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Principal, Building Science Corporation

Healthy, Durable, Low Energy Buildings:

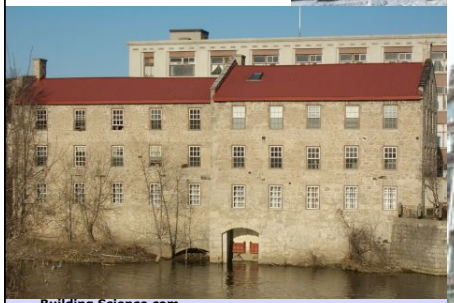
Fundamentals, techniques, and pitfalls

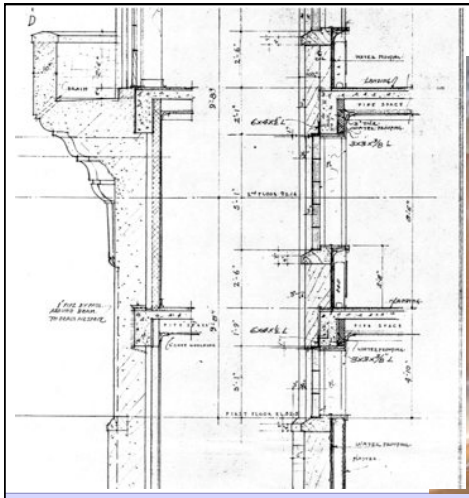
www.BuildingScience.com

Outline

- The world of building has changed
- Energy and buildings
- The "Perfect Wall"

Solid masonry





Wet Applied Plaster


Old Growth Timber
Building Science.com


Traditional Stucco Farmhouse


7 yrs old, non-traditional problems
What has changed?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Moisture No.8/78

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. Lower Permeance Enclosure Linings
3. More Water/Mold Sensitive Materials
4. Reduce Moisture Storage Capacity
5. Hollow Buildings = 3-D Airflow Networks

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1. Insulation & Airtightness

- Better insulation means
  - Cold exterior and/or interior surface
  - More extreme variations at exterior
  - Colder surfaces mean
    - more likely condensation
    - higher moisture content
    - slower drying
- So… **More insulation reduces durability**!
- Airtightness increases indoor humidity

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Buildings,Energy, Environment No. 12/84

2. Permeance

- Low permeance exterior layers
  - Metal panels, precast concrete
  - OSB and foam vs skip wood sheathing
- Very 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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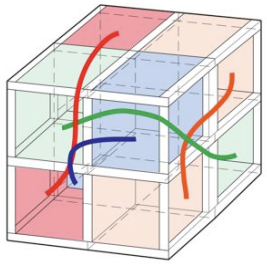
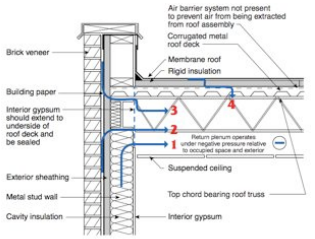
5. Three-D Airflow Networks

- 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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Hollow Buildings

Interconnected interstitial voids

18

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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Addressing these changes

- Reduce wetting, enhance drying
  - . . . 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

What are the Objectives?

Safe

Healthy

Comfortable

Durable

Affordable

Environmentally Responsible

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

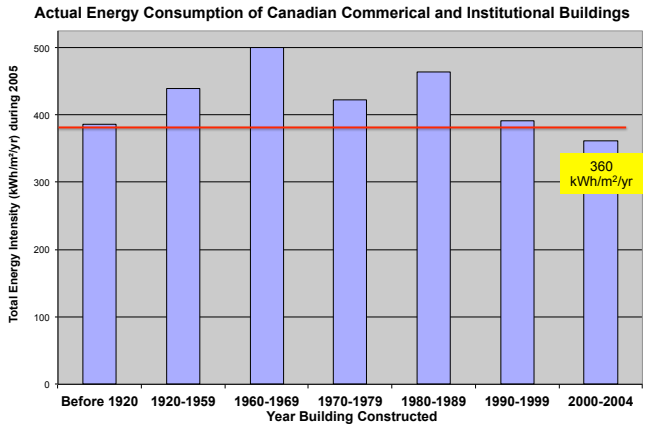
Buildings & the Environment

- 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

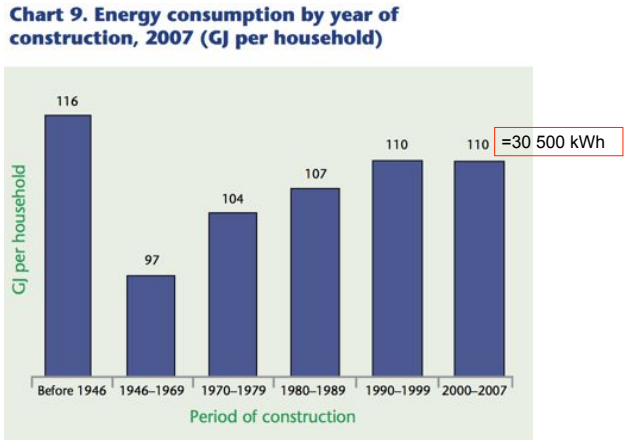
Damage Components

- 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



Data from NRCan, OEE



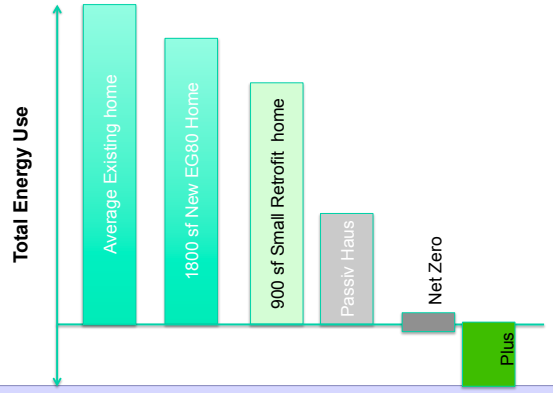
Natural Resources Canada, OEE, 2007 Survey

What uses energy in a house?

- Space heating: Big deal in Canada! (50-65%)
  - 15 000 to 30 000 kWh+ for average house
- Other
  - Domestic hotwater (≈4000+ kWh) = 4000
  - Refrigeration (500 kWh)+ Range (500 kWh) = 1000
  - Washer (250 kWh) + Dryer (900 kWh) = 1150
  - Lighting (750-2000 kWh) 750
  - Plug and misc (1000-3000 kWh) 2000

Typical Household: 20 000 to 35 000 kWh

Energy Use Comparison



Future

- We need aggressive cuts to make meaningful energy use changes
- We need to improve quality, durability, IAQ
- This will require a new approach and new thinking, not tweaks!

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Design Principles

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What is needed

- Great enclosure
  - Energy, durability, comfort
- Low-carbon mechanical systems
  - Heat pumps, natural gas, wood (biomass)
- Control appliance energy use
  - Esp new electronics

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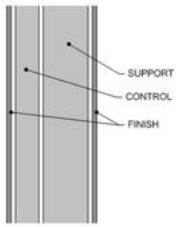
Basic Functions of the Enclosure

- 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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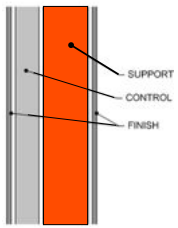
Enclosures No. 33 /

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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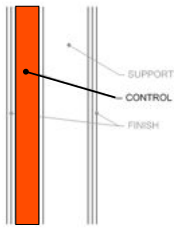
Enclosures No. 34 /

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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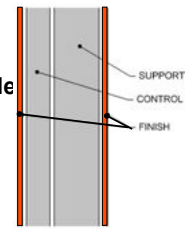
Enclosures No. 35 /

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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Enclosures No. 36 /

History of Control Functions

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

Building Science

What is a High-performance enclosure?

- One which provides high levels of control
- Poor continuity limits performance
- Poor continuity causes most problems too:
  - Rain leakage
  - Air leakage condensation /energy
  - Thermal bridging
- We need: Continuity + high levels

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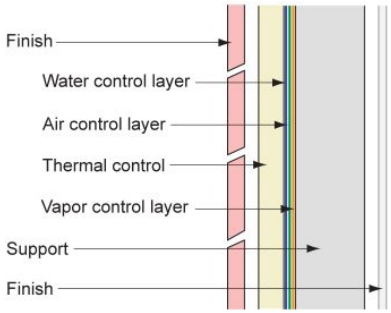
The perfect wall



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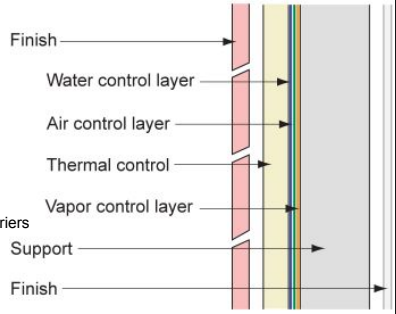
The "Perfect Wall"

- 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: anything that works



Fire Control may be needed
Sound Control optional

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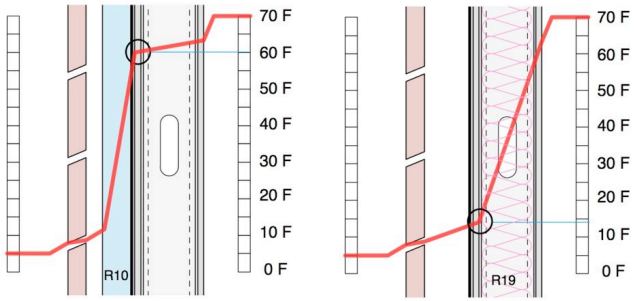
Condensation & Drying



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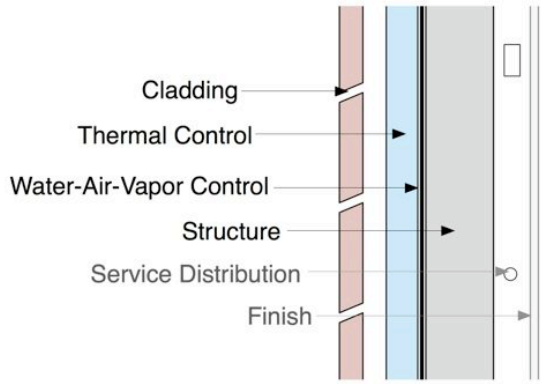

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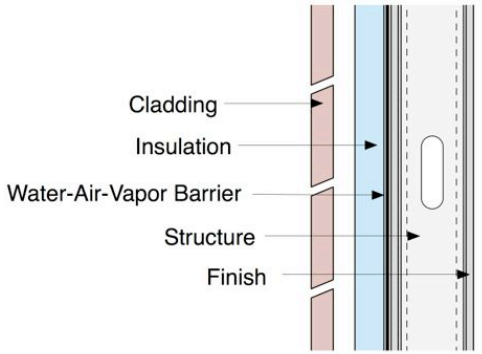

Look Ma, no poly!

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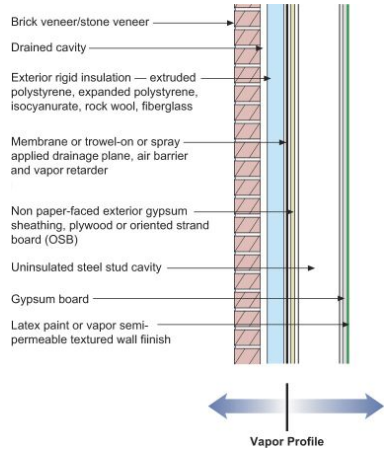

The Commercial Steel Frame High Performance wall

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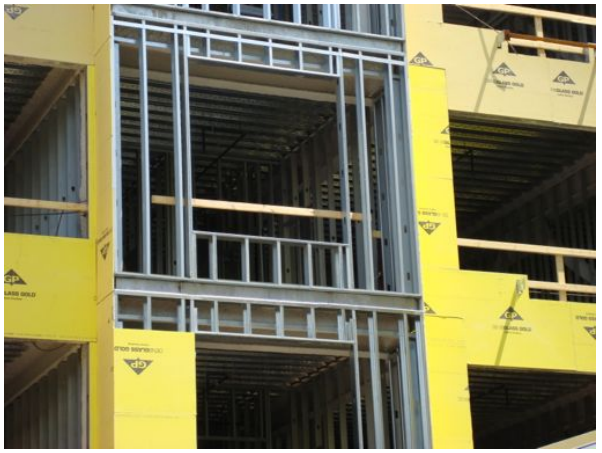
Building Science 45



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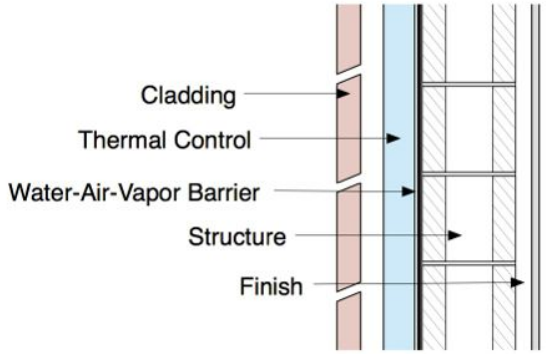
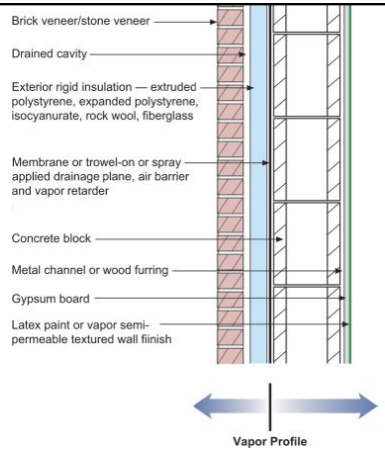
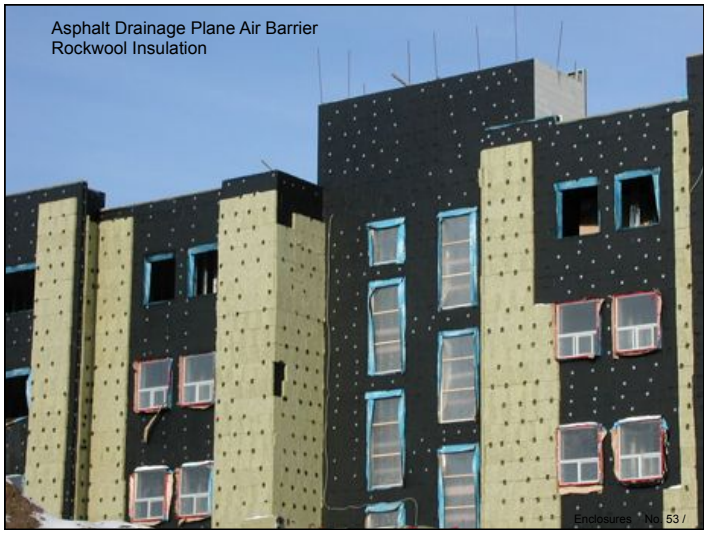


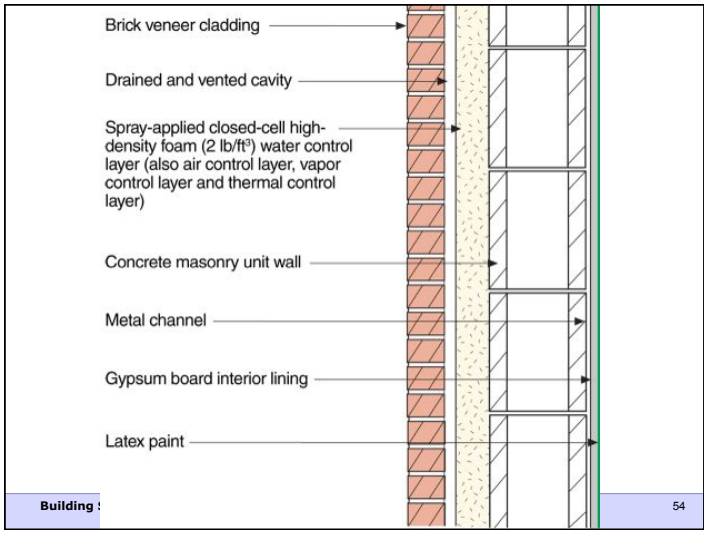
Building Science.com Enclosures No. 51 /



The “Perfect” wall: High Performance

Building Science Enclosures No. 52 /

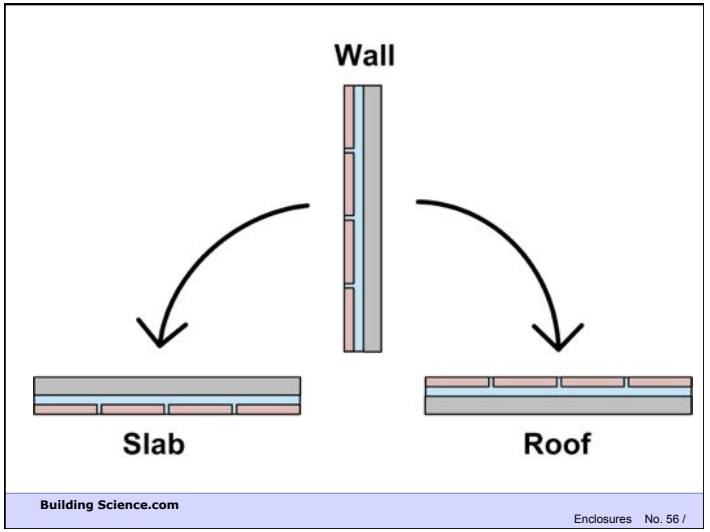


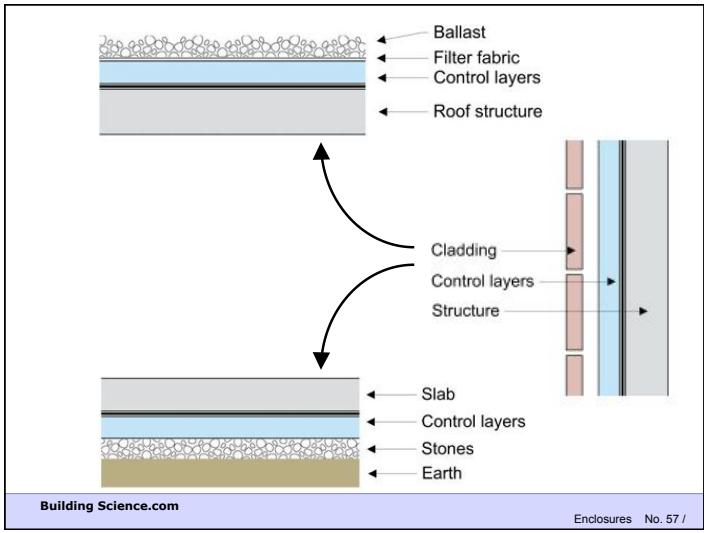


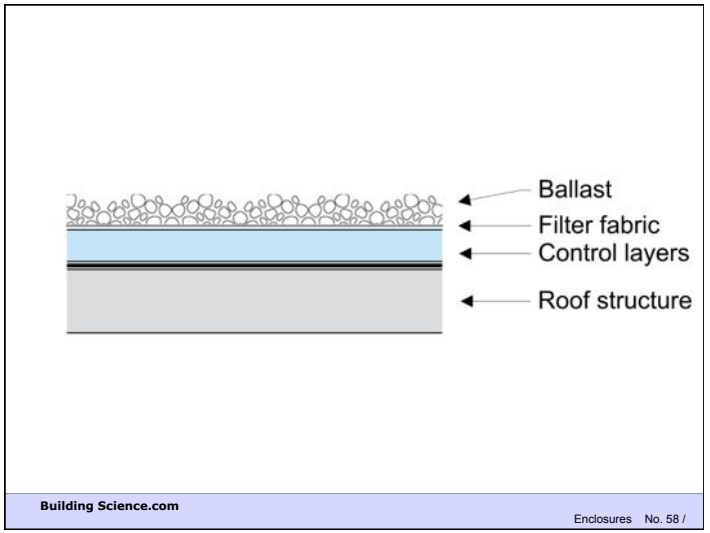
All Four Control Layers

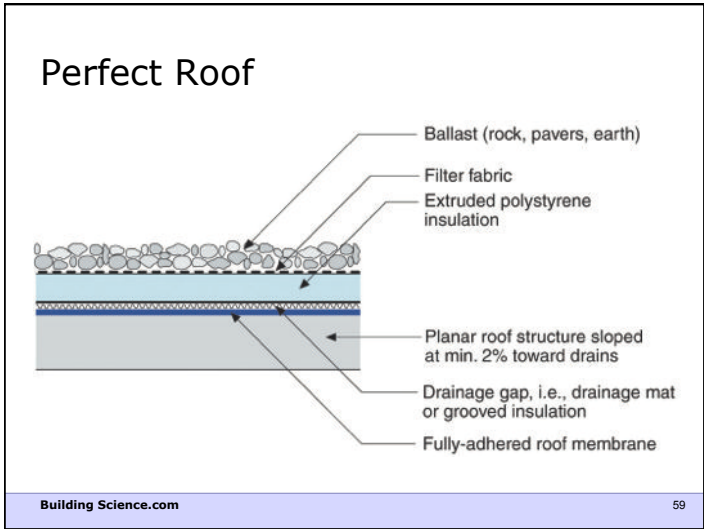
Spray foam= air barrier drainage plane insulation vapor control

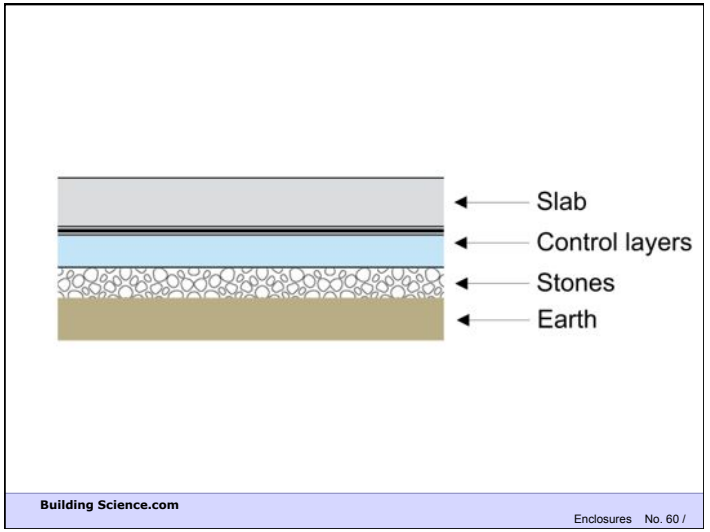
Transitions, Continuity, Penetrations

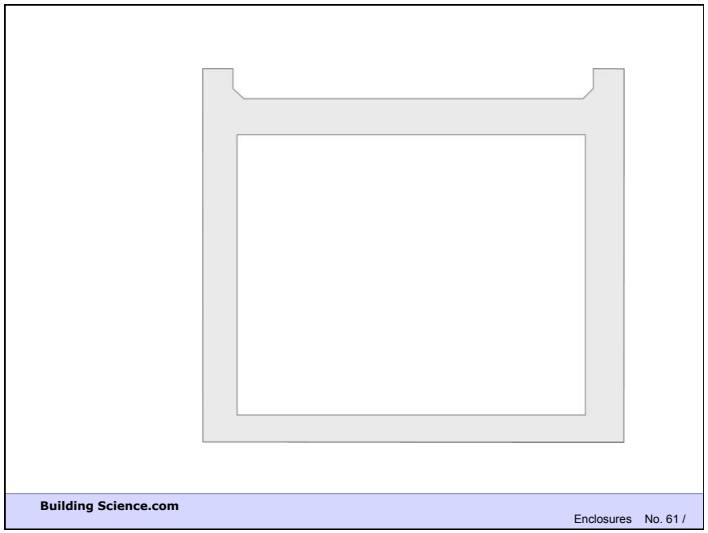


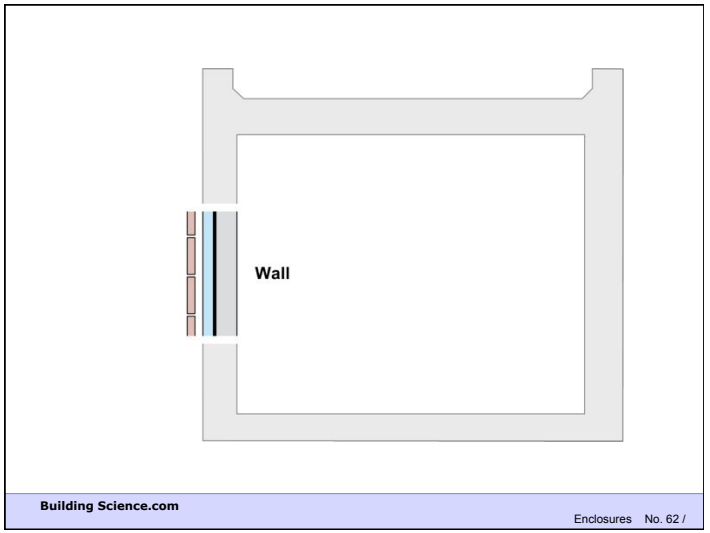

Ballast
Filter fabric
Control layers
Roof structure
Cladding
Control layers
Structure
Slab
Control layers
Stones
Earth
Building Science.com
Enclosures No. 57 /

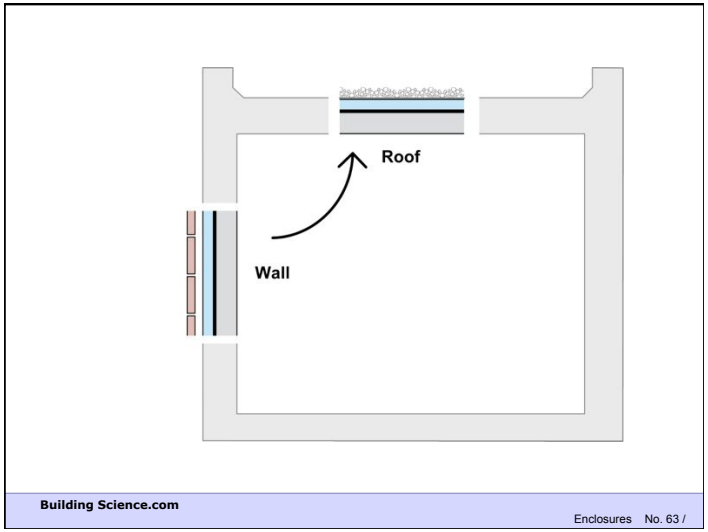

Ballast
Filter fabric
Control layers
Roof structure
Building Science.com
Enclosures No. 58 /

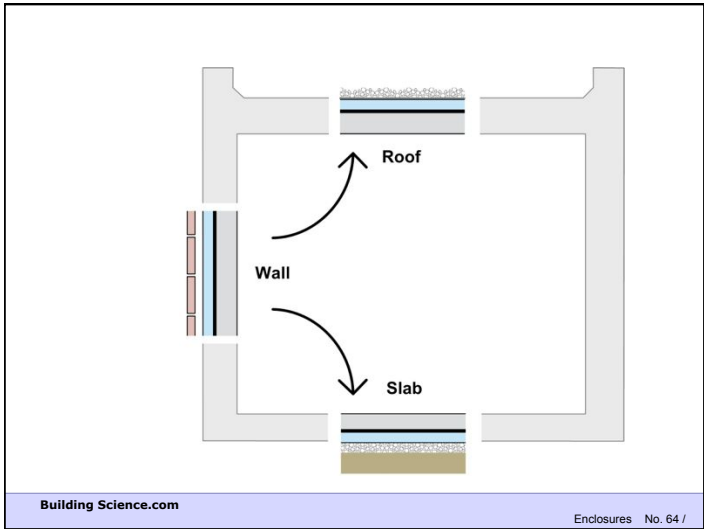

Perfect Roof
Ballast (rock, pavers, earth)
Filter fabric
Extruded polystyrene insulation
Planar roof structure sloped at min. 2% toward drains
Drainage gap, i.e., drainage mat or grooved insulation
Fully-adhered roof membrane
Building Science.com
59

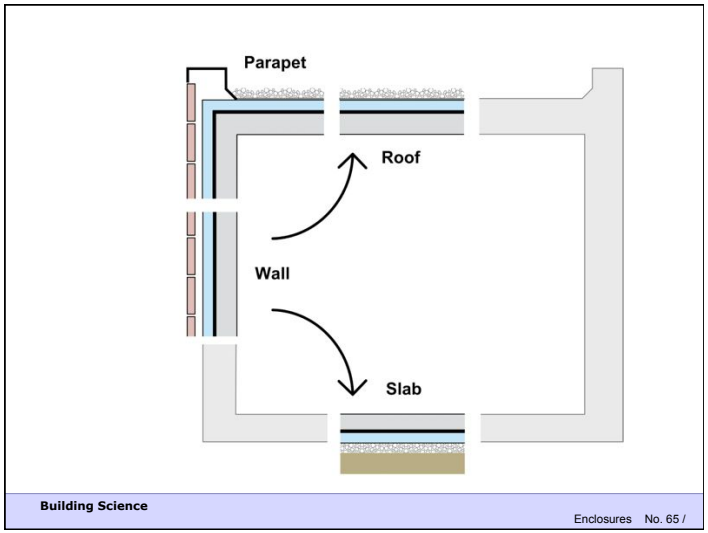

Slab
Control layers
Stones
Earth
Building Science.com
Enclosures No. 60 /

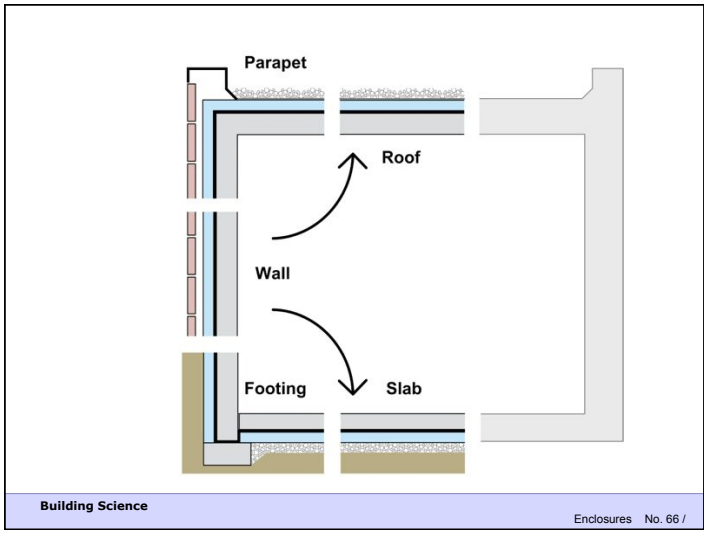

Building Science.com
Enclosures No. 61 /

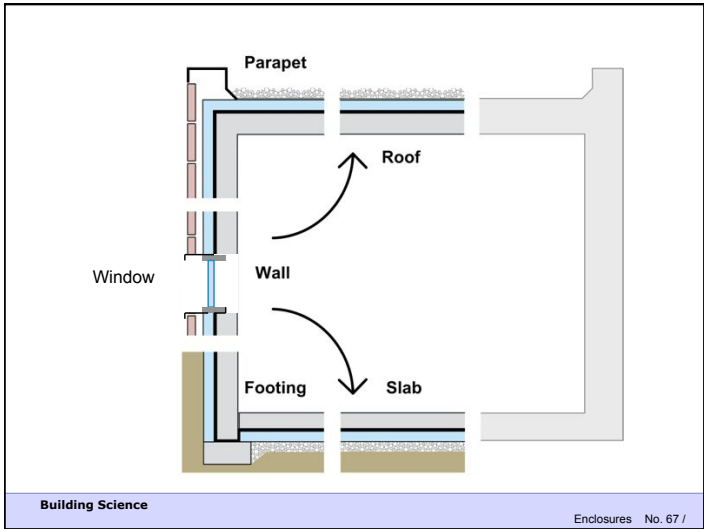

Wall
Building Science.com
Enclosures No. 62 /


Roof
Wall
Building Science.com
Enclosures No. 63 /


Roof
Wall
Slab
Building Science.com
Enclosures No. 64 /

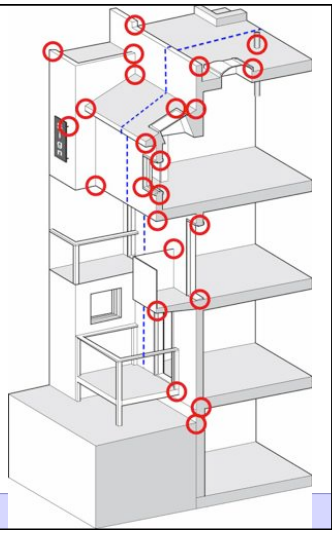

Parapet
Roof
Wall
Slab
Building Science
Enclosures No. 65 /


Parapet
Roof
Wall
Footing
Slab
Building Science
Enclosures No. 66 /

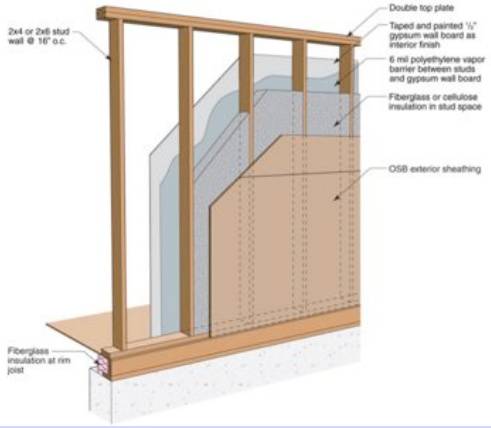

Parapet
Roof
Window
Wall
Footing
Slab
Building Science
Enclosures No. 67 /

Details required at
1. Changes in plane
2. Changes in material
3. Changes in system / trade

Thus penetration, windows, rails, signs etc.



- Discontinuous thermal and air barrier



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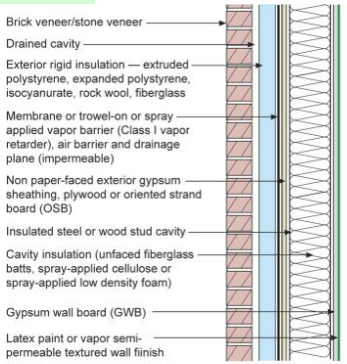
Ratio: Exterior R-value / Studbay R-value controls risk of condensation



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

R-value, e.g.
6" wood stud+
2" PIC= R30
3"XPS= R32
4"SPF= R40

Compromise

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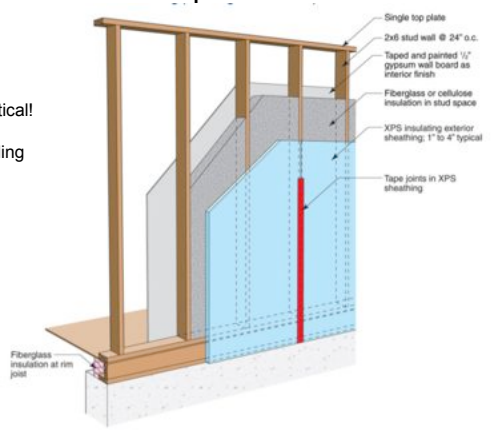
- Perfect Residential Compromise

•Ratio of R-values critical!
•This can be a retrofit of a wood frame building



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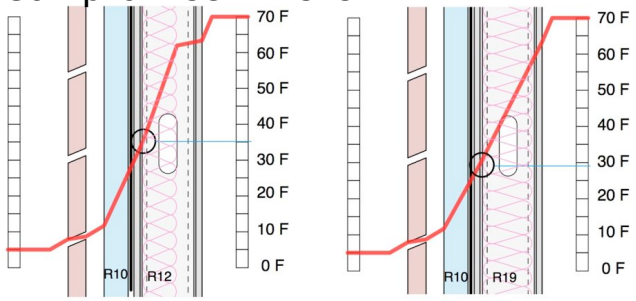
Compromise= Risks



More insulation on the exterior= lower risk

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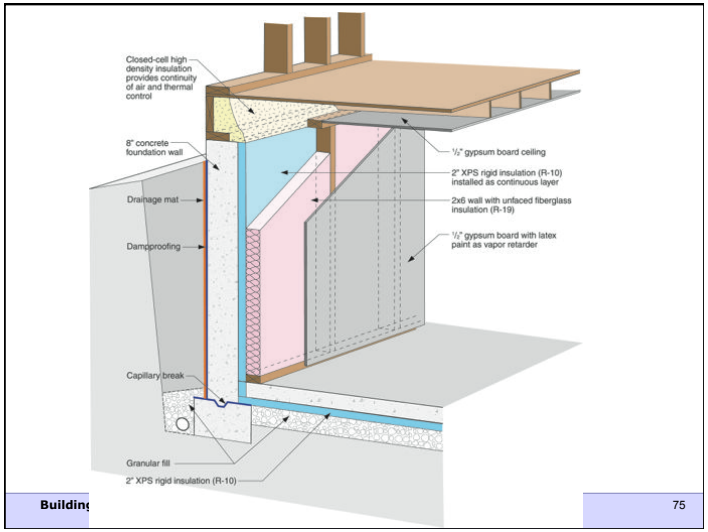
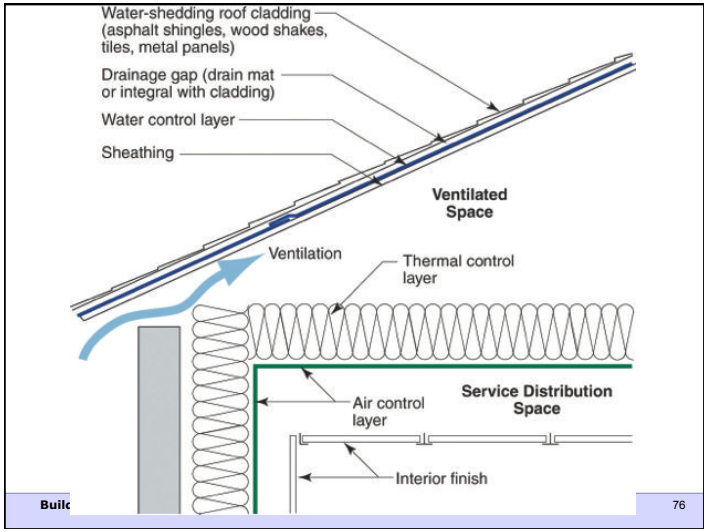
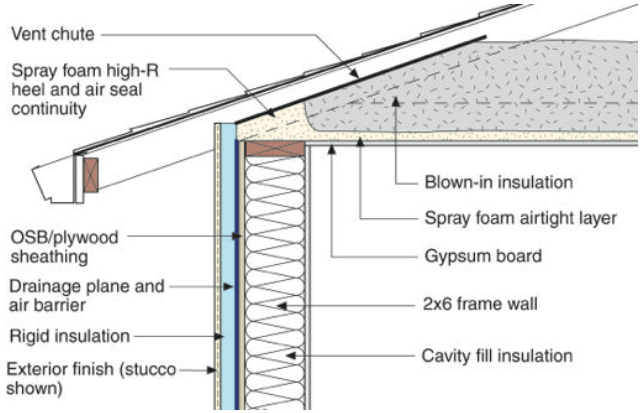


Building 75



Build 76



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Next Steps

- Investigate the 3 important layers
  - Rain
  - Air
  - Thermal

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