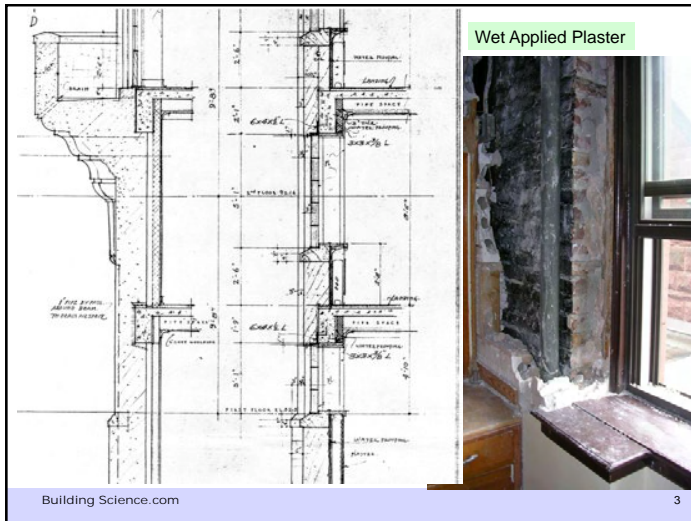


Dr John Straube, P.Eng.  
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Principal, Building Science Corporation

# Healthy, Durable, Low Energy Buildings: Fundamentals, techniques, and pitfalls

[www.BuildingScience.com](http://www.BuildingScience.com)

## Solid masonry



## 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

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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

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## 2. Permeability

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

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### 3. Water/Mold Sensitivity

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

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### 4. Moisture Storage Capacity

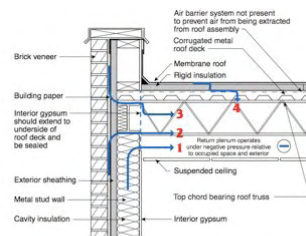
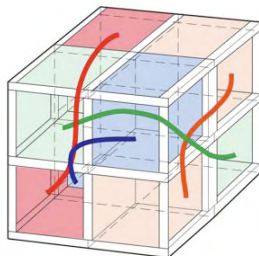
- Changing moisture storage
  - Concrete block / terra cotta
  - Rough cut wood / skip sheathing
  - Steel stud with exterior gypsum
- Orders of magnitude!
- Lightweight often low-impact

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### 5. Three-D Airflow Networks

- Hollow walls
- Taller buildings



- 1 Air is pulled from exterior wall cavity into return plenum since interior gypsum does not extend to underside of roof deck
- 2 Air is pulled from exterior through gaps in building paper and exterior sheathing
- 3 Air is pulled from exterior through gaps between corrugated metal roof deck and structural steel
- 4 Air is pulled from under roof membrane through gaps in rigid insulation and metal roof deck

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### Hollow Buildings

- Inter-connected voids



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## Five Fundamental Changes

1. Increasing Thermal Resistance
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5. 3-D Airflow Networks

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## Addressing these changes

- Get back in balance
  - . . . and we need more insulation
- Provide better moisture control
  - drainage, airtight, construction moist. control
- Allow diffusion drying of moisture
  - Use vapor barriers with care
- Compartmentalize
  - Air seal within buildings as well

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- Need to understand what we are doing from *first principles*
- Cant “learn by trying”
- Building Science can guide us

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### What Is A Building?

- A human construct that creates the desired environment for human use and occupancy in an enclosed volume

### What Is A Building Enclosure?

- The passive environmental separator between the inside environment and outside

### What Do We Want To Do?

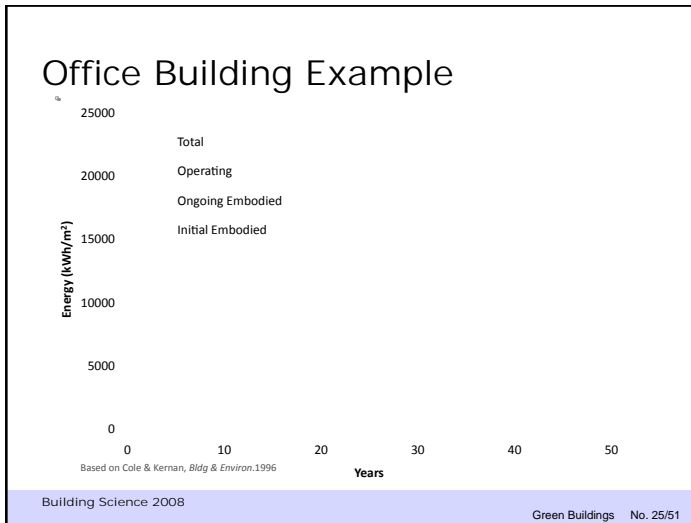
- Safe**
- Healthy**
- Comfortable**
- Durable**
- Affordable**
- Environmentally Responsible**

## 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, and operation

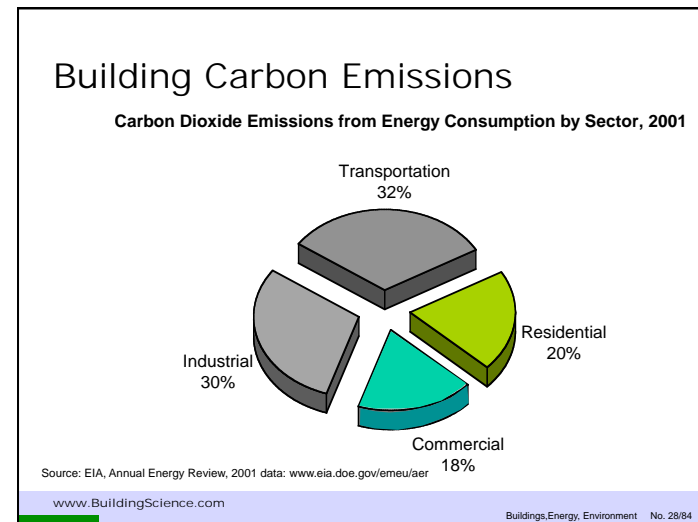
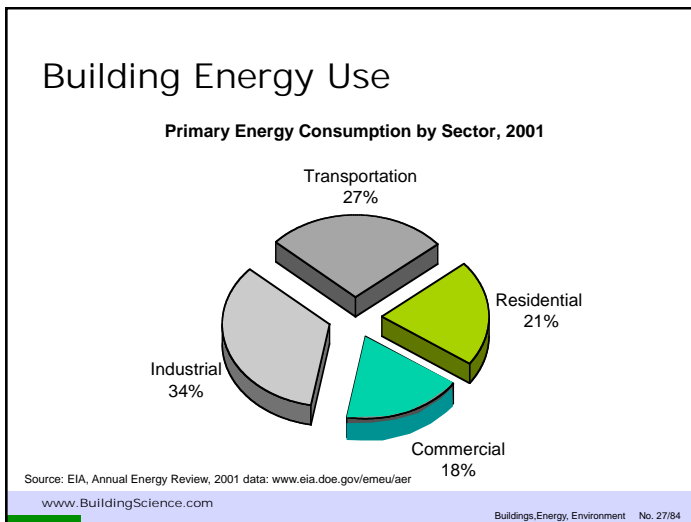


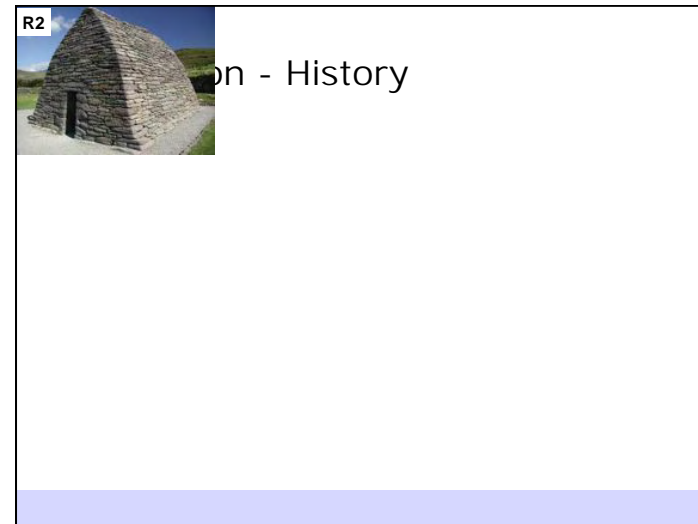
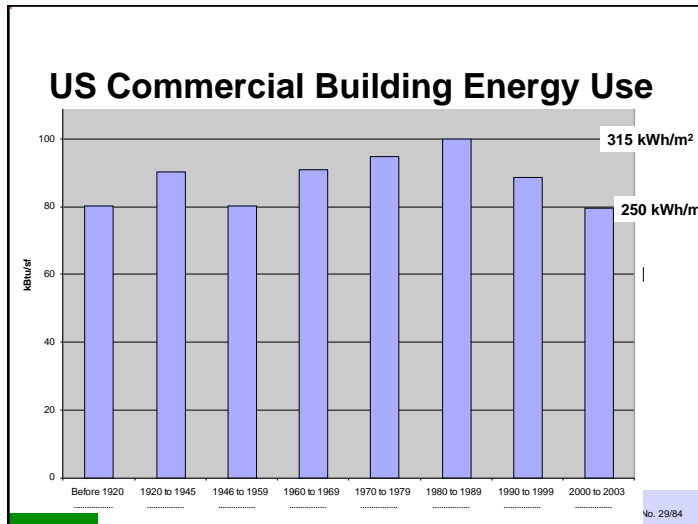
### Damage Components

- 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**

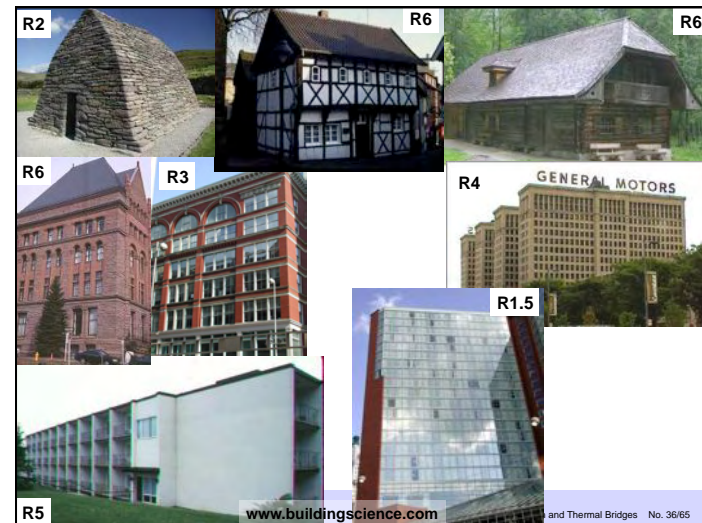
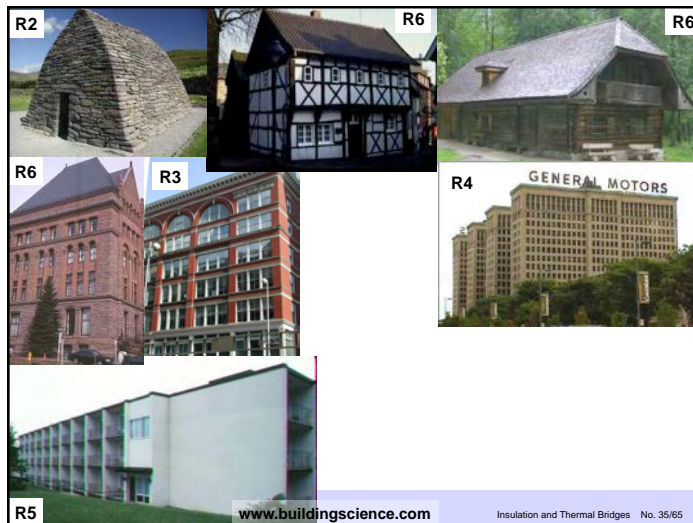
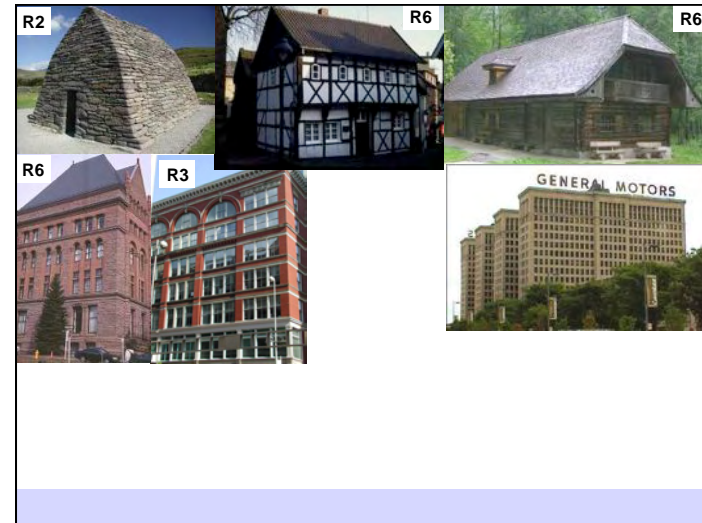
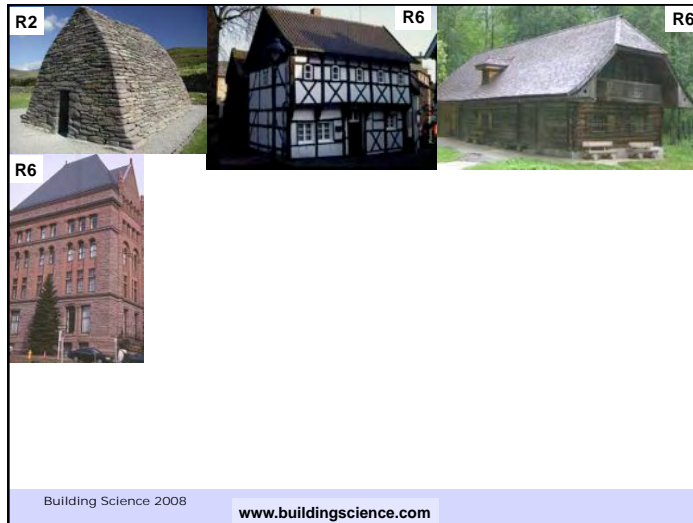
www.BuildingScience.com  
Buildings, Energy, Environment No. 26/84

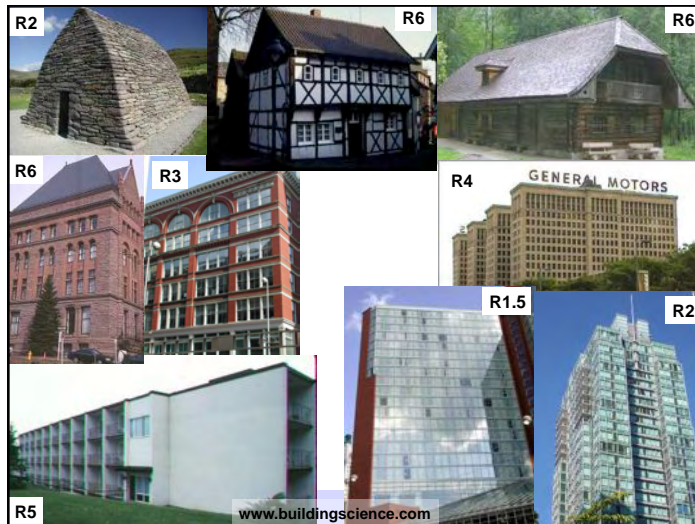






Healthy, Durable, Low Energy Buildings: Fundamentals, techniques and pitfalls





## Green Strategies

- 1. Keep it simple (compact) & small, orient to sun
- 2. Reduce heat loss and gain
  - Lots of **insulation**, avoid thermal bridges (true R-values)
  - Use very good **windows** and shade/reduce solar
  - **Airtight**, then control ventilation properly
- 3. Avoid energy use
  - Efficient heating, cooling, lighting, elevators, fans, appliance
  - Use daylighting, motion sensors, etc. Off=very efficient.
- 4. Durable
  - Moisture control: Drained, airtight, drying capacity
- 5. Only then, generate renewable energy
  - Passive solar then active

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Green Buildings No. 38/51

## Efficient Enclosures & HVAC

- Airtight buildings require ventilation systems
  - Don't over ventilate. Quality≠Quantity
- Better windows, insulation & lighting
  - = Low heat gain
  - = dehumidification = less sensible cooling
- Different HVAC systems can now be applied
  - Enthalpy recovery
  - Radiant cooling? DOAS?

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Buildings, Energy, Environment No. 39/84

## Building Science & Energy

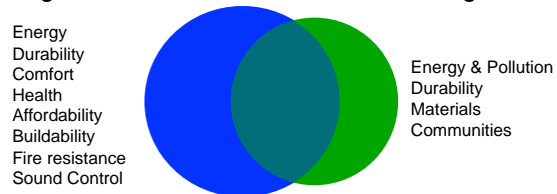
- Increasing resistance to heat flow
  - Better insulation values
  - Reduced thermal bridges
  - Better air leakage resistance
  - Better windows
  - Better solar control
- This will impact moisture & hence durability

www.BuildingScience.com

Buildings, Energy, Environment No. 40/84

## 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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## 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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## Energy Efficiency & Durability

- Better insulation means
  - Cold exterior and/or interior surface
  - More extreme variations at exterior
  - Colder surfaces mean
    - = more likely condensation
    - = higher RH = higher moisture content
- More insulation reduces durability!
- Air leakage dried as well as wets
  - Airtightness can reduce drying!

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Buildings, Energy, Environment No. 43/84

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

## Building Science

### Environmental Separation



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## Building Functions

- Human needs... more than shelter (e.g. Location, Shelter, Utility, Comfort & Delight)

- ...function of a building:

*“Provide the desired environment for human use and occupancy”*

*“Durability, Convenience, and Beauty”*  
Vitruvius, 70 BC

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Enclosures No. 45 /

## Building Components

- Buildings are made of several large systems
- The systems that make up a building can be grouped in four categories
  - Superstructure
  - Enclosure
  - Service Systems
  - Fabric

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Enclosures No. 46 /

## The Enclosure: An Environmental Separator

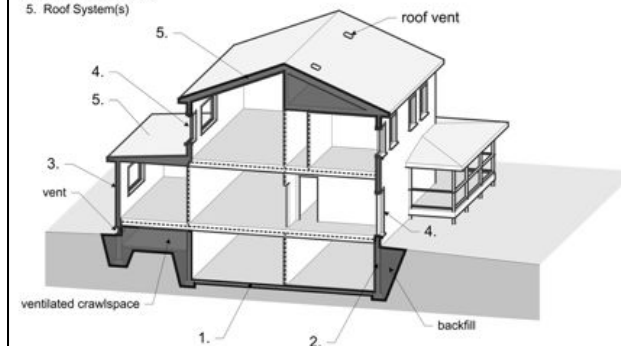
- The part of the building that physically **separates** the **interior** and **exterior** environments.
- Includes all of the parts that make up the wall, window, roof, floor, etc... from the innermost to the outermost layer.
- Sometimes, interior partition also are environmental separators (pools, rinks, etc.)

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Enclosures No. 47 /

### 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)



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Enclosures No. 48 /

## Climate Site

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



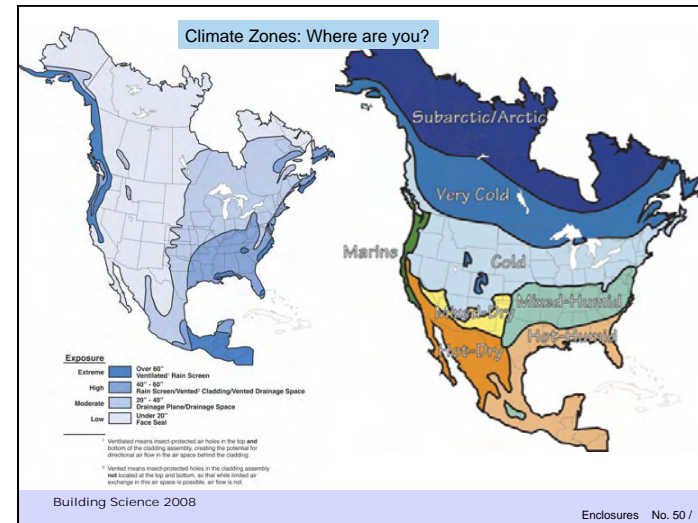
Seattle ≠ Sacramento  
Miami ≠ Minneapolis  
Edmonton ≠ Toronto

### 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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Enclosures No. 49 /



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Enclosures No. 50 /

## Climate Load Modification

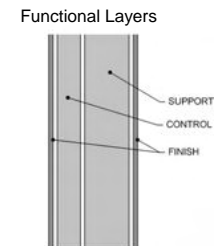
- Building & Site (overhangs, trees...)
  - Creates microclimate
- Building Enclosure (walls, windows, roof...)
  - Separates climates
  - Passive modification
- Building Environmental Systems (HVAC...)
  - Use energy to change climate
  - Active modification

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Enclosures No. 51 /

## 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



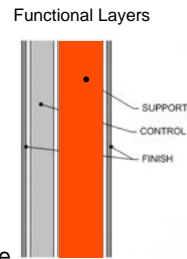
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Enclosures No. 52 /



## 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

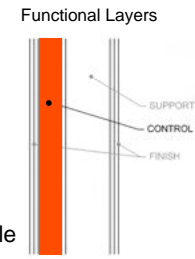


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Enclosures No. 53 /

## 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

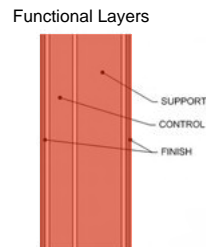


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Enclosures No. 54 /

## Other Control . . . .

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

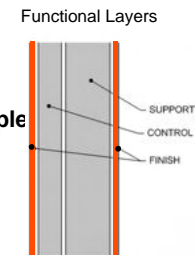


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Enclosures No. 55 /

## 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



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Enclosures No. 56 /

## Distribution

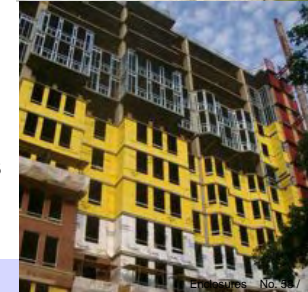
- A ***Building*** Function imposed on enclosure
- Distribute services or utilities to from through, within, the enclosure, e.g.,
  - Power
  - Communication
  - Water (Potable, sewage, etc.)
  - Gas
  - Conditioned air ◀
  - Cold or hot water ◀

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Enclosures No. 57 /

## History of Control Functions

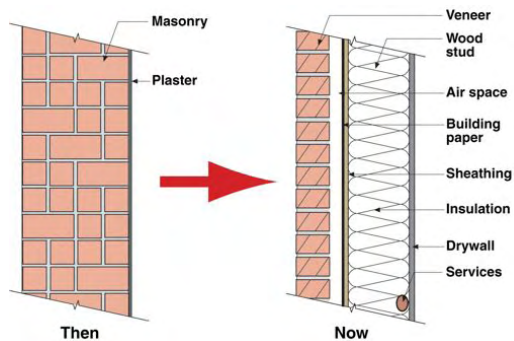
- Older Buildings
  - One layer does everything
- Newer Building
  - Separate layers, . . . separate functions



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Enclosures No. 58 /

## Changes

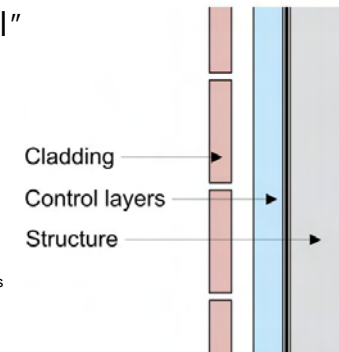


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Enclosures No. 59 /

## 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

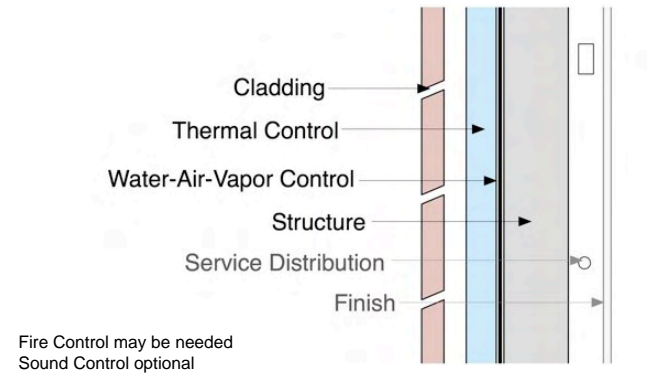


Fire Control may be needed  
Sound Control optional

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### Perfect Wall expanded

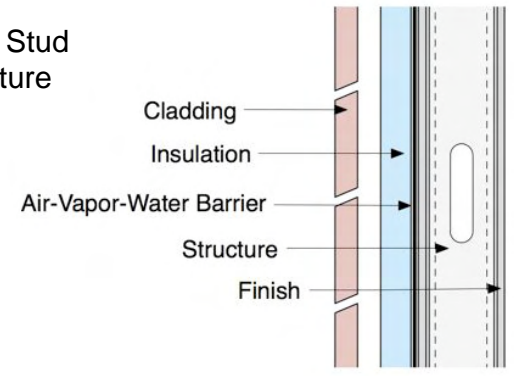


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### Perfect Wall

- Steel Stud Structure

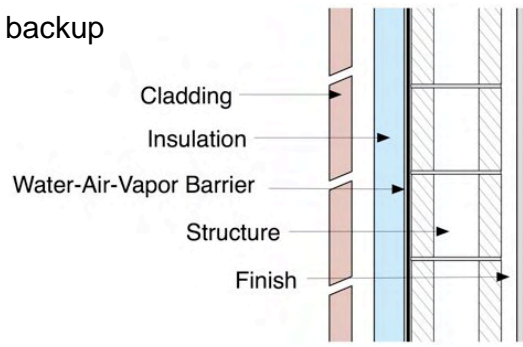


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### Perfect Wall

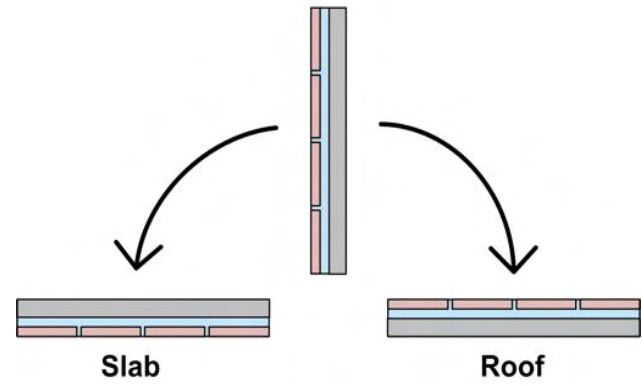
- CMU backup



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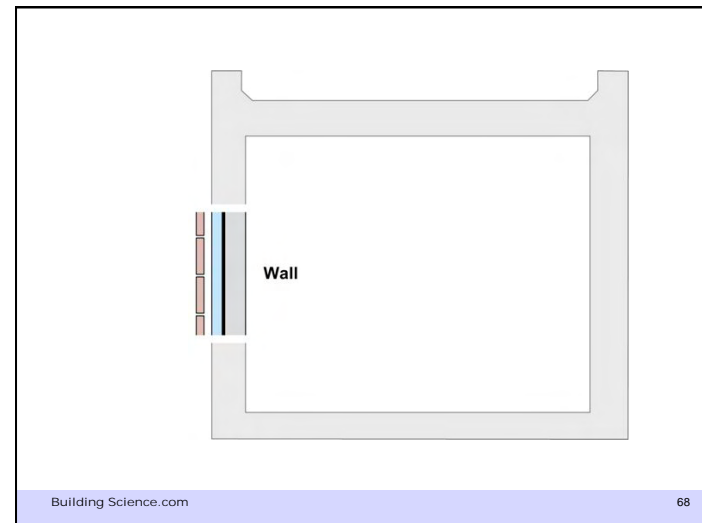
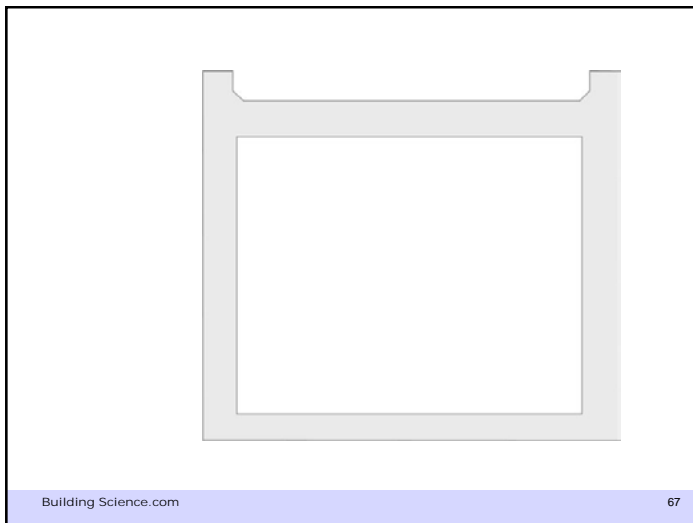
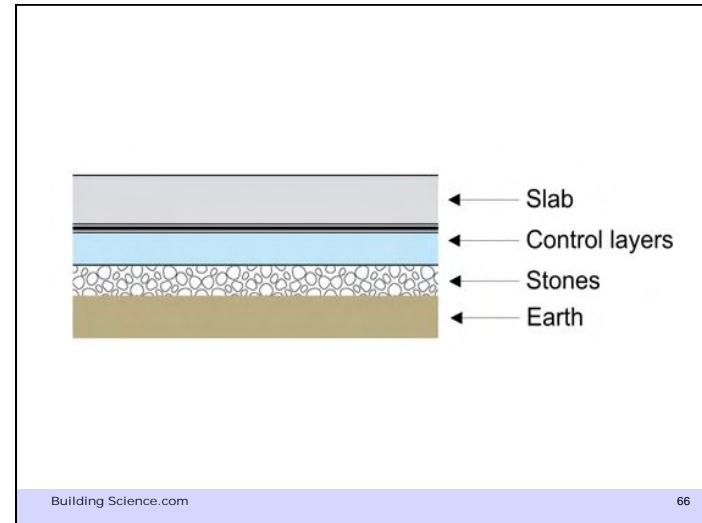
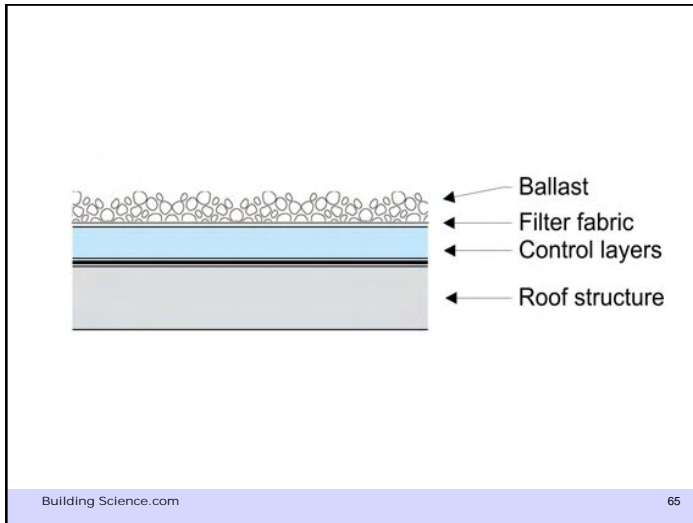
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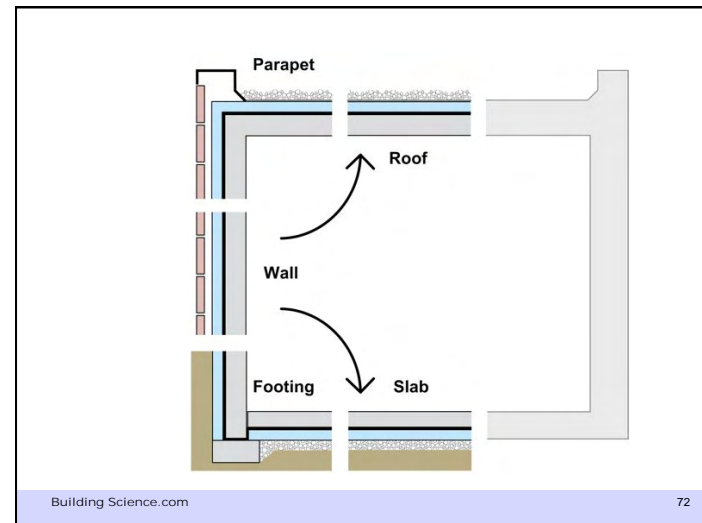
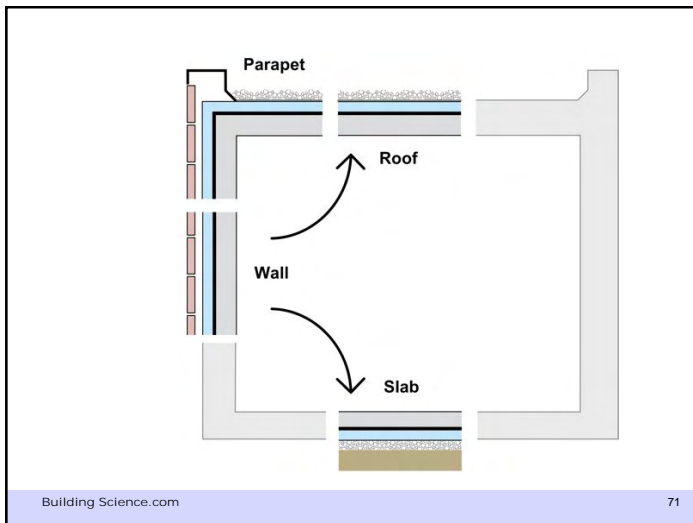
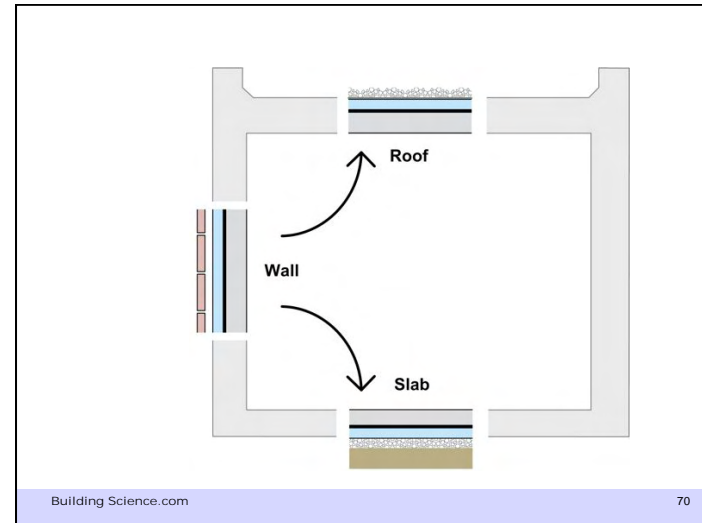
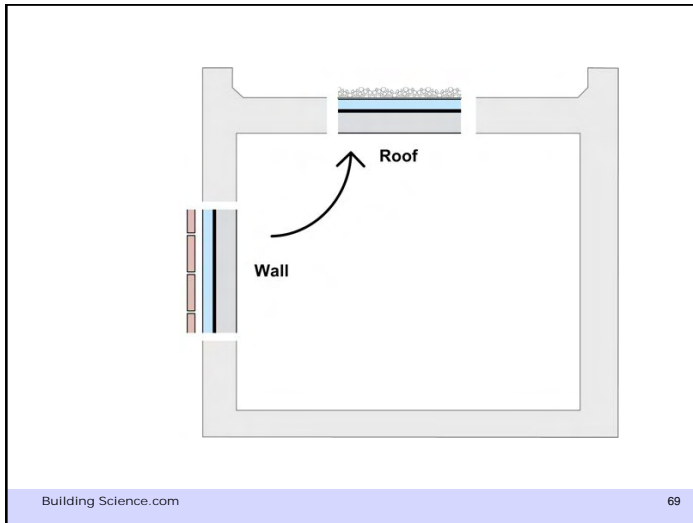
### Wall



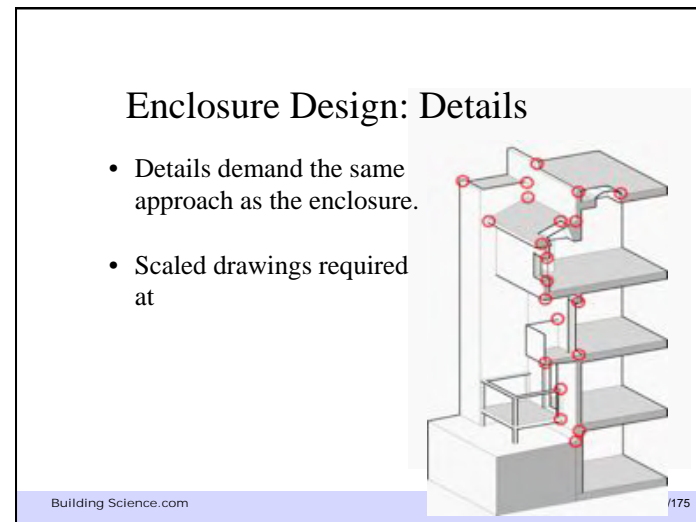
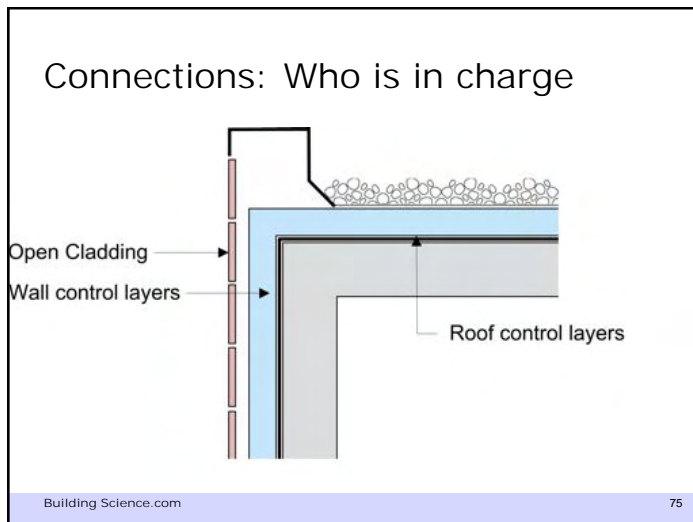
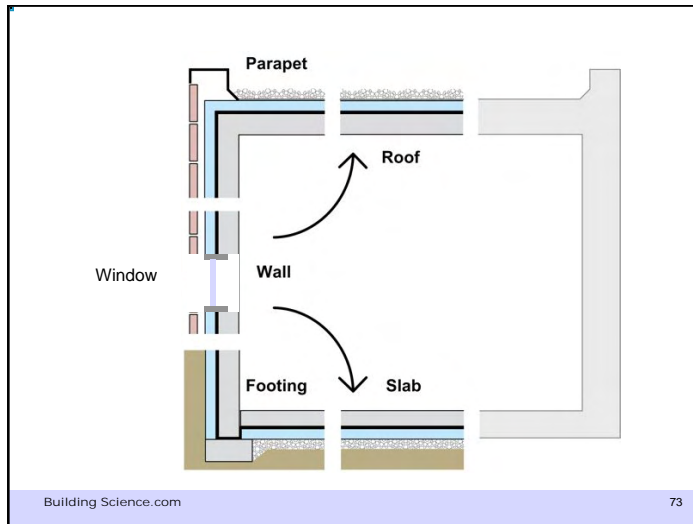
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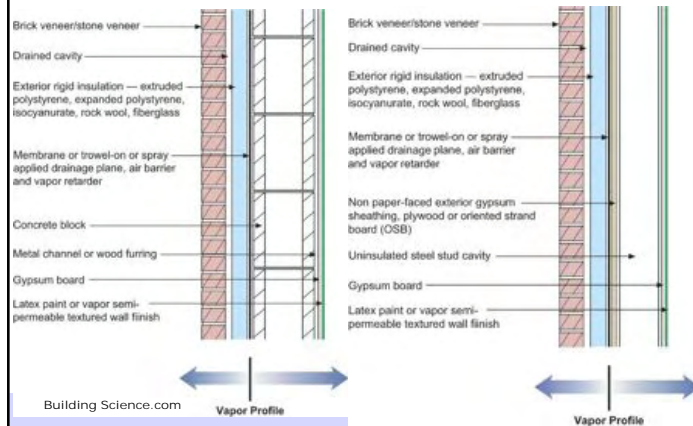




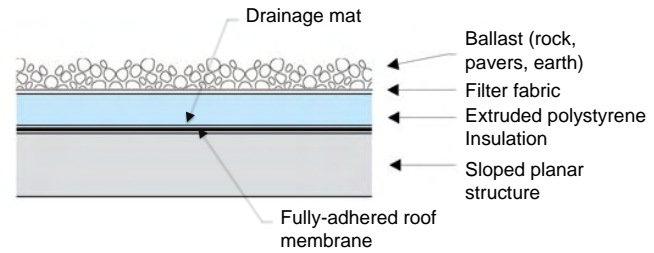




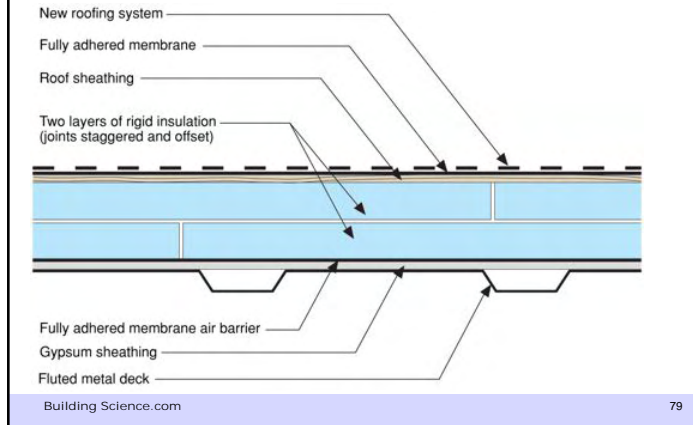
### The perfect wall



### Perfect Roof

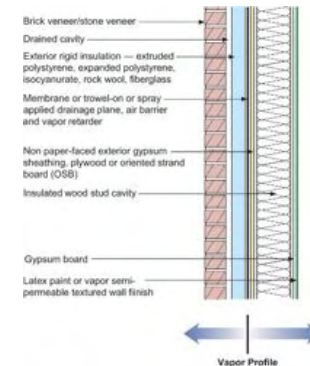


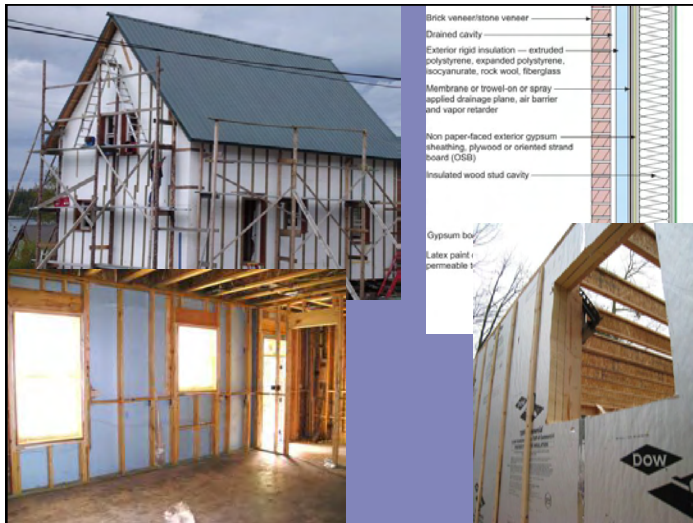
### Good Compromise



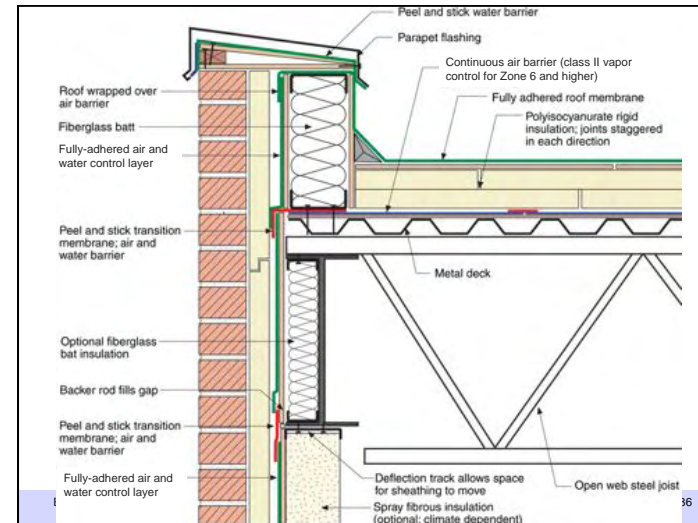
### More challenging ...

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









## Conclusions

- The world has changed
- We have changed our construction materials
- We need to adapt our design to accommodate
- More change is coming . . .

## Commercial Enclosure: Simple Layers



- Structure
- Rain/Air/Vapor
- Insulation
- Finish