Dr John Straube, P.Eng.
Principal, Building Science Corporation
Associate Professor, University of Waterloo

Better Buildings

Fundamentals

www.BuildingScience.com

Fundamental Goals

Safe

Healthy

Comfortable

Durable

Affordable

Environmentally Responsible

Performance

- An evolution is underway:
- Buildings will be expected to perform to measurable standards
  - Budget, schedule, LEED, 90.1,etc
  - Energy use
  - Durability
  - Maintenance
  - Health? IEQ?

The Rules

Heat Flow Is From Warm To Cold

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Air Flow Is From A Higher Pressure To A Lower Pressure

Gravity Always Acts Down

Joseph Lstiburek, Ph.D., P.Eng
John Straube, Ph.D., P.Eng

Building Science

Environmental Separation

presented by www.buildingscience.com

Building Functions

- Much more more than shelter
- Function of a building:

"Provide the desired environment for human use and occupancy"

"Durability, Convenience, and Beauty"
Vitruvius, 70 BC

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Building Components

- Buildings are made of several large systems
- Can be grouped in four categories
  - Superstructure
  - Service Systems
  - Fabric
  - Enclosure

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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, etc… from the innermost to the outermost layer.
- Sometimes, interior partition also are environmental separators (pools, rinks, etc.)

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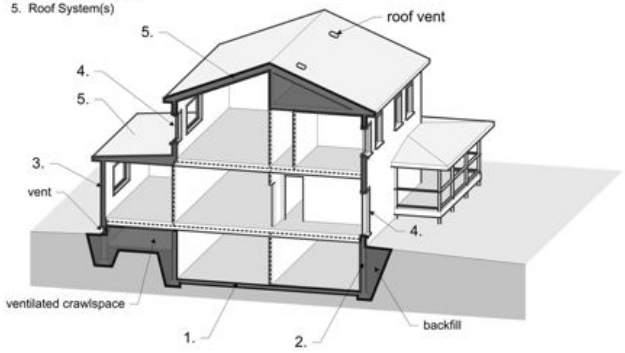
Building Enclosure Components:

1. Basement Floor System(s)
2. Foundation Wall System(s)
3. Above Grade Wall System(s)
4. Windows and Doors
5. Roof System(s)

Where is inside?
Where is outside?



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Climate Site

- Design for
  - Climate zone
  - Site
  - Building height, shape, complexity

Seattle ≠ Sacramento
Miami ≠ Minneapolis
Edmonton ≠ Toronto

Marcus Vitruvius Pollio

These are properly designed, when due regard is had to the country and climate in which they are erected. For the method of building which is suited to Egypt would be very improper in Spain, and that in use in Pontus would be absurd at Rome: so in other parts of the world **a style suitable to one climate, would be very unsuitable to another**: for one part of the world is under the sun's course, another is distant from it, and another, between the two, is temperate.

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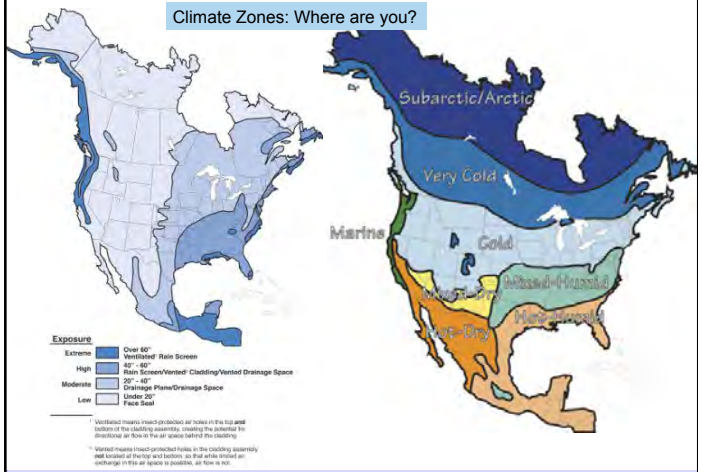
Climate Zones: Where are you?



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Climate Load Modification

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

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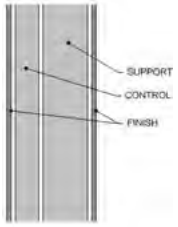
Basic Functions of the Enclosure

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

Functional Layers



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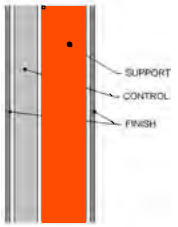
Basic Enclosure Functions

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

Functional Layers



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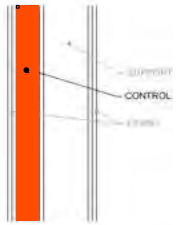
Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- **Control**
  - **Control mass and energy flows**
    - **Water/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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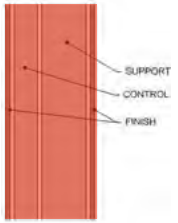
Other Control . . .

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

Functional Layers



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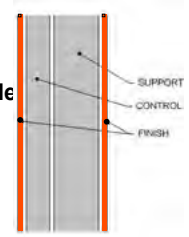
Basic Enclosure Functions

- 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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Distribution

- A *Building* Function imposed on enclosure
- Distribute services or utilities to from through, within, the enclosure, e.g.,
  - Power
  - Communication
  - Water (Potable, sewage, etc.)
  - Gas
  - Conditioned air
  - Cold or hot water

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History of Control Functions

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

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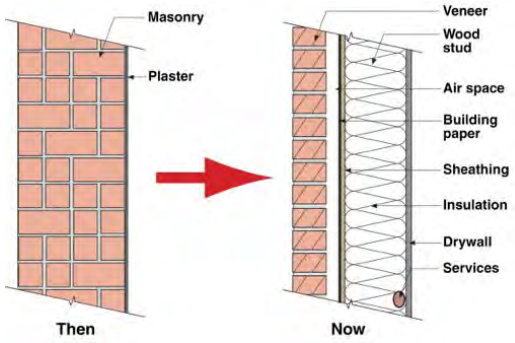
Changes



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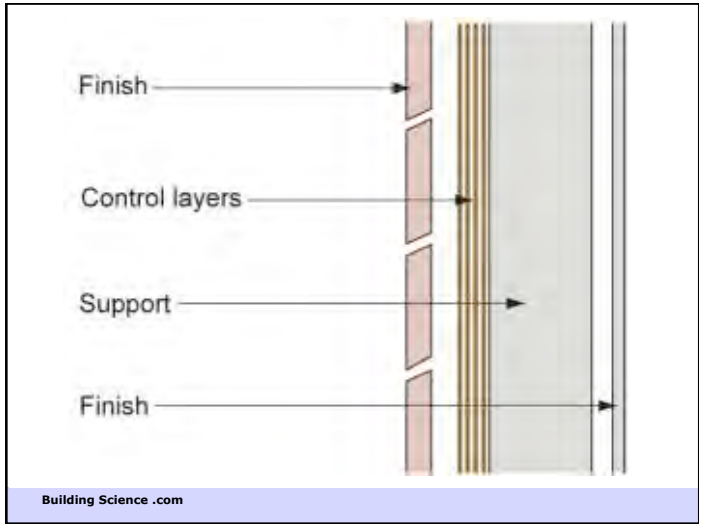
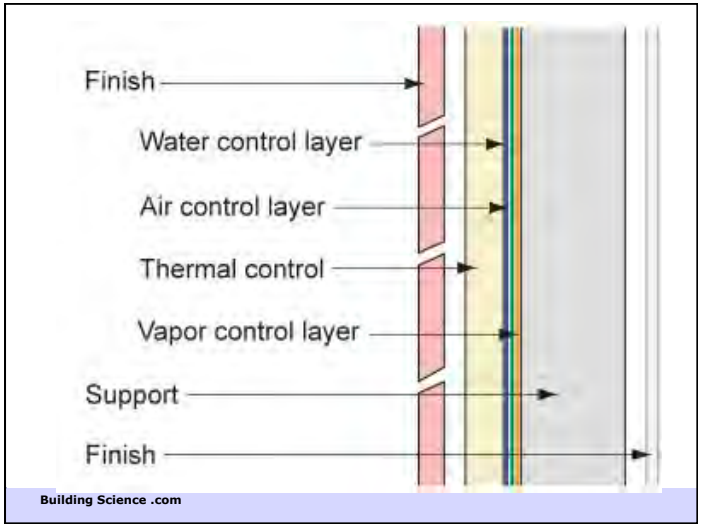
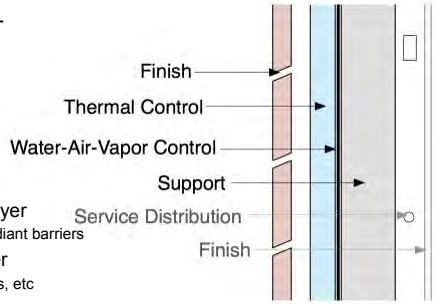




The "Perfect Wall"

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



Fire Control may be needed
Sound Control optional

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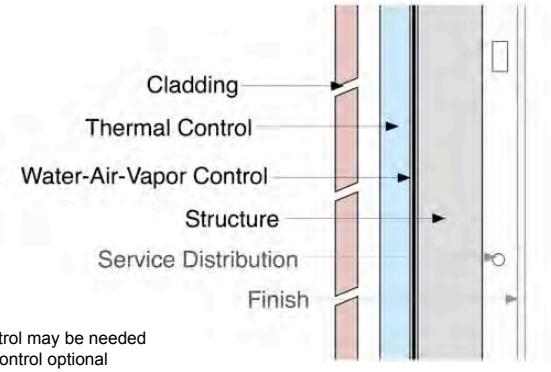
Perfect Wall expanded



Fire Control may be needed
Sound Control optional

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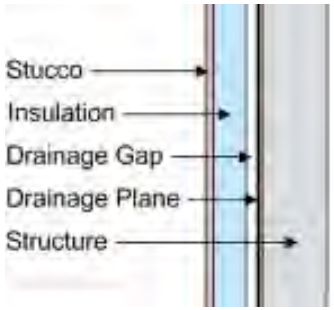
Different Arrangements

- Drained EIFS: Almost perfect retrofit



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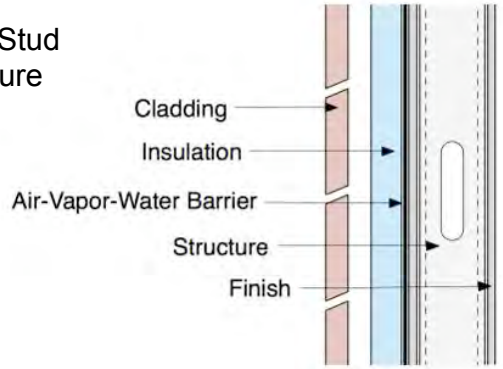
Perfect Wall

- Steel Stud Structure



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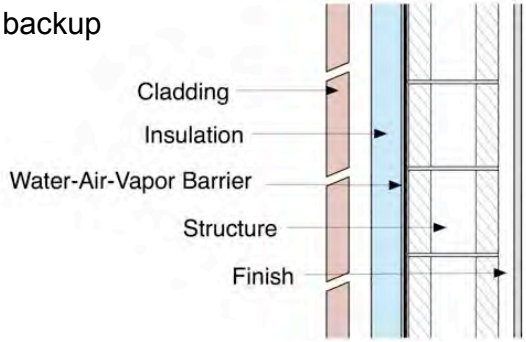
Perfect Wall

- CMU backup



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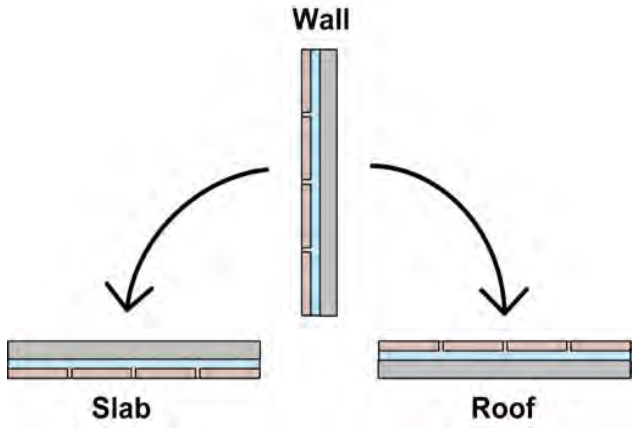

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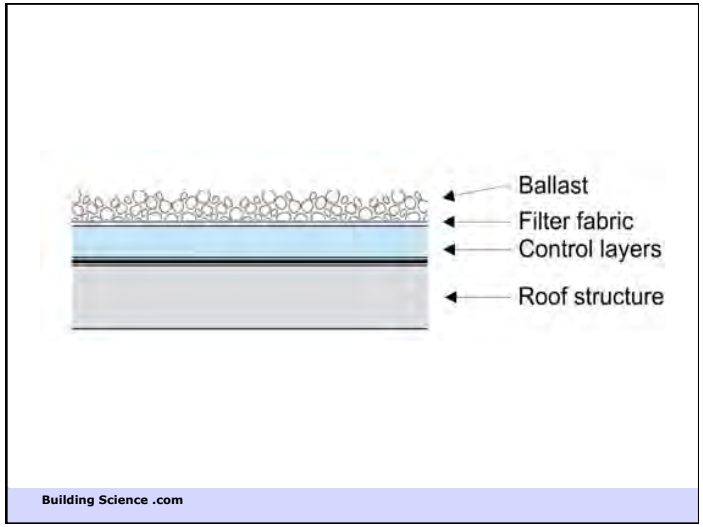
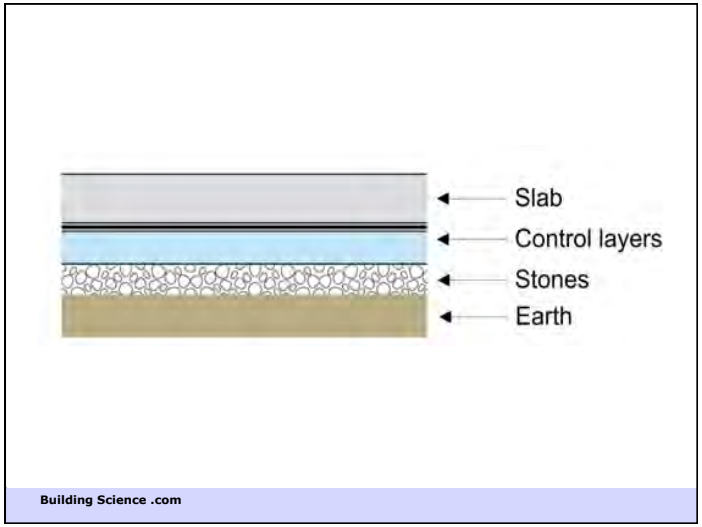
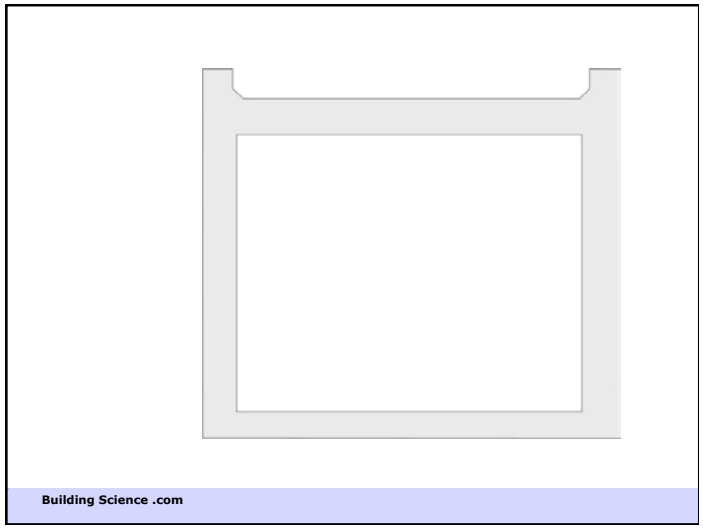

Ballast
Filter fabric
Control layers
Roof structure
Building Science .com


Slab
Control layers
Stones
Earth
Building Science .com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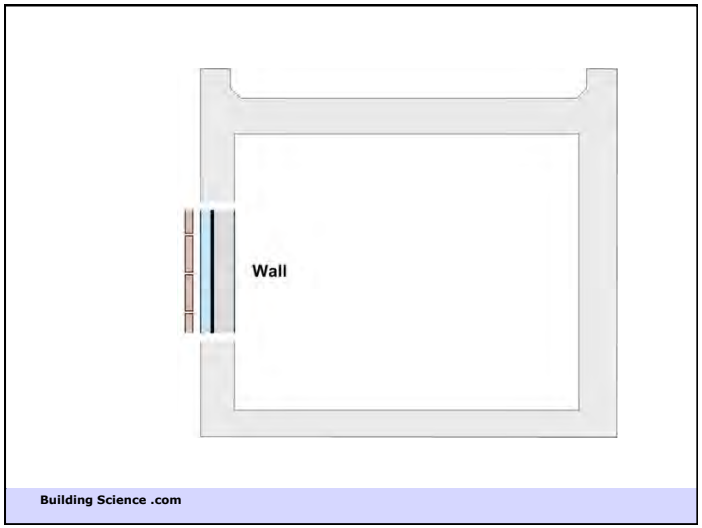
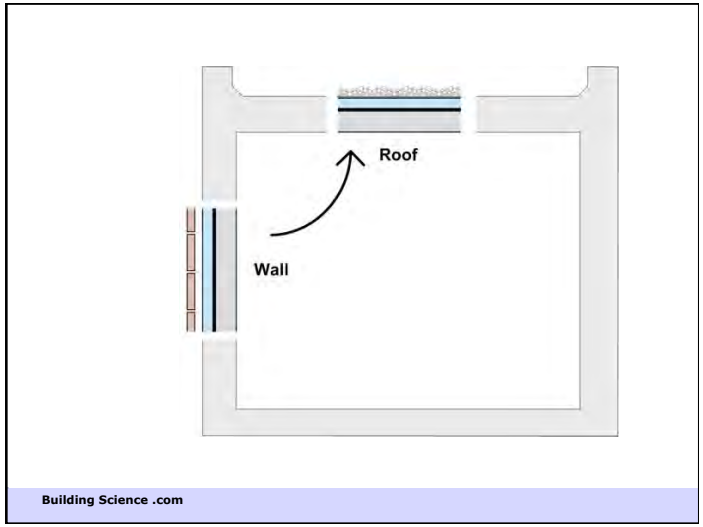
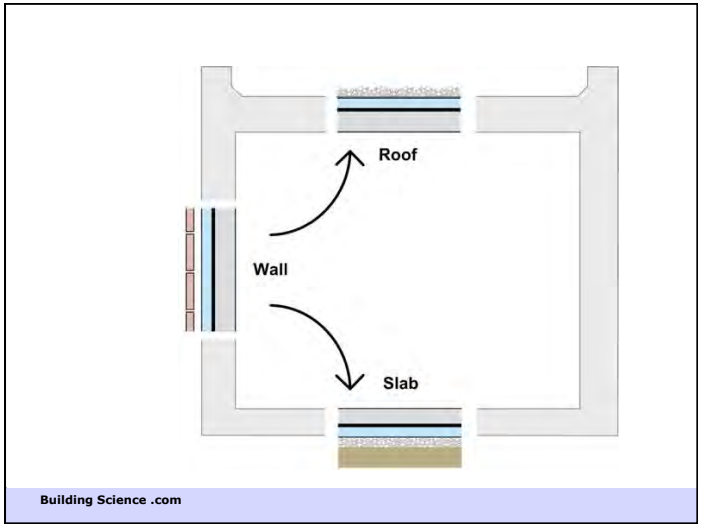
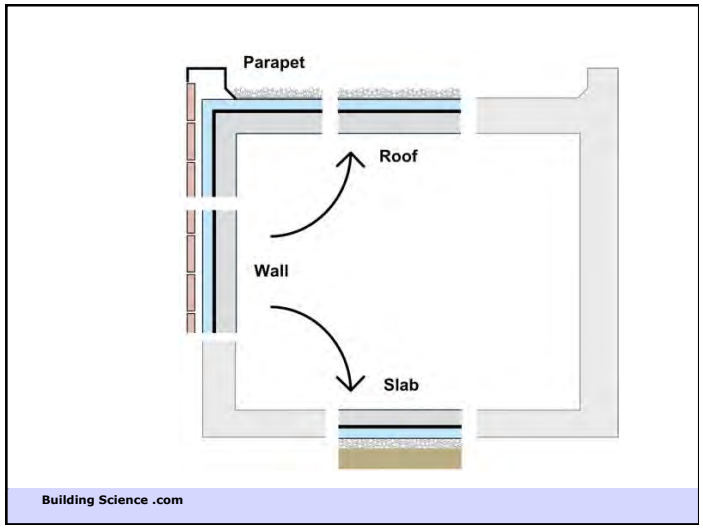
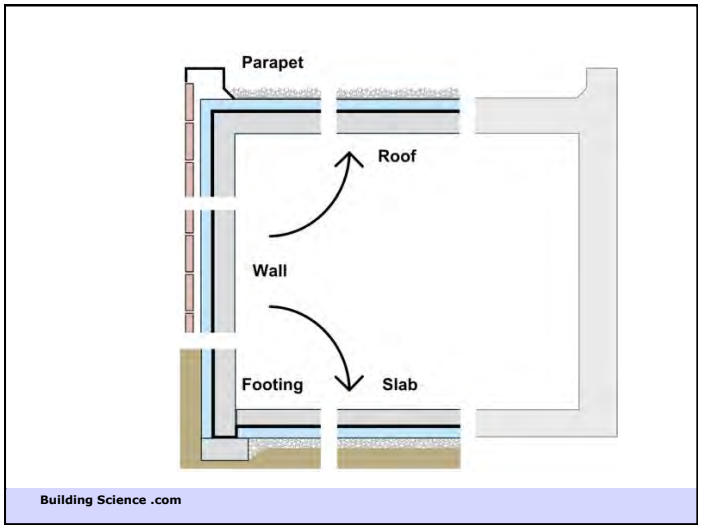
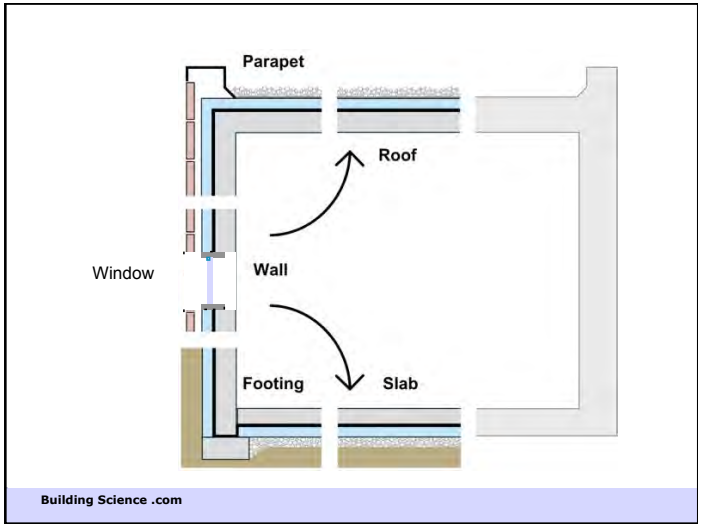

Wall
Building Science .com


Roof
Wall
Building Science .com

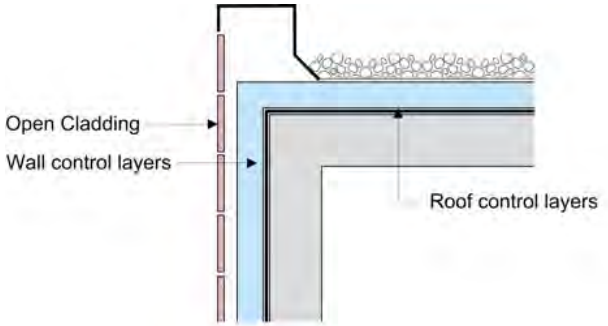

Roof
Wall
Slab
Building Science .com


Parapet
Roof
Wall
Slab
Building Science .com


Parapet
Roof
Wall
Footing
Slab
Building Science .com

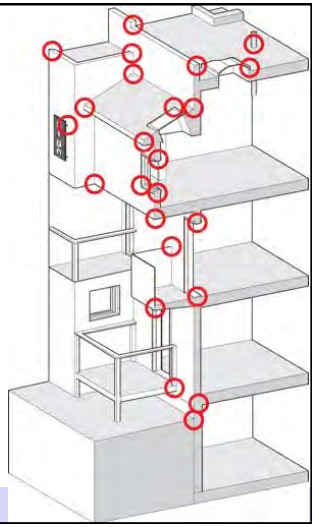


Connections: Who is in charge

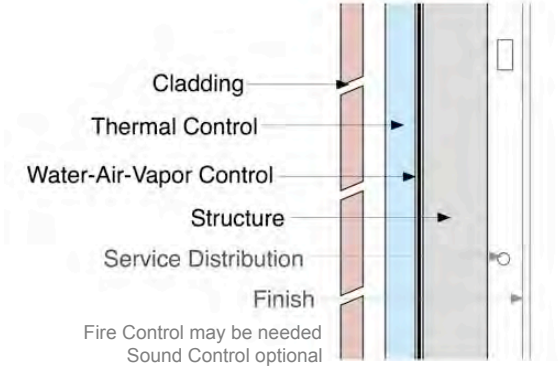


Enclosure Design: Details

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



Perfect Wall expanded



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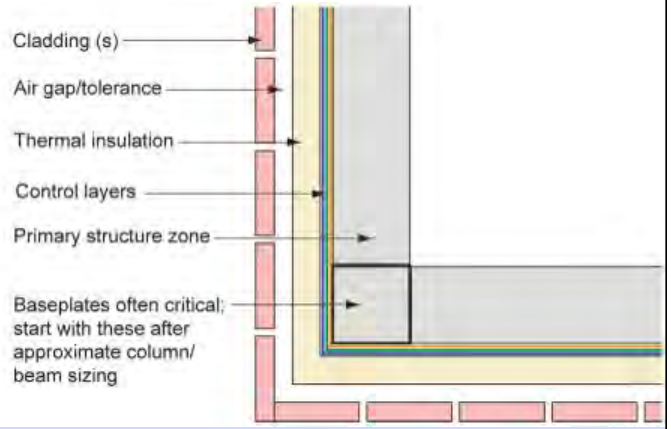
Plan Dimensions



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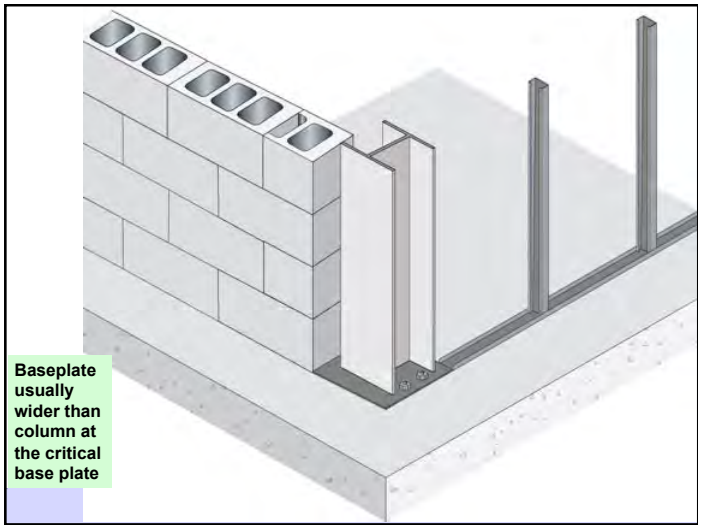
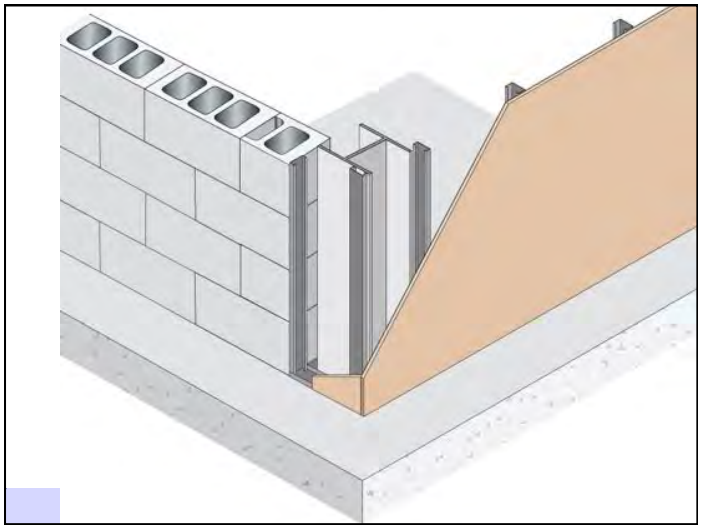
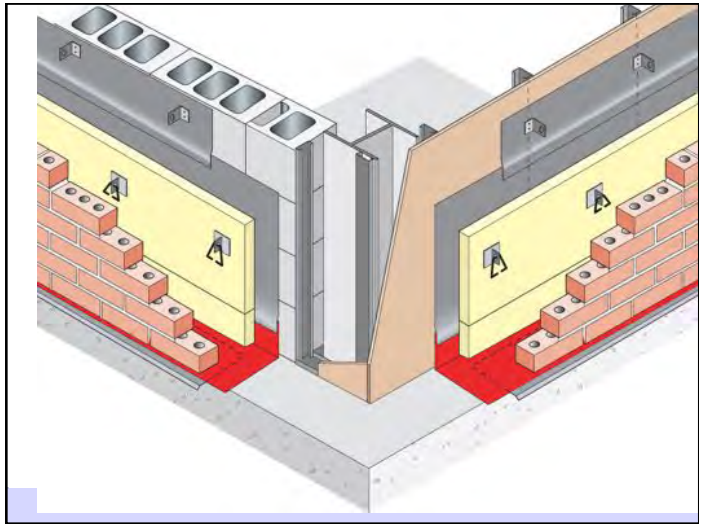
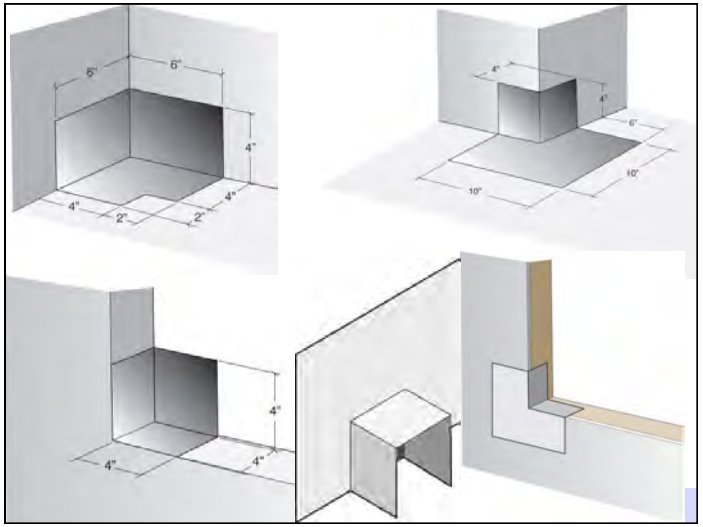


Baseplate usually wider than column at the critical base plate

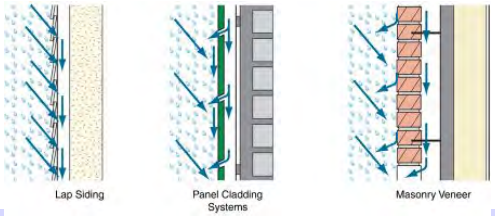






1. Water / Rain Control

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



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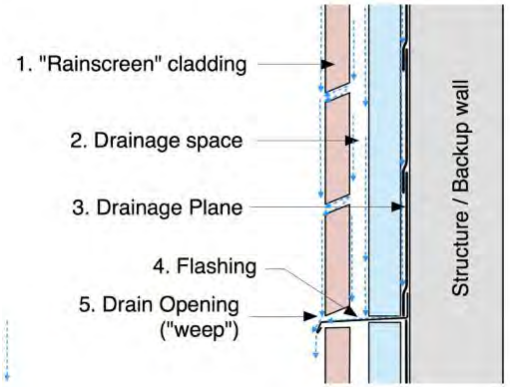
"Rainscreen" or "Drained" System



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Air-Water Control Layers

Sloped and complex surfaces demand very high performance

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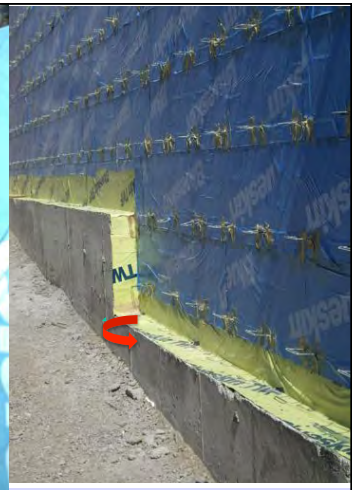
Shingle lap is the best, most reliable

Beware vertical installation and wrinkles!



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Fluid-applied products avoids laps

Details

- Air & water & vapor transition membranes

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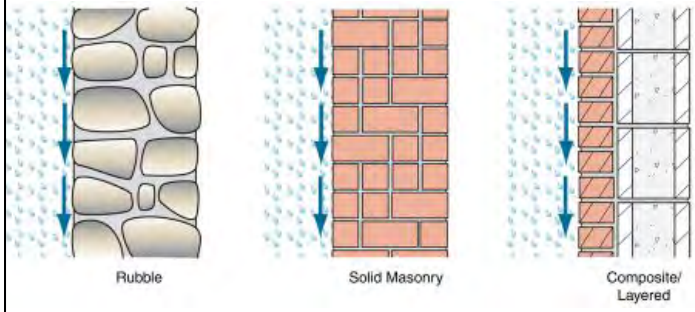
Mixed membrane + liquid

Often use membranes for transitions

Mass/Storage/Reservoir Walls



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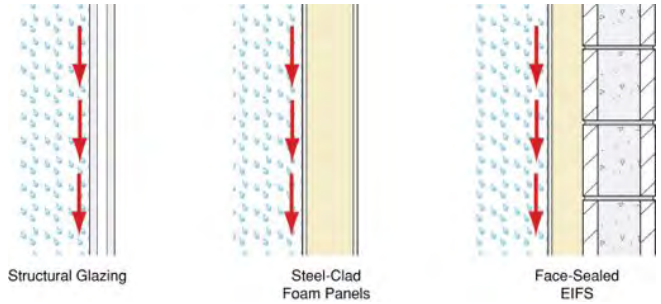
No building paper, flashing, weepholes

Perfect Barrier / Face Sealed



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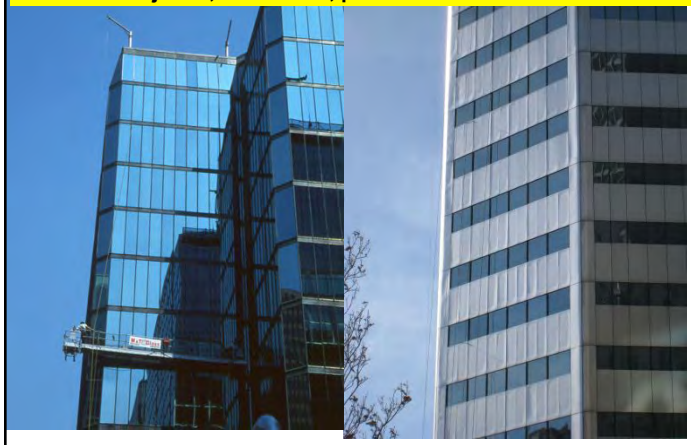
It is all about joints, transitions, penetrations



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2. Airflow control

- Airtightness critical for all climates
  - Control condensation and energy waste critical in cold climates
- Airflow Control Layer
  - Practically, an air barrier system
- Can't be TOO tight
  - But must provide ventilation

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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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Commercial Buildings: Often exterior air barrier is only practical so

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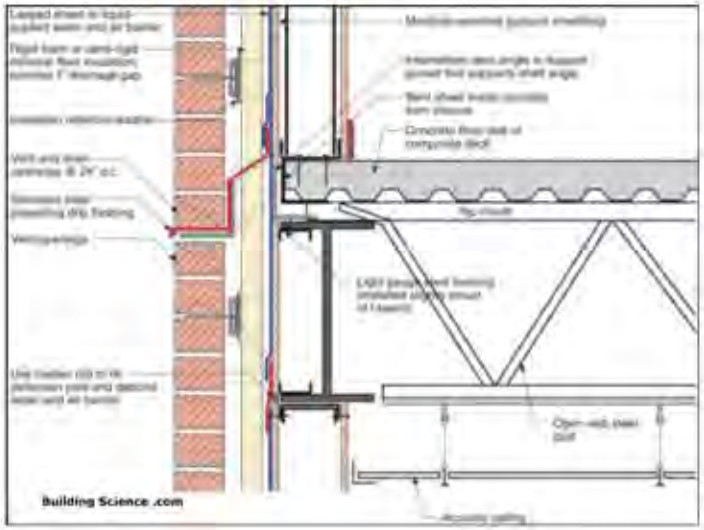

3. Thermal control

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

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Insulation

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

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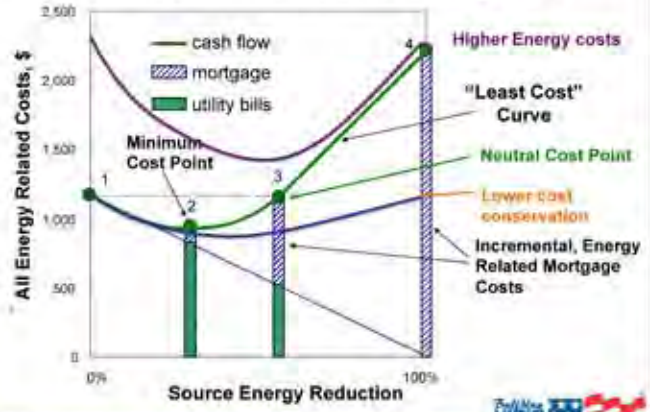
Capital Investment vs Operating Cost



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Underlying Source: Dr Ren Anderson, NREL

It's More Than Insulation!

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

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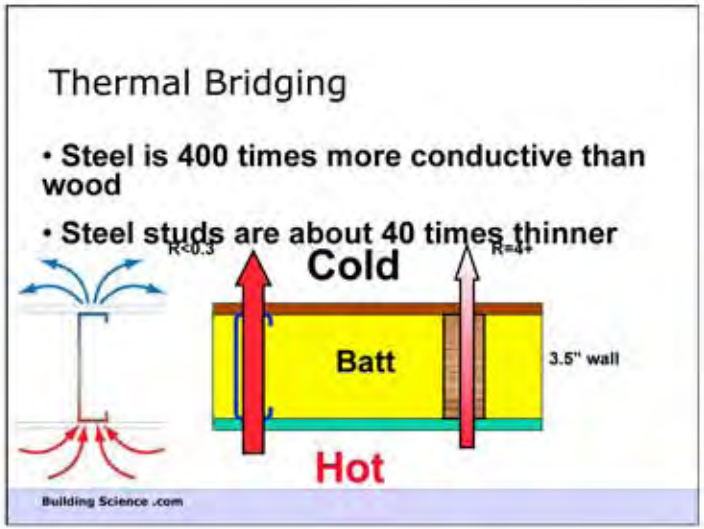
Thermal Bridging
• Steel is 400 times more conductive than wood
• Steel studs are about 40 times thinner
R<0.3
Cold
R=4+
Batt
3.5" wall
Hot
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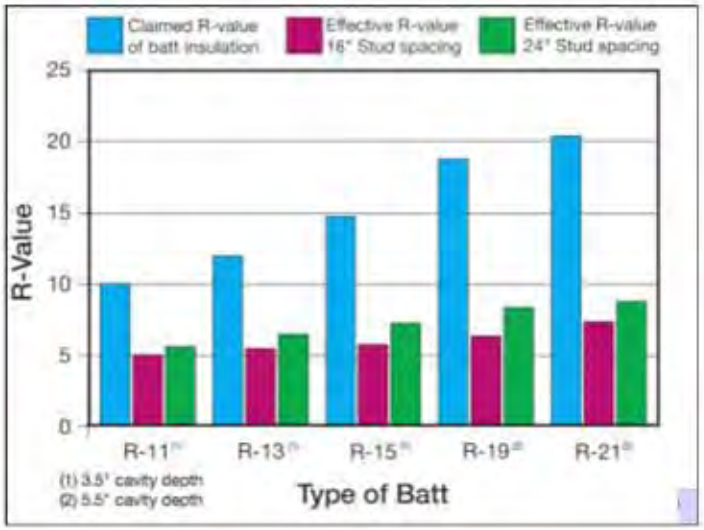
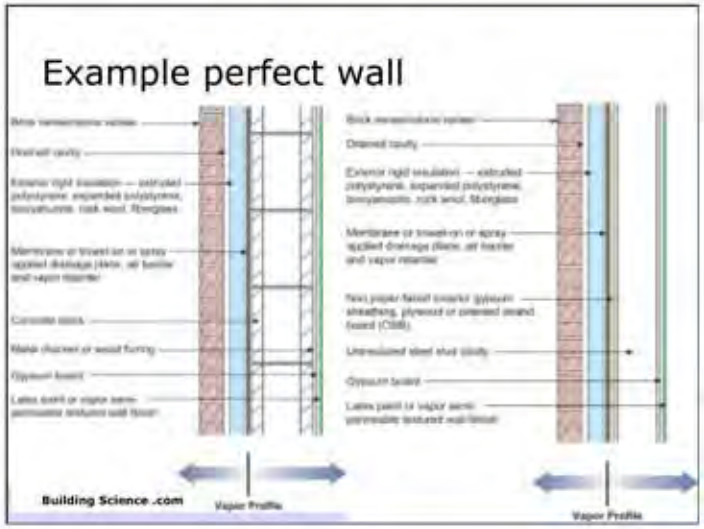

Claimed R-value of batt insulation
Effective R-value 16" Stud spacing
Effective R-value 24" Stud spacing
R-Value
25
20
15
10
5
0
R-11
R-13
R-15
R-19
R-21
(1) 3.5" cavity depth
(2) 5.5" cavity depth
Type of Batt


Example perfect wall
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Vapor Profile
Vapor Profile


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

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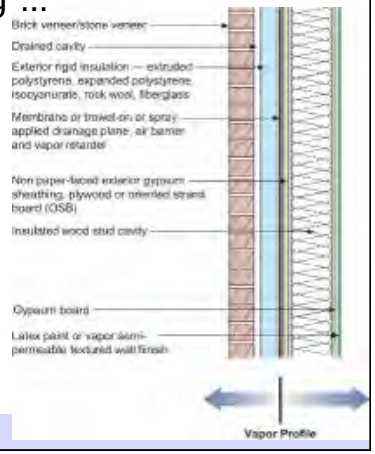
More challenging …

- Hybrid Compromise
  - Wood framing
  - High R-value steel
    - Eg 50%R outside
  - R-value on outside
    - Varies with climate + interior conditions



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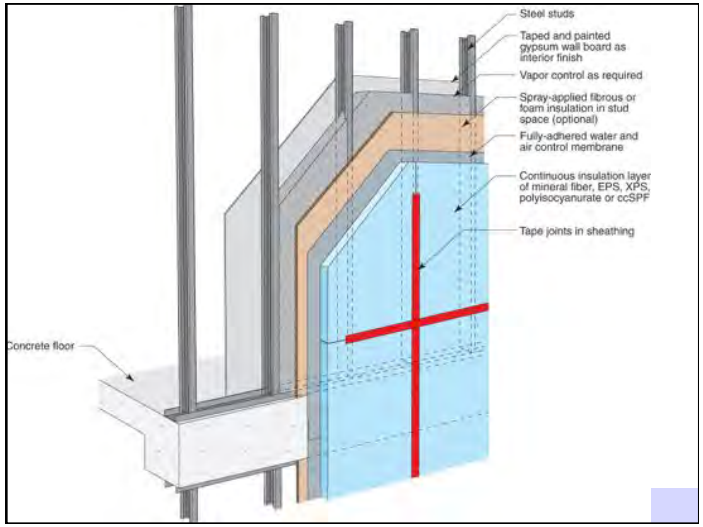
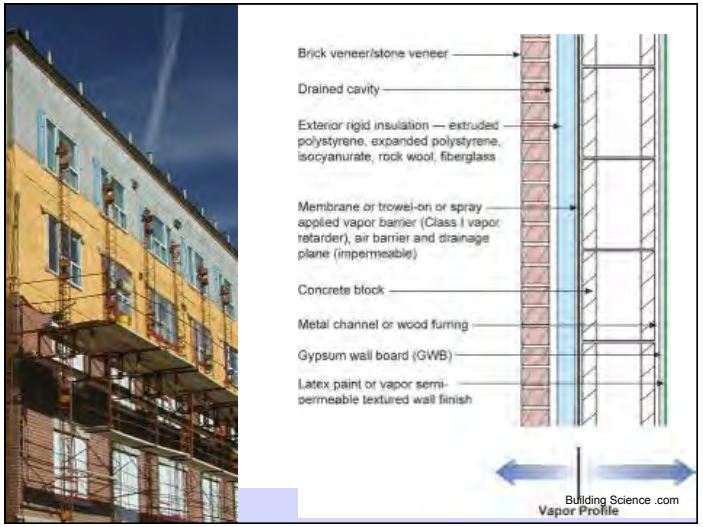
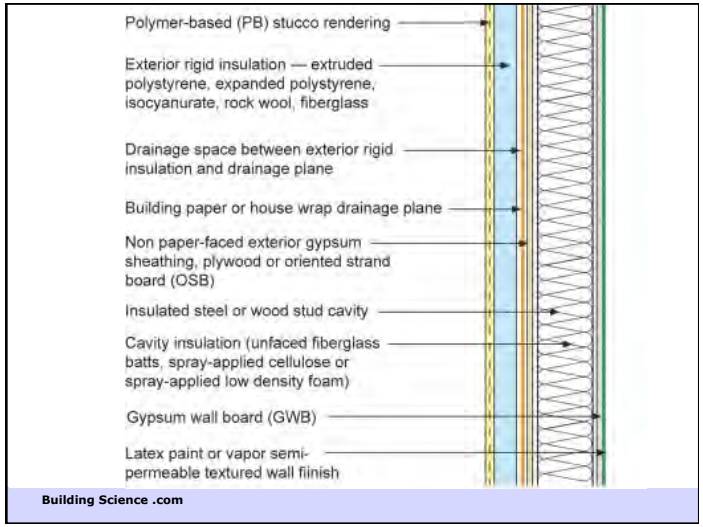


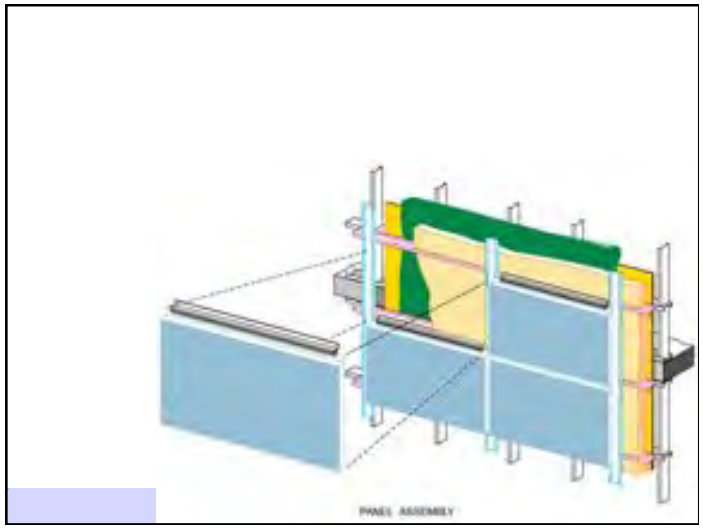


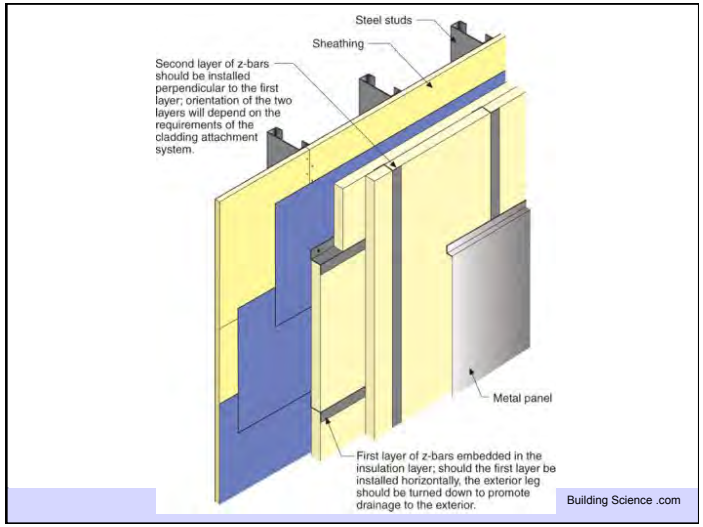
Closed-cell spray polyurethane foam: ccSPF
-Rain control
-Air Control
-Thermal Control
- Vapor Control



Metal Panels

- Lightweight, durable
- Should be **drained** system
- Have high performance potential
- High tech look




Steel studs
Sheathing
Second layer of z-bars should be installed perpendicular to the first layer; orientation of the two layers will depend on the requirements of the cladding attachment system.
Metal panel
First layer of z-bars embedded in the insulation layer; should the first layer be installed horizontally, the exterior leg should be turned down to promote drainage to the exterior.
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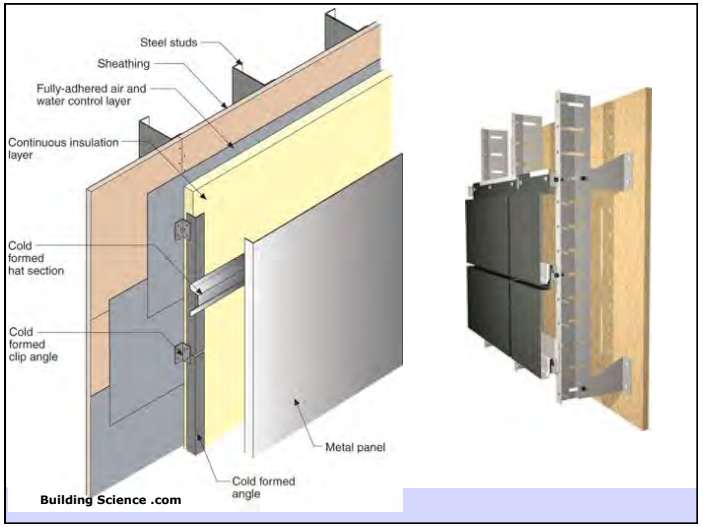
Steel studs
Sheathing
Fully-adhered air and water control layer
Continuous insulation layer
Cold formed hat section
Cold formed clip angle
Metal panel
Cold formed angle
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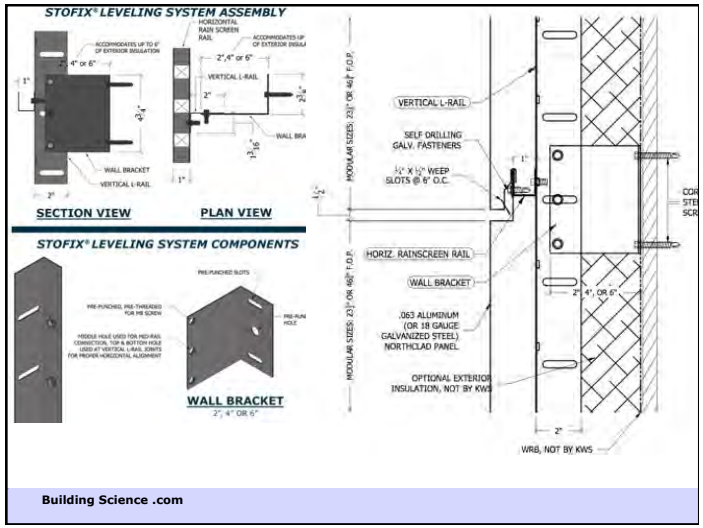
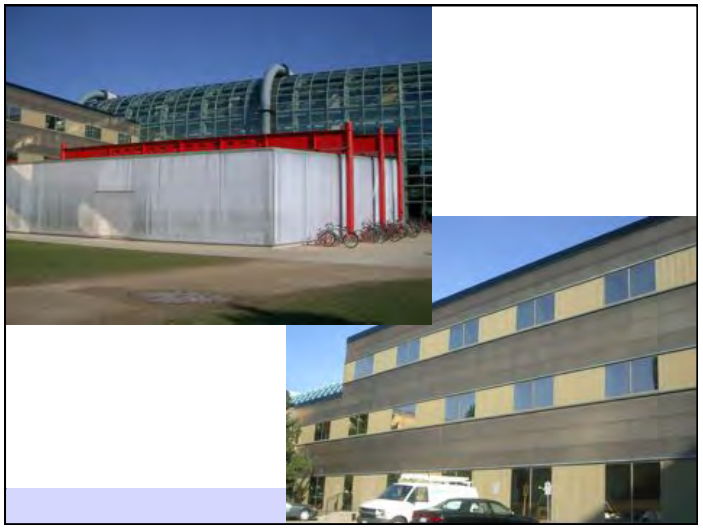
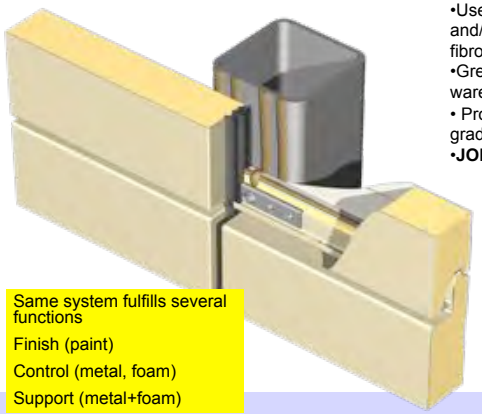

STOFIX® LEVELING SYSTEM ASSEMBLY
SECTION VIEW
PLAN VIEW
STOFIX® LEVELING SYSTEM COMPONENTS
WALL BRACKET
VERTICAL L-RAIL
SELF DRILLING GALV. FASTENERS
HORIZ. RAINSCREEN RAIL
WALL BRACKET
.063 ALUMINUM (OR 18 GAUGE GALVANIZED STEEL) NORTHCLAD PANEL
OPTIONAL EXTERIOR INSULATION, NOT BY KWS
WRB, NOT BY KWS
Building Science .com



Insulated metal panels

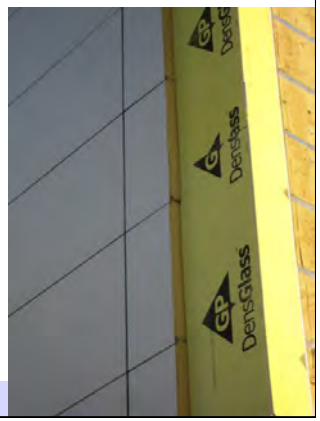


- Can be high-performance low-cost system
- Use thicker panels (4-8") and/or hybrid with interior fibrous insulation
- Great for arenas, pools, warehouses, big box stores
- Protect from impact at grade
- **JOINTS**

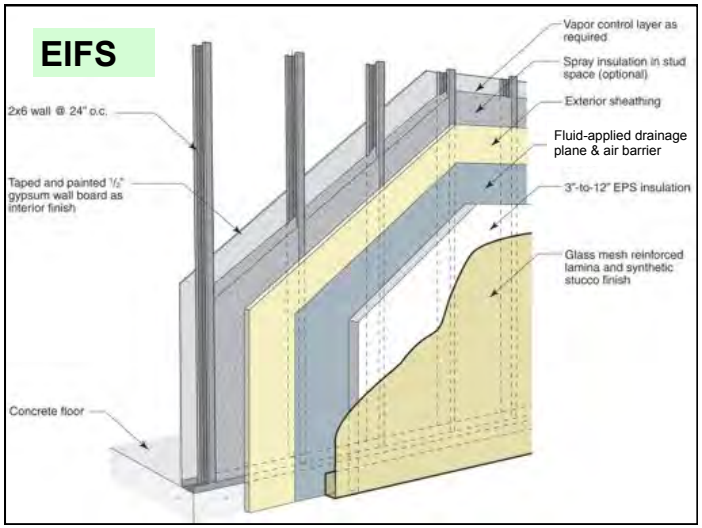
Same system fulfills several functions
Finish (paint)
Control (metal, foam)
Support (metal+foam)

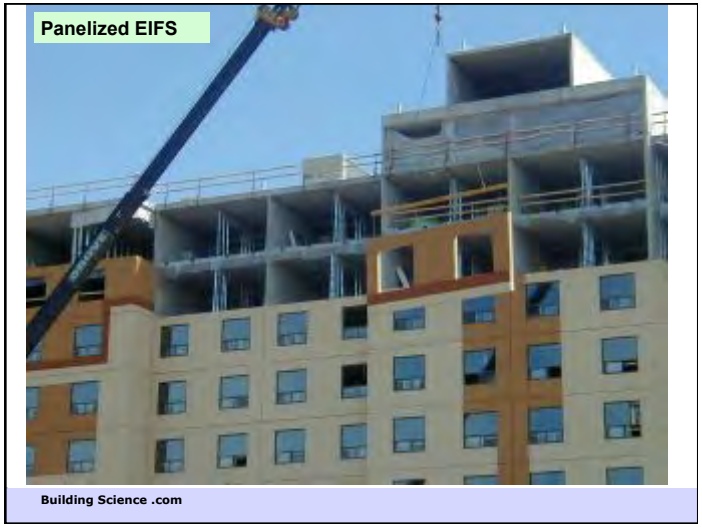
Insulated metal panels

Several suppliers
e.g. Centria, Kingspan
VicWest



EIFS




Panelized EIFS
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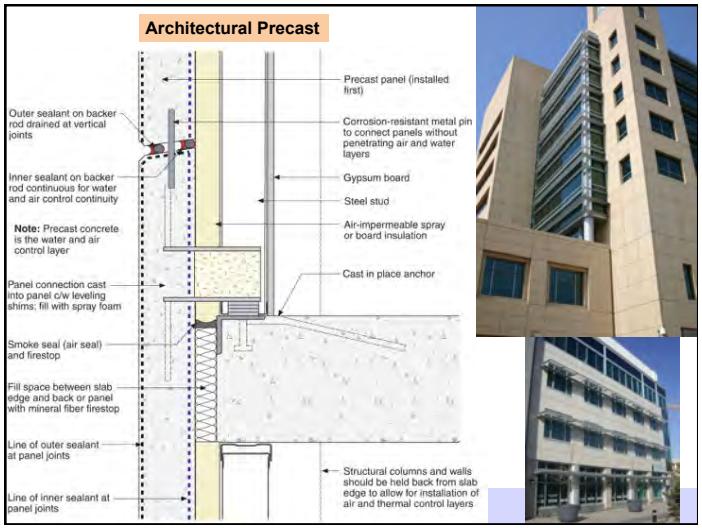
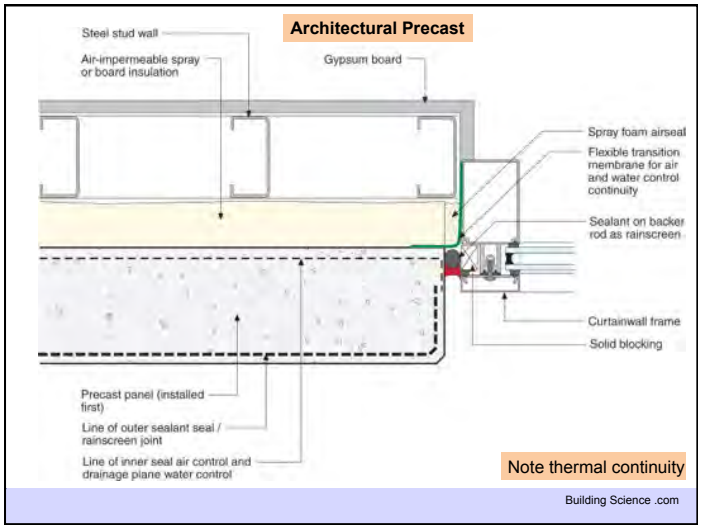

Architectural Precast
Precast panel (installed first)
Outer sealant on backer rod drained at vertical joints
Corrosion-resistant metal pin to connect panels without penetrating air and water layers
Inner sealant on backer rod continuous for water and air control continuity
Gypsum board
Steel stud
Note: Precast concrete is the water and air control layer
Air-impermeable spray or board insulation
Cast in place anchor
Panel connection cast into panel c/w leveling shims; fill with spray foam
Smoke seal (air seal) and firestop
Fill space between slab edge and back or panel with mineral fiber firestop
Line of outer sealant at panel joints
Structural columns and walls should be held back from slab edge to allow for installation of air and thermal control layers
Line of inner sealant at panel joints


Architectural Precast
Steel stud wall
Air-impermeable spray or board insulation
Gypsum board
Spray foam airseal
Flexible transition membrane for air and water control continuity
Sealant on backer rod as rainscreen
Curtainwall frame
Solid blocking
Precast panel (installed first)
Line of outer sealant seal / rainscreen joint
Line of inner seal air control and drainage plane water control
Note thermal continuity
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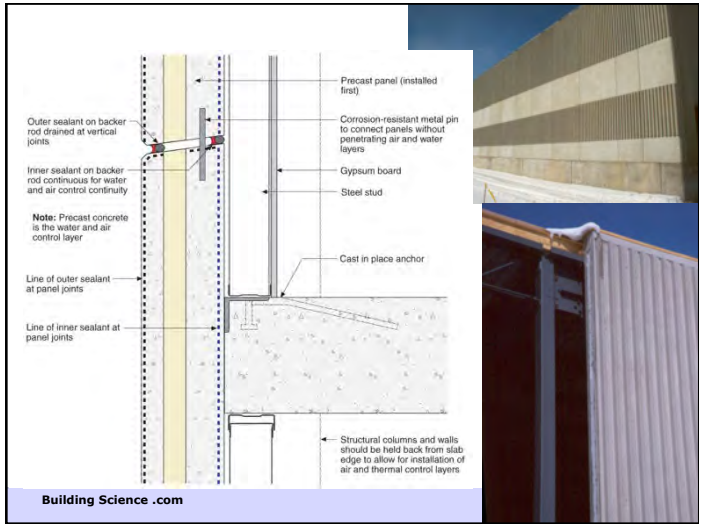
Precast panel (installed first)
Outer sealant on backer rod drained at vertical joints
Corrosion-resistant metal pin to connect panels without penetrating air and water layers
Inner sealant on backer rod continuous for water and air control continuity
Gypsum board
Steel stud
Note: Precast concrete is the water and air control layer
Cast in place anchor
Line of outer sealant at panel joints
Line of inner sealant at panel joints
Structural columns and walls should be held back from slab edge to allow for installation of air and thermal control layers
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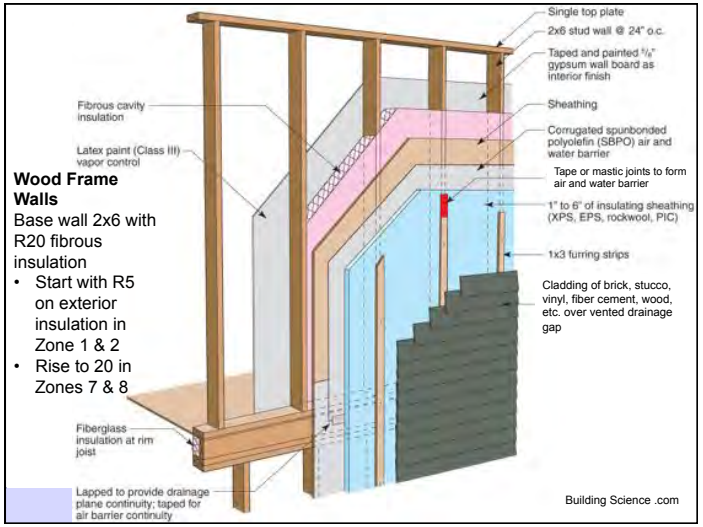
Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 5/8" gypsum wall board as interior finish
Fibrous cavity insulation
Sheathing
Corrugated spunbonded polyolefin (SBPO) air and water barrier
Latex paint (Class III) vapor control
Tape or mastic joints to form air and water barrier
Wood Frame Walls
Base wall 2x6 with R20 fibrous insulation
• Start with R5 on exterior insulation in Zone 1 & 2
• Rise to 20 in Zones 7 & 8
1" to 6" of insulating sheathing (XPS, EPS, rockwool, PIC)
1x3 furring strips
Cladding of brick, stucco, vinyl, fiber cement, wood, etc. over vented drainage gap
Fiberglass insulation at rim joist
Lapped to provide drainage plane continuity; taped for air barrier continuity
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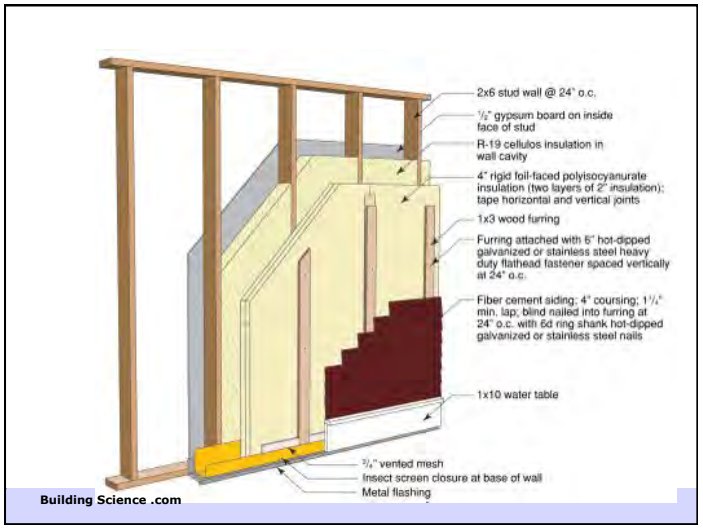
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated wood stud cavity


2x6 stud wall @ 24" o.c.
½" gypsum board on inside face of stud
R-19 cellulos insulation in wall cavity
4" rigid foil-faced polyisocyanurate insulation (two layers of 2" insulation); tape horizontal and vertical joints
1x3 wood furring
Furring attached with 6" hot-dipped galvanized or stainless steel heavy duty flathead fastener spaced vertically at 24" o.c.
Fiber cement siding; 4" coursing; 1¼" min. lap; blind nailed into furring at 24" o.c. with 6d ring shank hot-dipped galvanized or stainless steel nails
1x10 water table
¾" vented mesh
Insect screen closure at base of wall
Metal flashing
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End of Section

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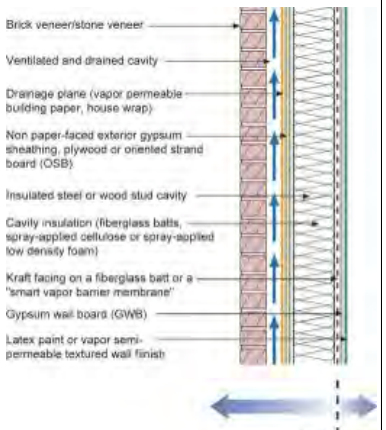
Vapour Profiles
In Wall Assemblies:



Vapor Profile
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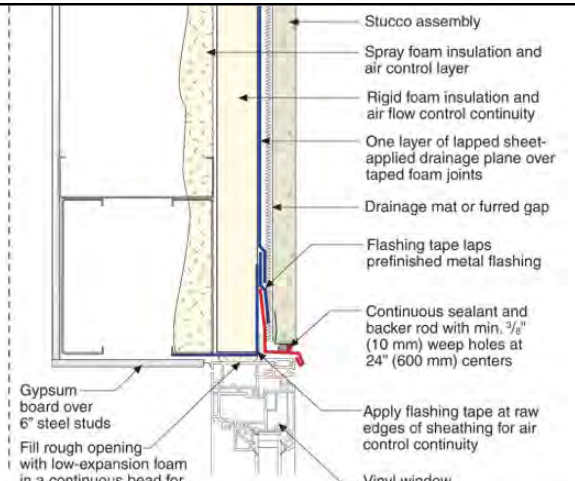

Build