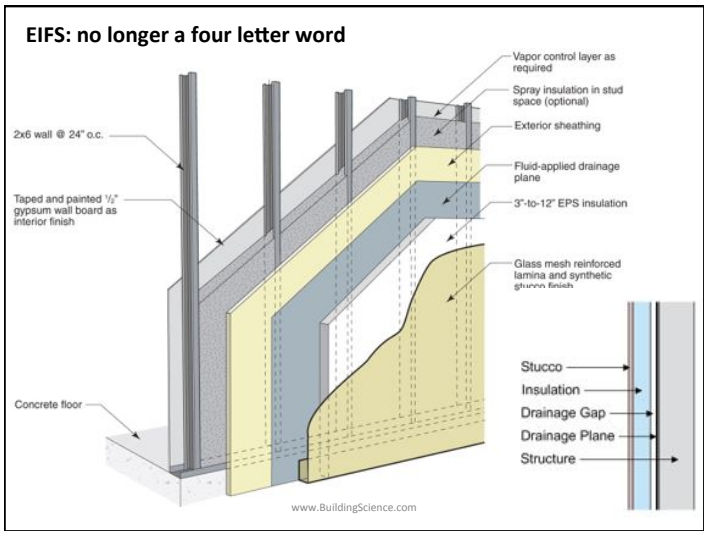





University of Hartford


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
Vapor control layer as required
Spray insulation in stud space (optional)
Exterior sheathing
Fluid-applied drainage plane
3"-to-12" EPS insulation
Glass mesh reinforced lamina and synthetic
2x6 wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Concrete floor
Stucco
Insulation
Drainage Gap
Drainage Plane
Structure
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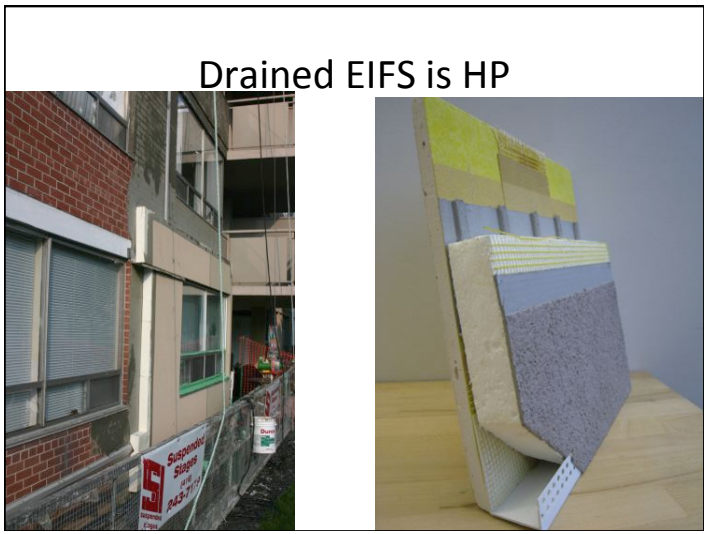
Drained EIFS is HP

Conclusions

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

Mechnicals

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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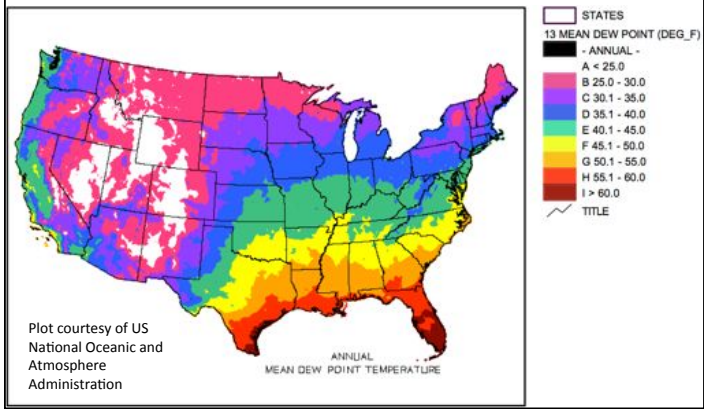
Humidity Control

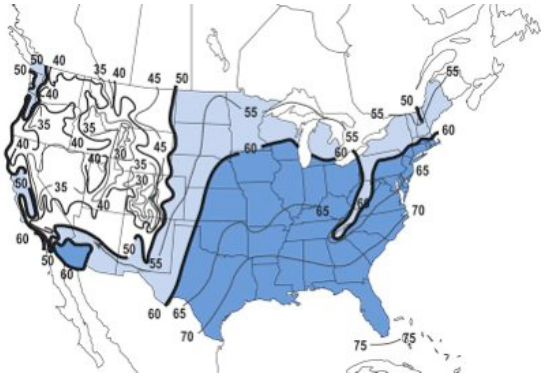
- Critical to control warm-weather RH for
  - Human comfort
  - Risk of surface mold growth
  - Paper curling, printers jamming, dripping pipes, etc
- Much of Eastern US and Canada have high summer humidity levels
  - South-east is toughest climate

Annual Average Outdoor Dewpoint



Plot courtesy of US National Oceanic and Atmosphere Administration

August Average Outdoor Dewpoint



Mean August Dewpoints for 1946-1965 from Climatic Atlas of the United States

Cooling ≠ Dehumidification

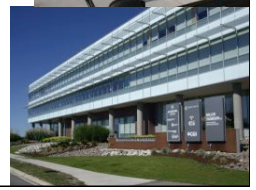
- Cooling dehumdifies **if** the coil is cold enough
  - Eg. Want leaving air dewpoint temperature about <50°F (10°C)
  - Danger: Modulating mixing valves in fancoils
    - Increases temperature of supply chilled water
  - Underfloor Air Distribution
    - Increase supply air temperature
- Cooling only dehumidifies if it is running

Cooling ≠ Dehumidification

- Increasing ventilation (ASHRAE 62) increases humidity load (latent)
- New / Retrofit Buildings: decreasing sensible heat gain, increasing latent gain
- Ratio of sensible to latent is *dropping*
  - Efficient healthy buildings in hot humid weather are at risk

Energy Efficient Buildings

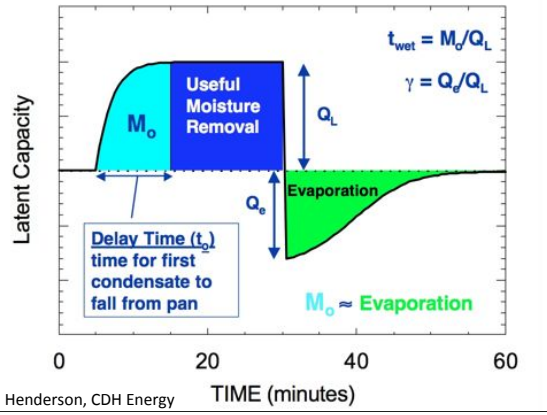
- Sensible Cooling load is reduced
  - White roofs
  - Low Solar Gain Windows / Shading
  - Efficient lights and office equipmen
  - Airtight construction
- Latent Cooling is reduced by…
  - Airtight construction
  - Enthalpy Recovery Ventilation



Changing loads

- More energy efficient: reduce heat gain
- Lights, windows, walls, cool roof, shade etc
  - Reduce sensible heat gain
- Airtightness, and ERV's
  - Reduce latent
- If sensible reduced more than latent …
  - Equipment run time reduced, humdity removal reduced

Short run time= no dehumidification



From Hugh Henderson, CDH Energy

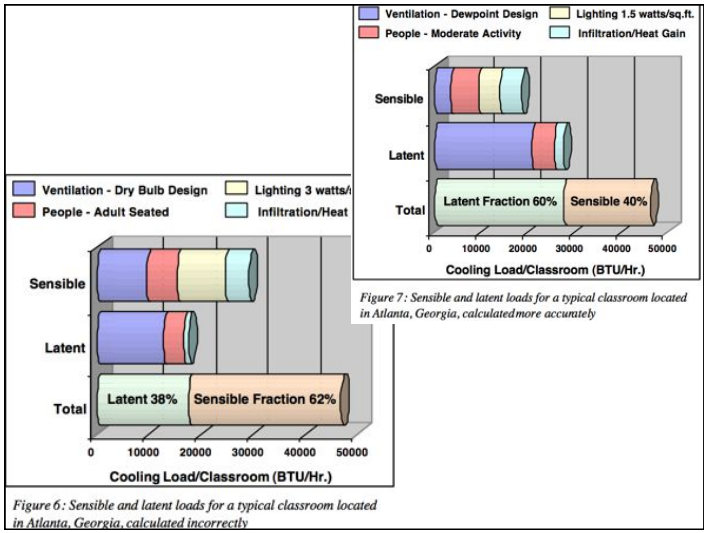


Figure 7: Sensible and latent loads for a typical classroom located in Atlanta, Georgia, calculatedmore accurately

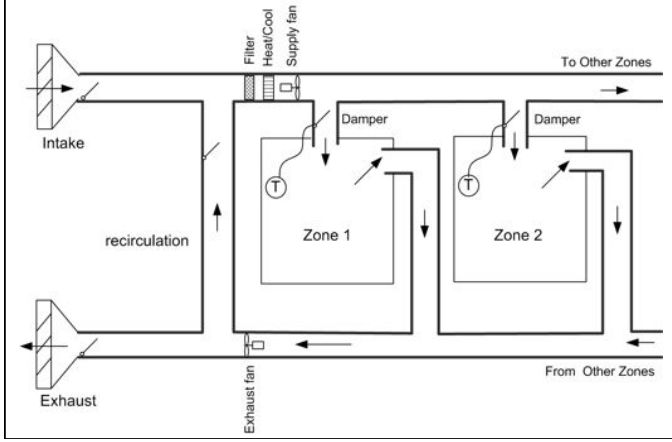
Figure 6: Sensible and latent loads for a typical classroom located in Atlanta, Georgia, calculated incorrectly

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)
- Answer usually is "not"
  - Reheat is energy intensive but works
  - ERVs reduce humidity load, they don't eliminate it

Multi-zone VAV is inherently flawed in most applications

Variable Air Volume: how it works



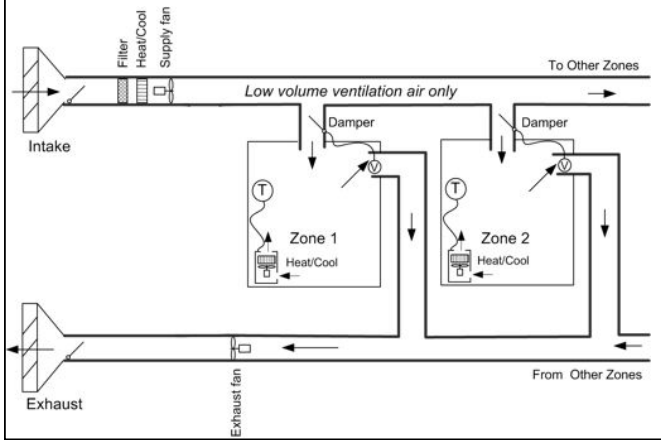
VAV: Fixing How it works

- 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!
  - How to choose fresh air volume in mult-zone systems

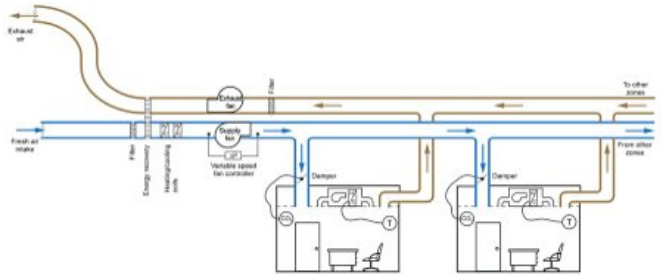
DOAS

- 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

DOAS



Direct Outdoor Air Supply



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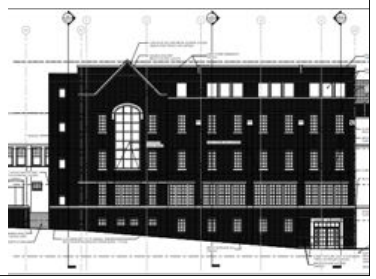
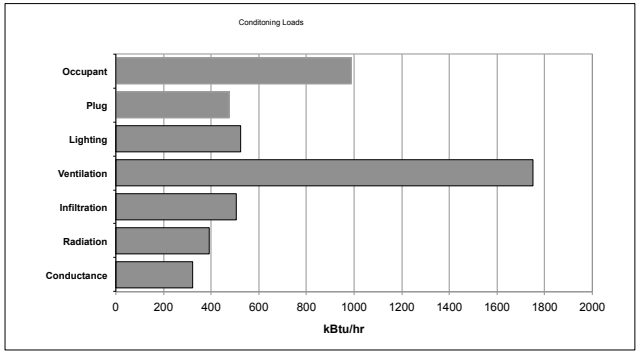
Florida University Building

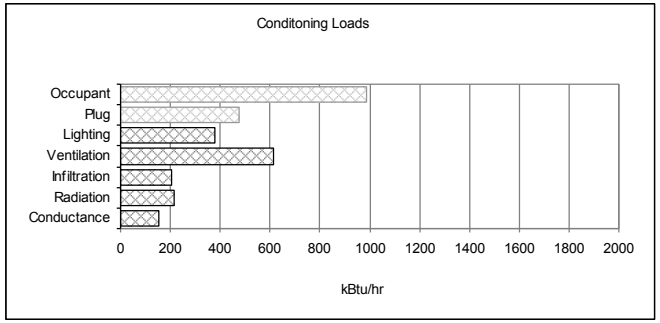
- Low window to wall ratio
- Compact building shape
- High occupancy



Florida University Building Loads



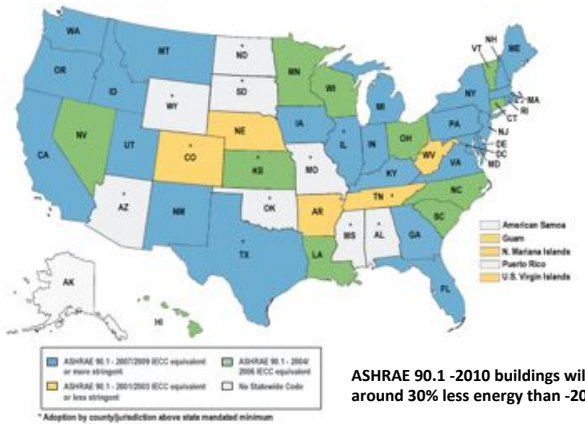
Florida university



ERV, Demand-controlled ventilation, low SHGC windows, better insulation (roof!)
Savings 58% of non-plug non-occupant

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

Future Changes

- High R-value requirements for enclosure
- More efficient Mechanicals
- More efficient electricals

- Less waste all around