Dr John Straube, P.Eng.
Associate Professor, University of Waterloo

Healthy, Durable, More Sustainable Buildings:

Five Big Changes in Buildings over the last 50 years

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Solid masonry

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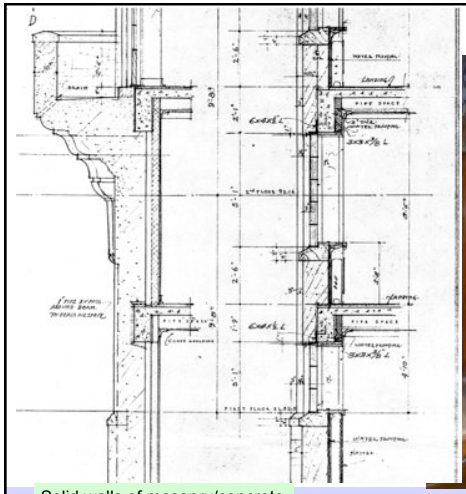

Wet Applied Plaster

Solid walls of masonry/concrete

3

Old Growth Timber

Building Science.com

4

This is what wood framing should look like

Pre-WWII Buildings

- Masonry and old-growth solid timber structures
- Plaster is the dominant interior finish
- No added insulation (or very little)
- No vapor barriers
- Heating systems only, some natural ventilation
- No air conditioning
- Few explicit air-tightening details
- Few ducts, pipes, wires, controls, gas, cables,etc

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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

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1. Thermal

- Old buildings used energy leakage to dry materials and assemblies
- Increased airtightness
  - Reduces drying, interior RH increases
- Increased insulation = less drying
  - Colder exterior, colder interior
  - Wider swings
- White roofs, efficient lights, etc

2. Vapor Permeability

- Low vapor permeance exterior layers
  - Metal panels, precast concrete
  - OSB and foam vs skip wood sheathing
- Low vapor permeance interior layers
  - Polyethylene, vinyl wall paper
  - Vinyl sheet flooring

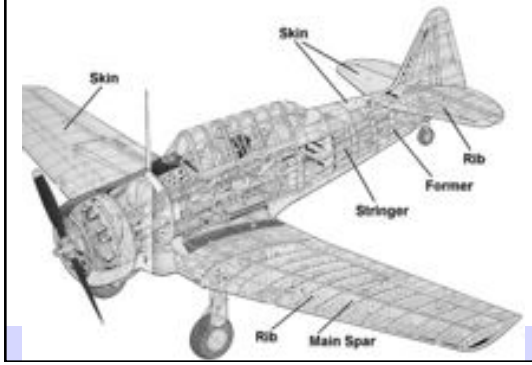
3. Water/Mold Sensitivity

- Moisture= mold growth
- Wood products
  - New growth vs old
  - Processing: plywood, OSB, particle board
  - Paper, Veneers
- Finishes
  - Drywall, ceiling tile

4. Moisture Storage Capacity

- Old
  - Concrete block / terra cotta
  - Rough cut wood / skip sheathing
- New
  - Steel stud lined with gypsum board
- Orders of magnitude change in moisture storage capacity!
- But, future is likely more hollow/lightweight

Lightweight hollow structures are environmentally preferred (lower resource use) if the material has low embodied energy and pollution



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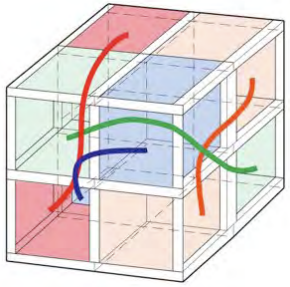
5. Three-D Airflow Networks

- Hollow enclosure
- Airflow+complexity



Hollow Buildings

Interconnected interstitial voids

19

Five Fundamental Changes

1. Increasing Thermal Resistance
2. Changing Permeance of Enclosure Linings
3. Water/Mold Sensitivity of Materials
4. Moisture Storage Capacity
5. Hollow, Airflow connected light structures

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Addressing these changes

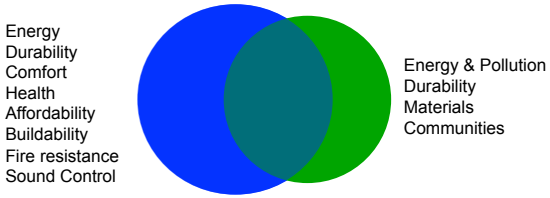
- Enhance design for durability
  - . . . and we need more insulation & airtightness
- Need better moisture control
  - rain, airtight, construction moisture control
- Allow drying of moisture
  - Use vapor barriers with care, consider ventilation

Building Science vs Tradition

- Can no longer “learn by trying”
  - Too slow
  - Failures of thousands of buildings = $$
- Need to understand what we are doing from *first* principles
  - Design for predictable performance
- This is Building Science
  - Physics + construction technology + experience

Building Science=Green Buildings

- Building Science?
  - The science of making buildings that work
- Green Buildings?
  - Buildings that reduce environmental damage



- Less impact for same function = **efficient**

Buildings & the Environment

- Largest single global industry
- Hence, buildings consume resources
  - Lots of materials
  - Lots of energy
  - Lots of money
  - Pollute, displace, and destroy habitats
- Last a long time: A “durable good”
  - Running shoe (1 yr), car (10 yr), bldg (100yr?)
- Hence - more careful long-term design
  - i.e. societal involvement is justified

Green Buildings

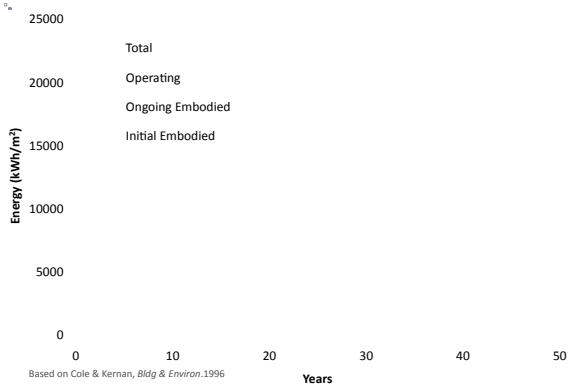
- Impact the environment less in construction, operation, end of life

Damage Components

- Resource Extraction
  - Cutting trees, mining, drilling oil, etc.
- Processing
  - Refining, melting, etc. Pollutants and energy
- Transportation
  - Mass and Mode (ship/truck) and Mileage
- Construction
  - Energy, worker transport
- Operational Energy

The Majority of Impact

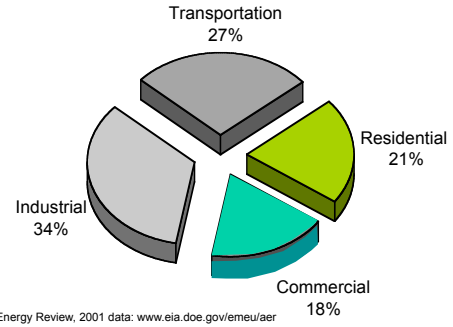
Office Building Example



Based on Cole & Kernan, *Bldg & Environ*.1996

Building Energy Use

Primary Energy Consumption by Sector, 2001



Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

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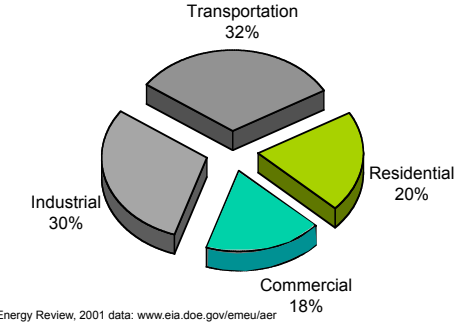
Building Carbon Emissions

Carbon Dioxide Emissions from Energy Consumption by Sector, 2001



Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

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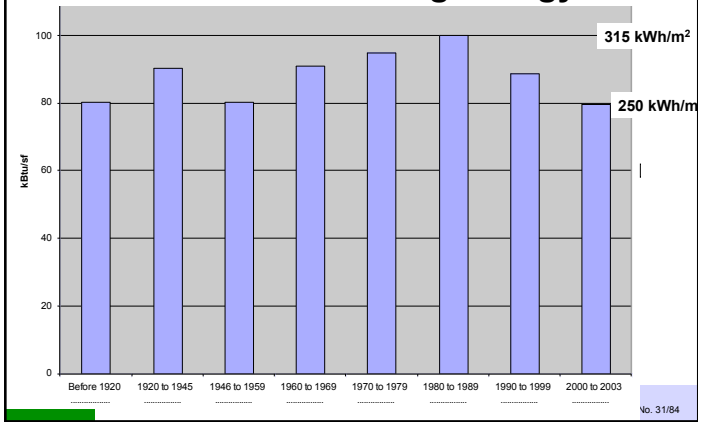
US Commercial Building Energy Use



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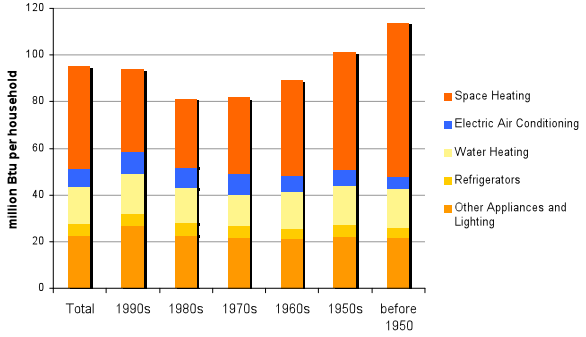
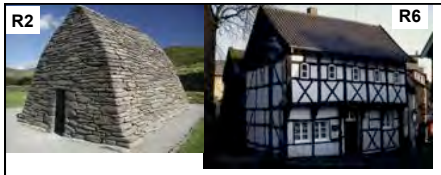
How Old and New Houses Use Ene

Total Btu Consumption per Household, 2001



Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

on - History



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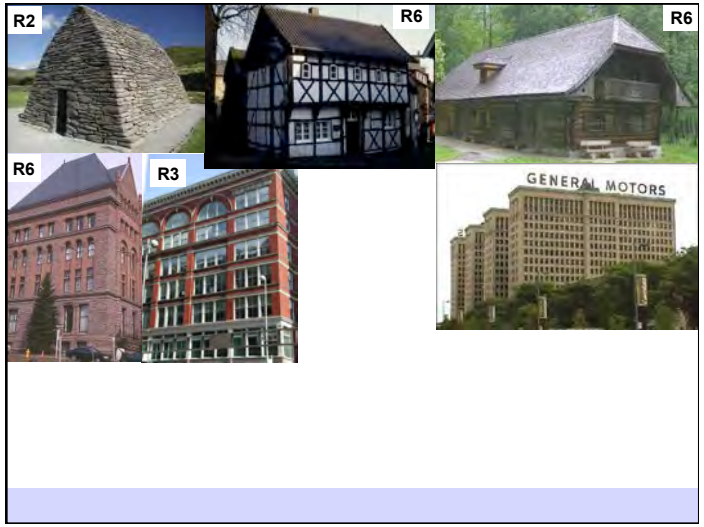
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R6
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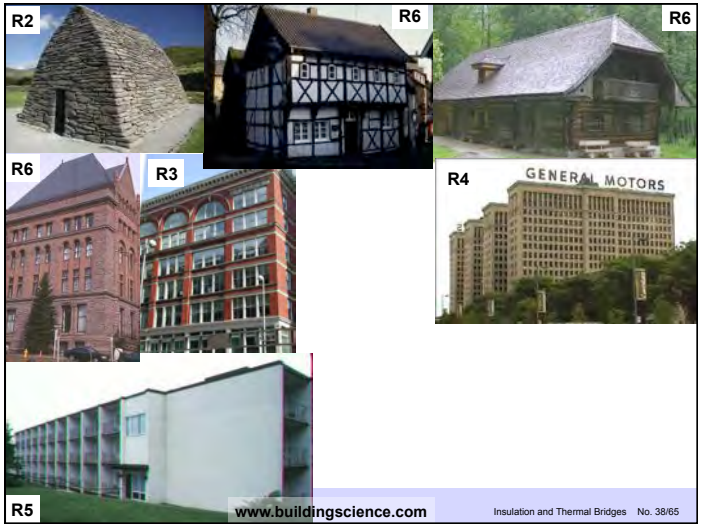
GENERAL MOTORS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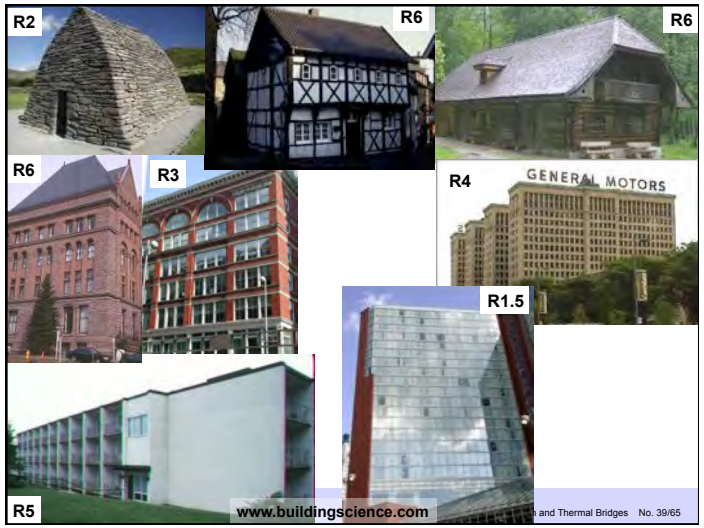
R5
www.buildingscience.com
Insulation and Thermal Bridges No. 38/65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GENERAL MOTORS
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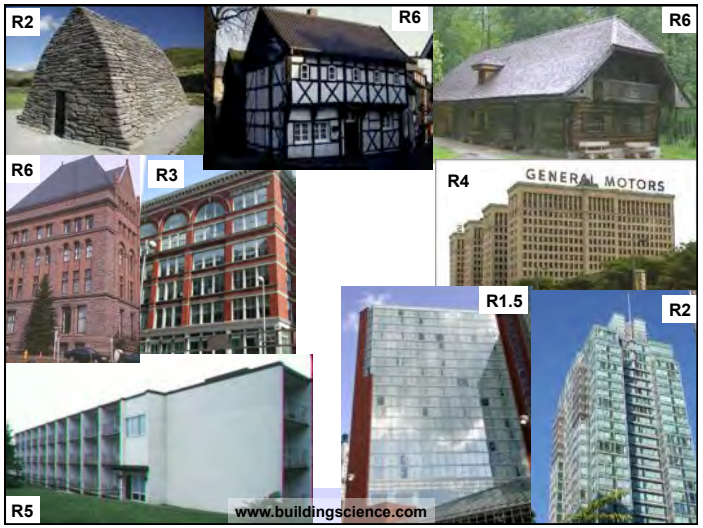
www.buildingscience.com
and Thermal Bridges No. 39/65


R2
R6
R6
R6
R3
R4
GENERAL MOTORS
R1.5
R2
R5
www.buildingscience.com

Fixing this mess

- More Insulation
- Better Airtightness
- Better Glazing of the right quantity
- Simple HVAC, Simple Controls

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Energy Efficiency & Durability

- Better insulation means
  - – Colder exterior and/or interior surface
  - – Colder surfaces mean
    - = more likely condensation
    - = higher RH = higher moisture content
  - – More extreme variations at exterior
- Therefore more insulation reduces durability!
- Air leakage dried as well as wets
  - – Airtightness increases indoor humidity

www.BuildingScience.com Buildings,Energy, Environment No. 42/84

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

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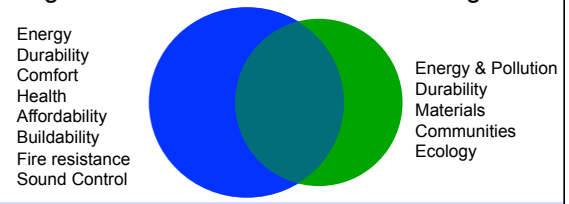
Building Science=Green Buildings

- Building Science?
  - – The science of making buildings that work
- Green Buildings?
  - – Buildings that reduce environmental damage



- Less impact for same function = **efficient**

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Fundamental Goals

- Safe
- Healthy
- Comfortable
- Durable
- Affordable
- Environmentally Responsible

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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

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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

Building Science.com Enclosures No. 48 /

Building Components

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

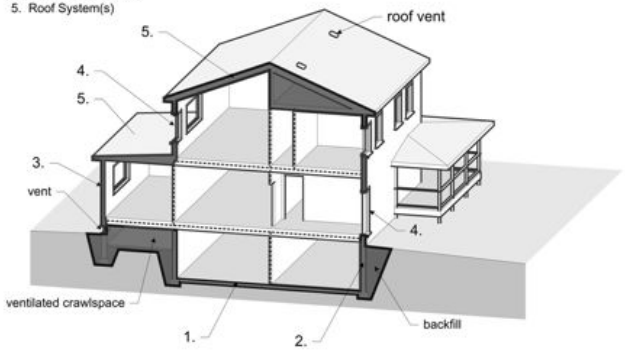
The Enclosure: An Environmental Separator

- 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.)

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?



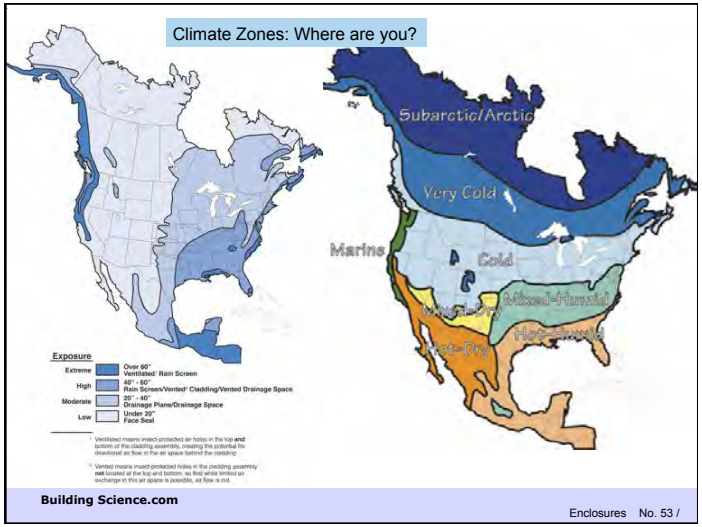
Climate Site

- 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 Load Modification

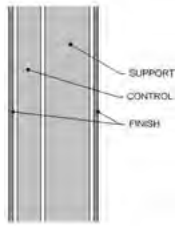
- Building & Site (overhangs, trees…)
  - Creates microclimate
- Building Enclosure (walls, windows, roof…)
  - Separates climates
  - Passive modification
- Building Environmental Systems (HVAC…)
  - Use energy to change climate
  - Active modification

Building Science 2008 Enclosures No. 54 /

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

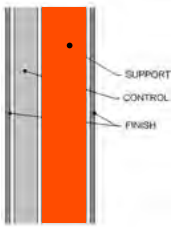


Building Science 2008 Enclosures No. 55 /

Basic Enclosure Functions

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

Functional Layers

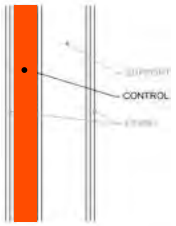


Building Science 2008 Enclosures No. 56 /

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

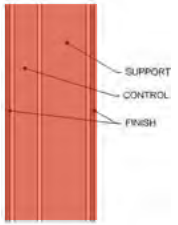
Functional Layers



Other Control . . .

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

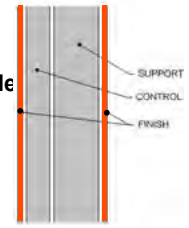
Functional Layers



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



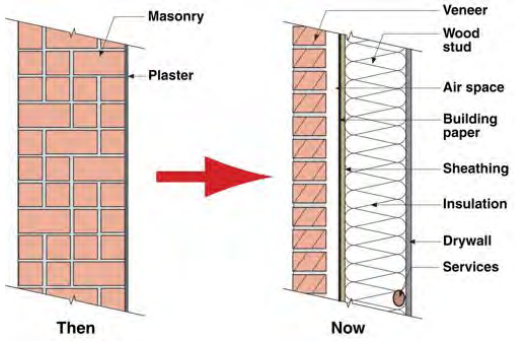
Distribution

- 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 ◄

History of Control Functions

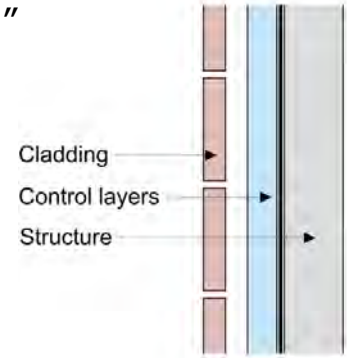
- Older Buildings
  - One layer does everything
- Newer Building
  - Separate layers,
    . . . separate functions

Changes



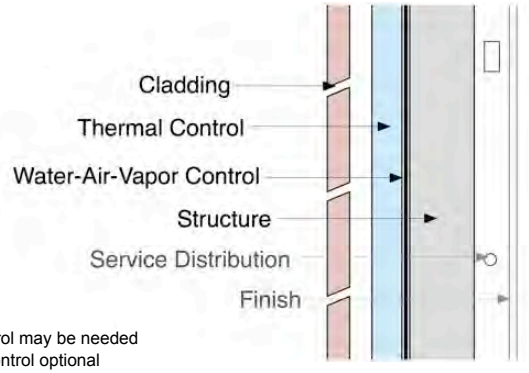
The "Perfect Wall"

- 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

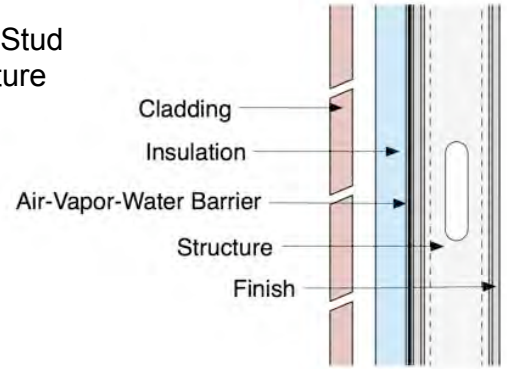
Perfect Wall expanded



Fire Control may be needed
Sound Control optional

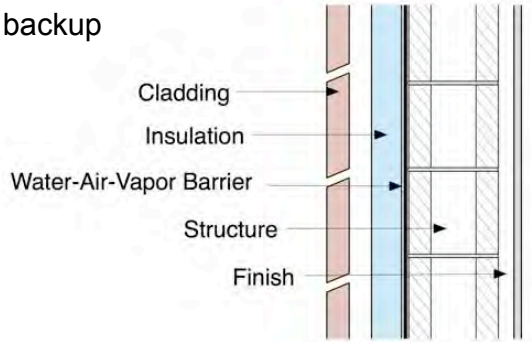
Perfect Wall

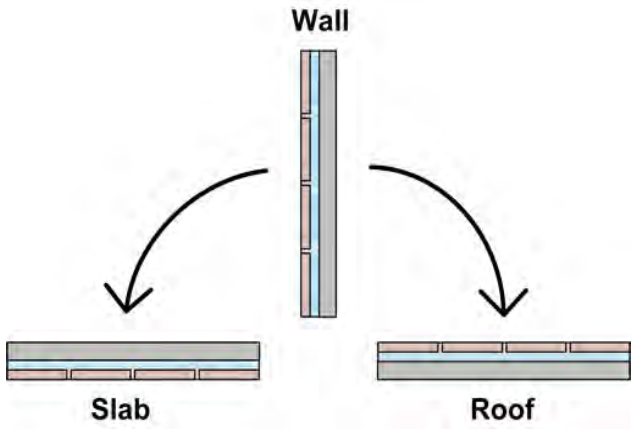
- Steel Stud Structure

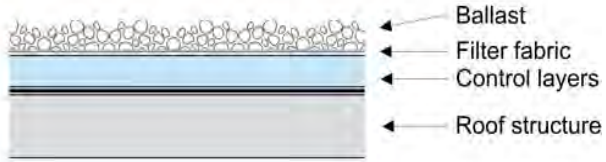


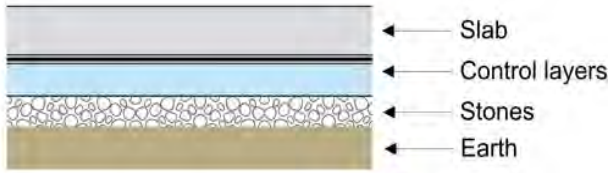
Perfect Wall

- CMU backup









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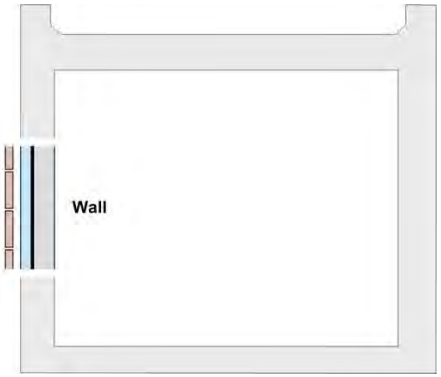

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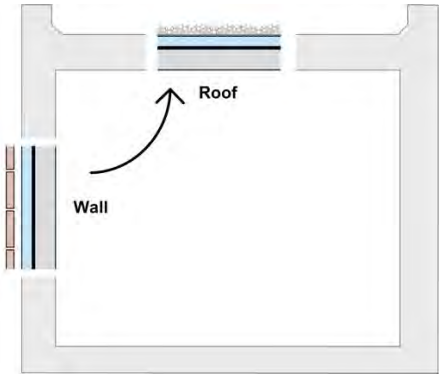

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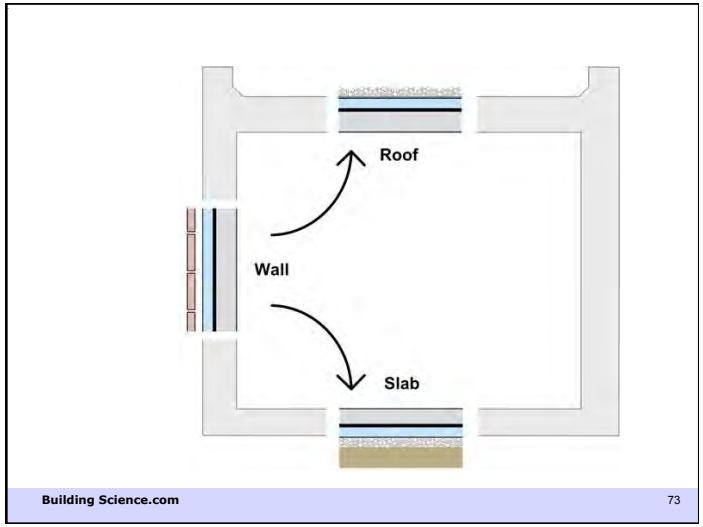
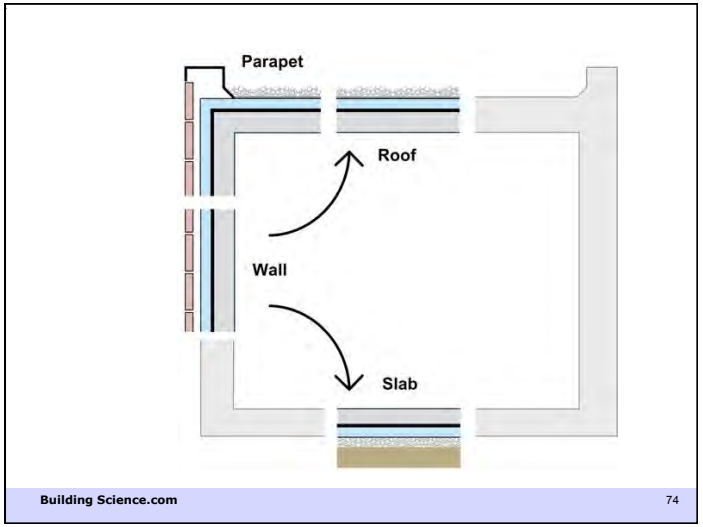
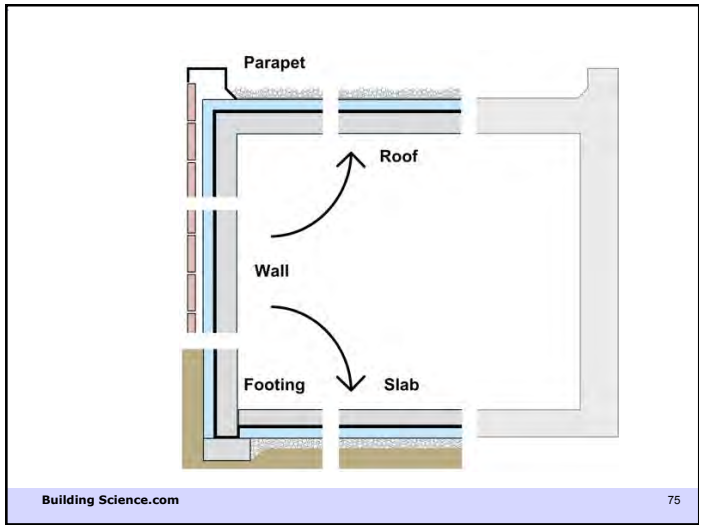

Roof
Wall
Slab
Building Science.com
73


Parapet
Roof
Wall
Slab
Building Science.com
74


Parapet
Roof
Wall
Footing
Slab
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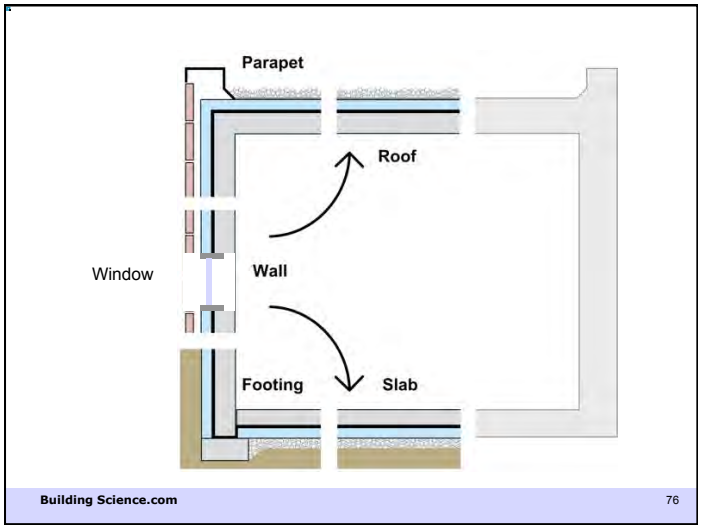
Parapet
Roof
Window
Wall
Footing
Slab
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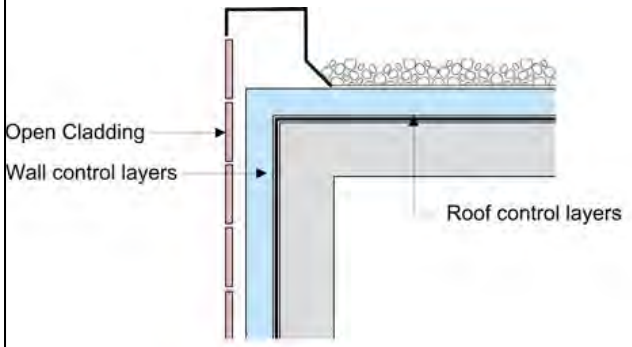
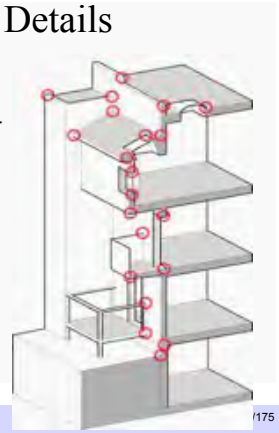
Connections: Who is in charge



Enclosure Design: Details

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



High-performance Enclosure Strategies

Strategies- Airtightness

- Airtightness critical for all climates
  - Control condensation and energy waste critical in cold climates

2/2/11 81/175

Strategies- Insulation

- 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
  - = durability and health strategy
  - Keep structure warm and dry and stable

2/2/11 82/175

Insulation?

Spreadsheet Interactive

- 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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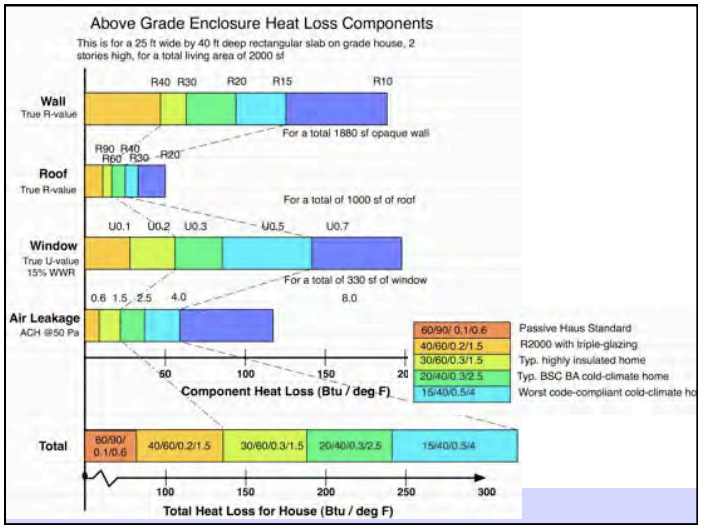

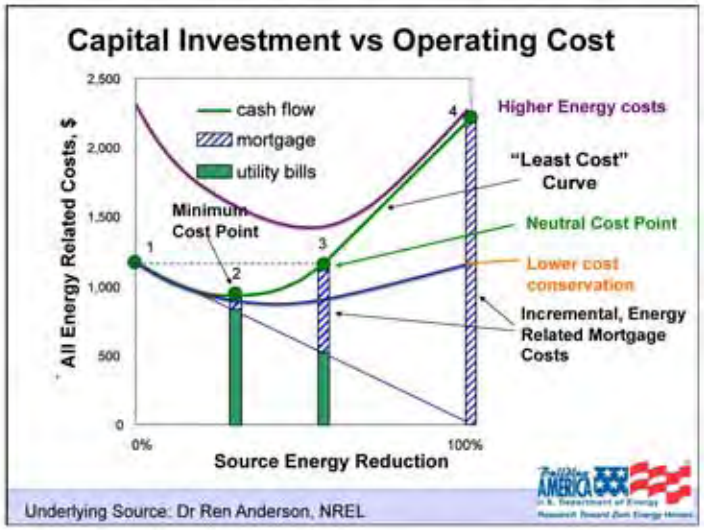
Capital Investment vs Operating Cost
2,500
2,000
1,500
1,000
500
0
All Energy Related Costs, $
cash flow
mortgage
utility bills
Minimum Cost Point
1
2
3
4
Higher Energy costs
"Least Cost" Curve
Neutral Cost Point
Lower cost conservation
Incremental, Energy Related Mortgage Costs
0%
100%
Source Energy Reduction
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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Find the thermal bridge


Find the thermal bridge
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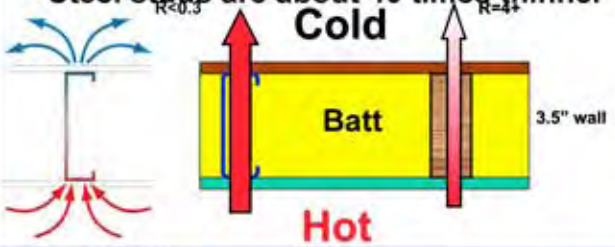
Thermal Bridging

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



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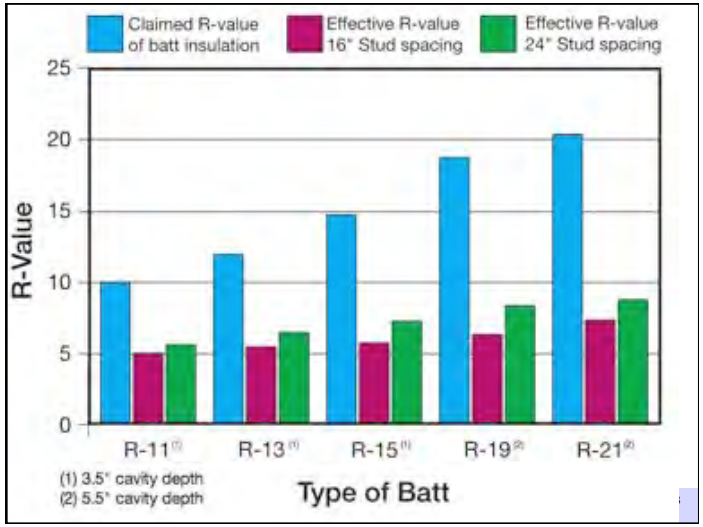
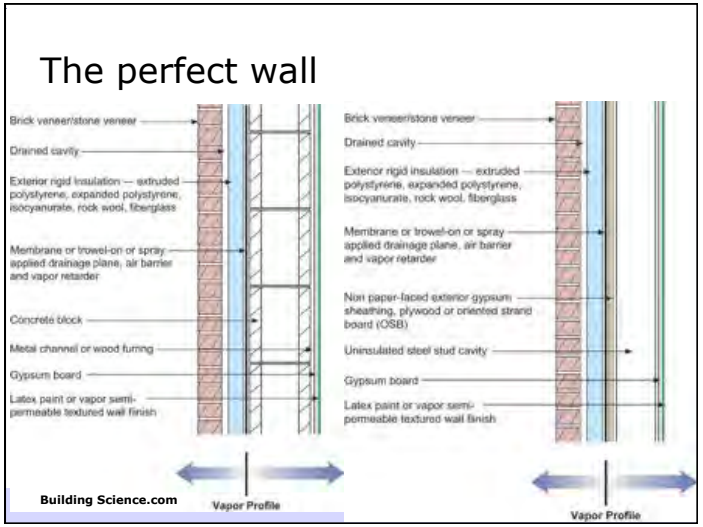
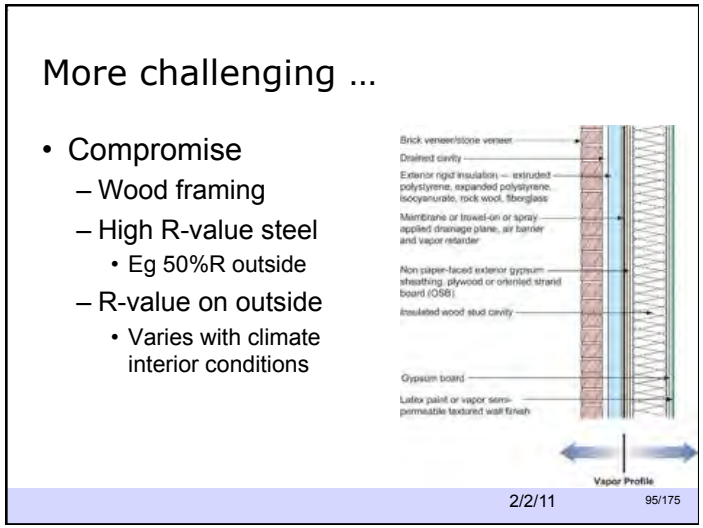
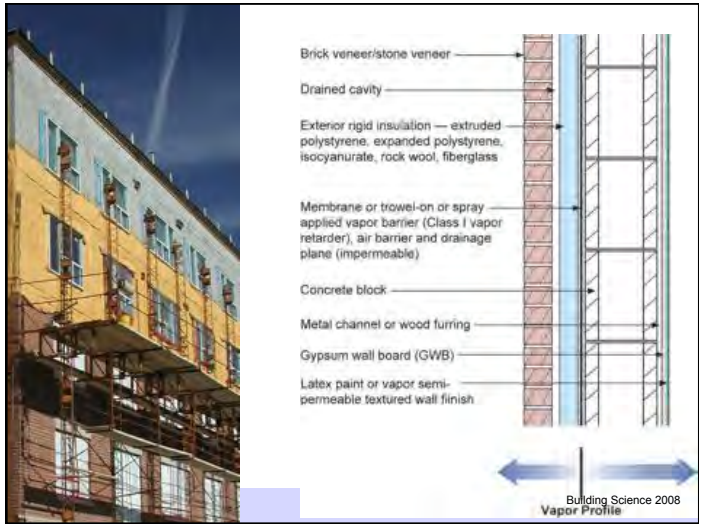

Claimed R-value of batt insulation
Effective R-value 16" Stud spacing
Effective R-value 24" Stud spacing
R-Value
25
20
15
10
5
0
R-11(1)
R-13(1)
R-15(1)
R-19(2)
R-21(2)
(1) 3.5" cavity depth
(2) 5.5" cavity depth
Type of Batt


The perfect wall
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
Concrete block
Metal channel or wood furring
Gypsum board
Latex paint or vapor semi-permeable textured wall finish
Building Science.com
Vapor Profile
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)
Uninsulated steel stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall finish
Vapor Profile


More challenging …
• Compromise
– Wood framing
– High R-value steel
• Eg 50%R outside
– R-value on outside
• Varies with climate interior conditions
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
Gypsum board
Latex paint or vapor semi-permeable textured wall finish
Vapor Profile
2/2/11
95/175


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


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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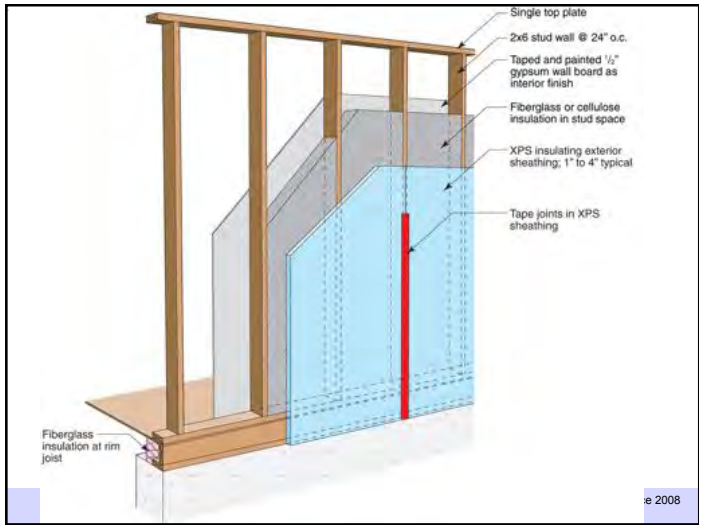
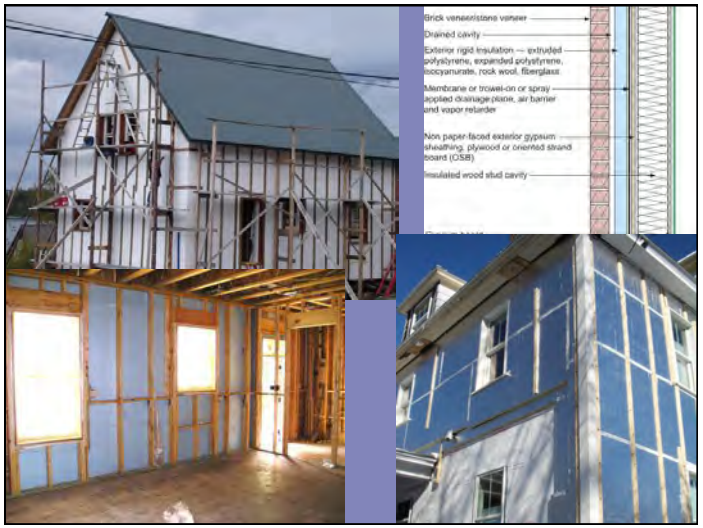
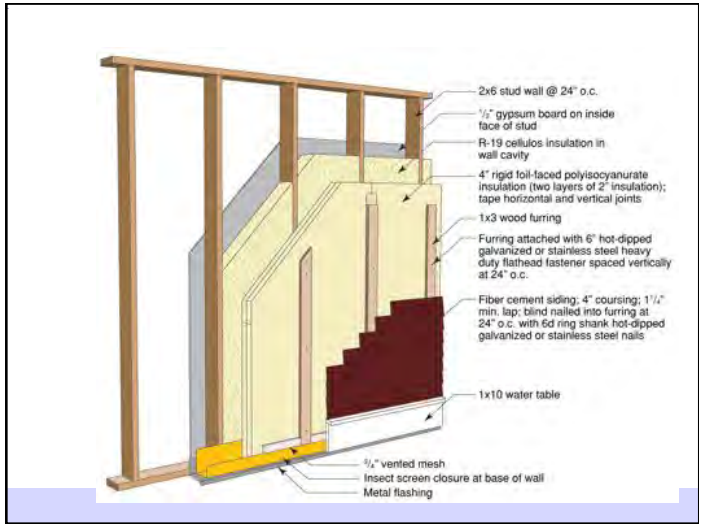
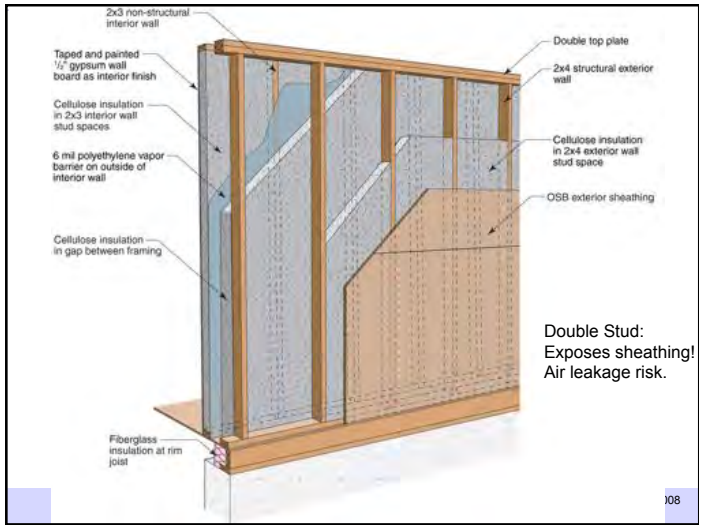
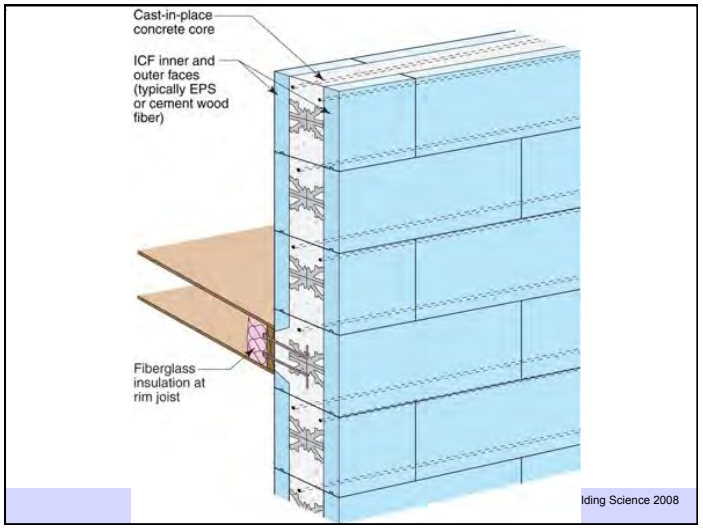

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Fiberglass or cellulose insulation in stud space
XPS insulating exterior sheathing; 1" to 4" typical
Tape joints in XPS sheathing
Fiberglass insulation at rim joist


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

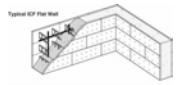

2x6 stud wall @ 24" o.c.
½" gypsum board on inside face of stud
R-19 cellulos insulation in wall cavity
4" rigid foil-faced polyisocyanurate insulation (two layers of 2" insulation); tape horizontal and vertical joints
1x3 wood furring
Furring attached with 6" hot-dipped galvanized or stainless steel heavy duty flathead fastener spaced vertically at 24" o.c.
Fiber cement siding; 4" coursing; 1 1/4" 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

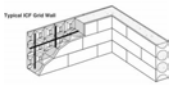

2x3 non-structural interior wall
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in 2x3 interior wall stud spaces
6 mil polyethylene vapor barrier on outside of interior wall
Cellulose insulation in gap between framing
Fiberglass insulation at rim joist
Double top plate
2x4 structural exterior wall
Cellulose insulation in 2x4 exterior wall stud space
OSB exterior sheathing
Double Stud:
Exposes sheathing!
Air leakage risk.


Cast-in-place concrete core
ICF inner and outer faces (typically EPS or cement wood fiber)
Fiberglass insulation at rim joist

Insulated Concrete Forms

- Excellent enclosure system
- Concrete acts as air barrier
- No vapor barrier needed
- Expensive, but high performance





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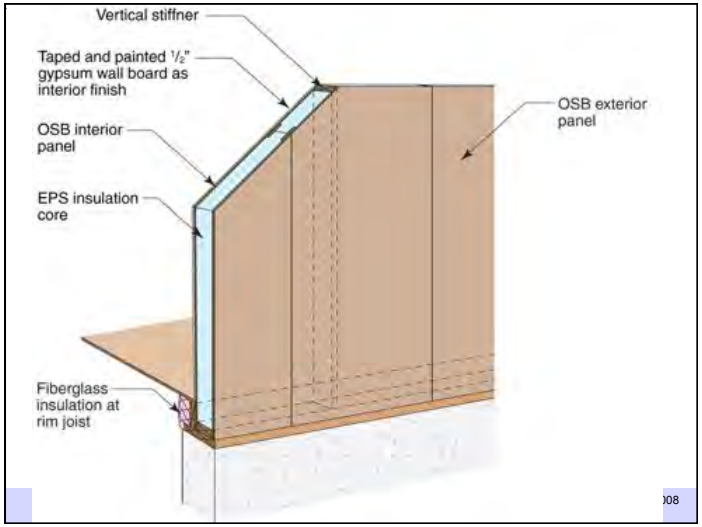

Structural Insulated Panels

- Advantages
  - Superior blanket of insulation
  - if no voids then no convection or windwashing
  - May seal OSB joints for excellent air barrier system
- Therefore, done right = excellent
- Small air leaks at joints in roofs can cause problems
- Don't get them too wet from rain
  - Low perm layers means limited drying

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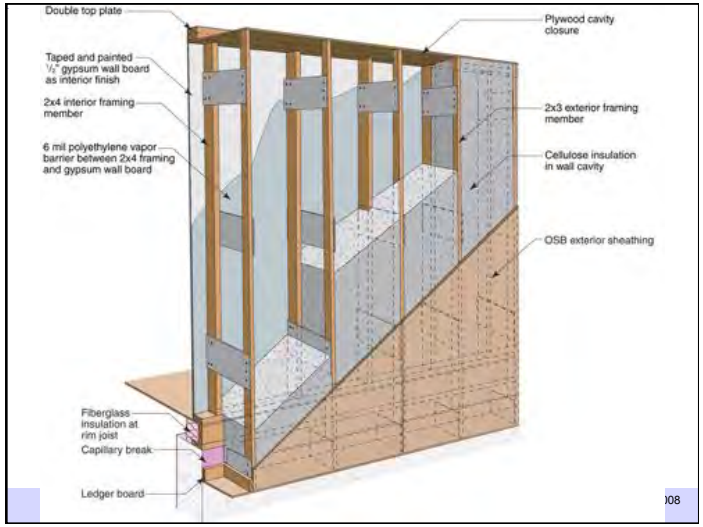
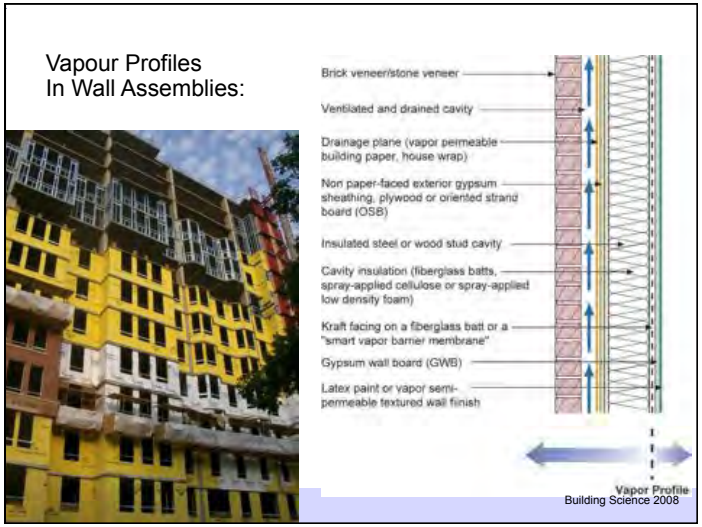
Insulation and Thermal Bridges No. 107/65


Double top plate
Plywood cavity closure
Taped and painted ½" gypsum wall board as interior finish
2x4 interior framing member
2x3 exterior framing member
6 mil polyethylene vapor barrier between 2x4 framing and gypsum wall board
Cellulose insulation in wall cavity
OSB exterior sheathing
Fiberglass insulation at rim joist
Capillary break
Ledger board


Vapour Profiles
In Wall Assemblies:
Brick veneer/stone veneer
Ventilated and drained cavity
Drainage plane (vapor permeable building paper, house wrap)
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated steel or wood stud cavity
Cavity insulation (fiberglass batts, spray-applied cellulose or spray-applied low density foam)
Kraft facing on a fiberglass batt or a "smart vapor barrier membrane"
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Vapor Profile
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