Traditional Stucco Farmhouse

What has changed?

7 yrs old, non-traditional problems

Healthy, Durable, Low Energy Buildings

BPCA: Building Performance Contractors of New York

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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.

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

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. 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
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

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

5. Three-D Airflow Networks

- Hollow walls
- Taller buildings

Hollow Buildings

- Inter-connected voids
# Hollow Buildings

Interconnected interstitial voids

## Five Fundamental Changes

1. Increasing Thermal Resistance
2. Changing Permeance of Enclosure Linings
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4. Moisture Storage Capacity
5. 3-D Airflow Networks

## 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

- Need to understand what we are doing from *first* principles
- Can’t “learn by trying”
- Building Science can guide us
What Do We Want To Do?

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

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 increases indoor humidity
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

Office Building Example

<table>
<thead>
<tr>
<th>Energy (kWh/m²)</th>
<th>Years</th>
</tr>
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<tr>
<td>25000</td>
<td></td>
</tr>
<tr>
<td>20000</td>
<td></td>
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<tr>
<td>15000</td>
<td></td>
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<tr>
<td>10000</td>
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<td>5000</td>
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</tbody>
</table>

Building Energy Use

Primary Energy Consumption by Sector, 2001

- Transportation: 27%
- Residential: 21%
- Commercial: 18%
- Industrial: 34%

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

Carbon Dioxide Emissions from Energy Consumption by Sector, 2001

Transportation 32%
Industrial 30%
Residential 20%
Commercial 18%

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

US Commercial Building Energy Use

Series 1

kBtu/sf

Before 1920
1920 to 1945
1946 to 1959
1960 to 1969
1970 to 1979
1980 to 1989
1990 to 1999
2000 to 2003

250 kWh/m²
315 kWh/m²

How Old and New Houses Use Energy

Total Btu Consumption per Household, 2001


Existing Housing Stock

Age of US Housing Stock (all unit types)

Number of Housing Units (Thousands)

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

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.)
Climate Site

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

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.

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

Seattle, Sacramento, Miami, Minneapolis, Edmonton, Toronto
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

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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Functional Layers

• Support
  – Resist & transfer physical forces from inside and out
• Control
  – Control mass and energy flows
• Finish
  – Interior and exterior surfaces for people

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Other Control . . .

• Support
• Control
  – Fire
    • Penetration
    • Propagation
  – Sound
    • Penetration
    • Reflection
  – Light
    • Diffuse/glare
    • View
• Finish
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

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**

- CMU backup

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

- Brick veneer/stone veneer
- Drained cavity
- Exterior rigid insulation — extruded polystyrene, expanded polystyrene, polyisocyanurate, rock wool, fiberglass
- Membrane or trowel-on or spray-applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
- Concrete block
Perfect Wall

• Steel Stud Structure

Condensation & Drying

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

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 = Risks

Wall

Slab

Roof

Ballast
Filter fabric
Control layers
Roof structure

Slab
Control layers
Stones
Earth
Enclosure Design: Details

- Details demand the same approach as the enclosure.
- Scaled drawings required at
Connections: Who is in charge

Process and Philosophy

- Decide to value low energy consumption
- Set targets, predict usage, measure performance
- Do not compromise comfort, safety or durability!
- Stamp out waste everywhere

Residential, single family

1. Comfortable, durable, healthy, safe
2. Insulate wall, roof basement, airtighten
3. Limit window-to-wall ratio (WWR) to <25%
4. Control ventilation, use energy recovery ventilation
5. Upgrade windows (control SHGC and R-value)
6. Use efficient lighting, right-sized
7. Use efficient appliances
8. Use efficient heating and domestic hotwater equip.
9. Consider source of energy
10. Add renewables to push toward zero
Small, Compact Form
- Fewer resources
- Less heat loss and gain

Rain control
- After support, most important function
- Largest source of moisture
- Drained approach is preferred

Lapped Housewrap, membrane
Shingle lap is the best, most reliable.

Beware vertical installation and wrinkles!

Requirements for a Drained Enclosure

1. "Rainscreen" cladding
2. Drainage space
3. Drainage Plane
4. Flashing
5. Drain Opening ("weep")

Air-Water Control Layers

Sloped and complex surfaces demand very high performance. LAPPING very important.
Non-adhered, vapor permeable = modest performance
Supported flexible membrane is better

• Taped Foam

• Huber ZIP
Fluid-applied products avoids laps

Fully-adhered air-water barrier

Vapor Permeable!
**Form & Massing**

- **Keep it simple**
- **Cheaper, easier, faster**
- **Fewer**
  - thermal bridges, air leaks
  - Material volumes
  - construction challenges

**Strategies- Airtightness**

- **Airtightness critical for all climates**
  - Humidity loads from air critical health comfort and durability issue in hot-humid
  - Control condensation and energy waste critical in cold climates
  - Natural ventilation useful in dry (night) and moderate climates (e.g., marine)

**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
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 like the limit
  - How much space available in studs?
  - Fastening, windows: exterior sheathing of 1-1/4"
- Increased insulation should reduce HVAC capital as well as operating!

Capital Investment vs Operating Cost

- Airtightness
  - Hard to design
  - Easy to measure post mortem
- Thermal bridging
  - Easy to predict most in design
- Thermal mass
  - Solar gains? Solar rejection?
Typical Air Leakage Points

- At chimney/fireplace penetrations
- Behind bathtubs, enclosures, above suspended ceilings
- Around windows
- Through window joints
- Nails, plates, backboards
- Joints & cracks
- Ceiling light fixtures
- Attic hatch
- Airflow Control No. 108/79

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Rigid Exterior Air Barrier

- Exterior sheathing: taped or sealed joints in exterior sheathing
- Vapor permeable housewrap wrapped around floor assembly
- Ceiling resistant
- Polyethylene
- Insulation
- Ceiling resistant
- Polyethylene
- Insulation
- Vapor permeable housewrap
- Insulation
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Poly can be (?) an air and vapour barrier
But
BEWARE when Air Conditioning
Definitely not in South

Insulation, Air barrier, WRB

• Fully adhered air barrier drainage plane and insulation
• Joints, movement, cost?
Thermal bridges

- 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

Complexity

- Air, thermal continuity

![Diagram showing thermal bridging and complexity in building insulation.](image-url)

![Graph comparing R-values of batt insulation with different stud spacings.](image-url)
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?

The perfect wall

More challenging ...

• Compromise
  – Wood framing
  – High R-value steel
    • Eg 50% R outside
  – R-value on outside
    • Varies with climate
      interior conditions
Double Stud:
Exposes sheathing!
Air leakage risk.
Insulated Concrete Forms

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

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
Beware Joints
No vapor barriers

Vapour Profiles
In Wall Assemblies: