Insulating Load-Bearing Masonry Buildings
Overview
Mass Walls (Rain Control)

- Moisture is absorbed/safely stored during rain
- Moisture re-evaporates/dries while warmer
- No “drainage plane”
Inside or Outside Insulation?

• Insulating on exterior always preferable (masonry durability, condensation risks)
• Interior insulation → historic preservation reasons
• Interior → potential durability risks
• Energy efficiency, preserve exterior, museum-level durability: choose 2 of 3
Cold Climate Risks

1. Freeze-thaw (reduced drying)
2. Air leakage condensation on interior face of masonry
3. Rot / corrosion of embedded elements
Cold Climate Risks: Condensation

- Requires perfect workmanship at air barrier—around penetrations, etc.
- Made worse by air gap behind insulation
- **NOT RECOMMENDED**
Condensation Risks
Embedded Wood Member Risks
The Moisture Balance

- Large storage capacity (mass wall)
- Drying decreases with insulation
- Design should reduce/control wetting to compensate
Do We Need to Insulate Mass Walls?

Climate: Burlington, VT

Case 1: Uninsulated Masonry (~R-5)

Case 2: 1.5" ccSPF Foam (~R-5+R-8.7)

Case 3: 3" ccSPF Foam (~R-5+R-17.3)

Mass vs. no mass → Adds ~R-1
Window Heat Loss in Context

- Large windows (4’ x 8’), high glass %
- Can’t change frame profile (historic)
- Aluminum, double, low E: $U \approx 0.5$ (center of glass $U-0.30$)
- R-2 holes in R-20 walls
Window Heat Loss in Context

- Improved thermal breaks available
- Improved edge spacers available
- Improved center-of glass (triple, films, etc.)
- All add cost; not typical construction
- Alternate frame materials?
Retrofit Approaches
Recommended Approaches

• Spray foam against masonry
• Open cell (0.5 PCF)? Closed cell (2.0 PCF)? Intermediate (1.0 PCF)?
• Air seal at joist pockets
• Montreal experience
Hybrid Wall Insulation Assembly

- Remove all loose and peeling paint on existing masonry walls.
- Tie back stud to masonry as necessary with non-metallic clips.
- 2" continuous high density spray foam insulation (typ.)
- Blown damp spray cellulose insulation; leave steel stud space clear.
- Narrow section steel framing: no insulation.
- Interior gypsum board finish.
- Provide continuous sealant; seal gypsum board to underside of deck (typ. both sides).

Air seal at beams.

Structural beam.
Rain Control

- Don’t change a successful mass rain control to a problematic drained one!
- Flashing, weeps, etc.
Non-Foam Options?

- Dense pack cellulose against brick
- High-density mineral fiber/glass fiber & variable permeability vapor retarder
- Requires meticulous workmanship/air barrier—air barrier outboard of framing & services

Photo: Chris Benedict
Mineral Fiber Interior Retrofit?

Climate Zone 4-OK

Preferred approach: air/vapor control outboard of stud wall
Problem Items
Tapered Window Openings

Minimum ~R-5 for thermal comfort (radiant surface temperatures)

Leverage spray foam for air barrier barrier continuity to window opening
Thermal Bridging at Slab Floors

Outdoor air supplied and heated to near indoor temperature during cold weather (very low RH). Pressure controlled to 2-4 Pa above indoor pressure in each zone.

Vapor permeable, low density spray foam air barrier insulation

Dry, warm air leaks to the interior through unintentional openings/cracks

Interior humidity conditions controlled to prevent condensation on thermal bridges (e.g. slabs)
Thermal Bridging at Slab Floors

R-20 for 10 foot wall
R-3 for 1 foot floor slab
R-13 overall R value
Thermal Bridging at Slab Floors

▪ Typical Insulation Levels
  ▪ R-14 for 8 foot wall
  ▪ R-3 for 8 inch floor slab
  ▪ R-10.9 overall opaque R value
  ▪ 22% loss from nominal value

▪ High Insulation Levels
  ▪ R-38 for 8 foot wall (6” ccSPF)
  ▪ R-3 for 8 inch floor slab
  ▪ R-19.9 overall opaque R value
  ▪ 47% loss from nominal value
Interior Brick Exposed to Exterior

Reference: Canadian Building Digests 138: On Using Old Bricks in New Buildings
Air Barrier Issues

Can’t rely on masonry alone to be an air barrier

13” brick wall, 100 sf = 3.1 sq. in. leakage EqLA

Same with 3 coat plaster = 0.054 sq. in. EqLA
Assessment Steps
Where is the Building?
Freeze-Thaw Risk Assessment Process

In order of importance:

• 1. Site Visit Assessment
• 2. Materials Tests & Modeling
• 3. Site Load Assessment
• 4. Prototype Monitoring
• 5. Retrofit and Repair (execution)
• 6. Maintenance and Repair
1. Site Visit

- Most important!
  - Walk around exterior and interior of the building
- Rain leaks?
  - Large/small, often/rare
- Freeze-thaw damage
  - parapet, chimney, at-grade, below windows
Site Assessment: Where is it Wet?
Site Assessment: Where is it Wet?
Windows (Water Concentration)

Sill pan flashing: note backdamp to prevent inward water movement; overlaps and drains onto surface of sill; pan flashing should extend min. 4" up jamb vertically.

Caulk and backer rod joint, to avoid entry of water into masonry wythes.

Regletted flashing/drip edge; can be wedged in place instead of mechanical fastening, if acceptable. Alternate: improves drainage but is more visible—have drip edge fall from outside edge of sill.
Drip Edges

- Minimum projection of drip edge

![Correct drip edge example](image1)

- Incorrect drip edge example

![Incorrect drip edge example](image2)

- Correct drip edge example

![Correct drip edge example](image3)
Windows (Potential Rain Entry Point)

Diagram details:
- Liquid applied membrane waterproofing
- Flanged window
- 2x6 wood buck
- Trim closure
- Concrete sill
- Approx. 4” overhang
- 1x2 backdam
- 2” spray applied foam insulation (closed cell, high density)
- Uninsulated steel stud assembly
- Gypsum board
Roof-Wall Interface

[Diagram showing roof-wall interface with a bar chart indicating percent of walls with problems based on width of overhang above the wall (in/mm).]
Existing Damage

- Where is it? Still active or not?
Existing Damage

• Map damage—can correlate to exterior drainage issues?

• If you can identify the source, you can fix it
2. Materials Tests & Modeling

- Brick sample testing (basic tests)
  - Thermal conductivity
  - Dry density
  - Water uptake A-value (transport)
  - Saturation moisture content (storage)
- Quantitative freeze-thaw resistance
  - Fagerlund’s Critical Degree of Saturation ($S_{\text{crit}}$)
  - More details in following section
- WUFI modeling
  - Requires knowledge, experience, comparison to measured data, and real experience
Hygrothermal Simulations

- Simulate existing (uninsulated) wall
- Simulate retrofitted (insulated) wall
- Vary rain loading—sensitivity analysis
Assessment

- Freeze Thaw Event
  - Brick must have higher moisture than Critical Degree of Saturation
  - Brick must freeze/thaw (<23 F and >32 F)
3. Site Load Assessment

- Assess driving rain load
  - Monitor rain deposition on building
  - Monitor run down
- Driving rain is the largest load
- Large uncertainty
4. Prototype Monitor

- Install retrofit over a small area
- Measure temperature and moisture content
- Compare wetting, MC, temperatures to model results
- Potentially could compare bricks after 1-2 years, e.g., ultrasonic transit time
5. Retrofit and Repair (execution)

• Repair masonry—repointing, improve rain control features and detailing as indicated by site survey
6. Maintenance & Repair

- As for all building enclosures
- Require a program of inspection/repair
- Mortar will often be damaged first
- Downspouts? Roof flashing? Backsplash?
- Formal manual for owner would be helpful
- Damage less visible from inside compared to pre-retrofit building (assuming bare masonry inside)
Freeze-Thaw Testing
Freeze-Thaw Damage

• The physics of Freeze-Thaw damage in porous materials is still NOT completely understood

• Several theories proposed
  – Some decades old
  – Some recent

• “Closed container”—milk bottle in freezer

• Ice lensing theory—ice “pulls” water from voids

• Hydraulic pressure theory—freezing pipes
Old Approach: Use Graded Bricks

- ASTM C62 & C67
  - Grade Bricks SW, MW, NW
  - Weather Index = days of cycling around freezing x annual rainfall
  - If weather index > 50, must use SW brick
Old Test Methods

- Method A: c/b ratio
  - $c =$ Moisture Content after 24 hr cold soak
  - $b =$ Moisture Content after 5 hr boil
  - SW brick if Saturation Coefficient $(c/b) < 0.78$ or $0.80$
- Method B: 50 Cycle Freeze-Thaw
  - Freezing (20 hrs); brick in 12 mm of standing water in cold room
  - Thawing (4 hrs); brick submerged in thawing tank
  - Repeat 24 hr cycle 50 times & measure loss of dry mass; must be less than 3% for ASTM
Problems with the Old Methods

• Freeze-Thaw resistance is a misnomer
• Both A & B are digital test methods
• Lead to false positives & negatives
  – Butterworth & Baldwin, 1960s
• A is based on incomplete physics of freeze thaw
  – Closed Container (expansion of water as it freezes)
    – Hydraulic Pressure
    – Ice Lensing
    – Disequilibrium Theory
• B doesn’t identify critical degree of saturation
Measurement of $S_{\text{crit}}$

- Critical Degree of Saturation ($S_{\text{crit}}$)
  - European research on stone and masonry
  - Below this moisture content: no damage w. F/T
  - Above this moisture content: damage occurs quickly
- Cut brick samples; measurements
- Vacuum saturate to range of moisture contents
- Subject to freeze-thaw cycles
- Measure dilation (growth) of samples (very small!)
- “Hook” in graph signifies $S_{\text{crit}}$
Preparing Test Specimens (Brick Slices)
Saturation Moisture Content

Image: P. Mensinga, UofW BEG
Measuring Dimensions (Dilation)

- Small dilation ~200 to 3000 microstrain
- One microstrain = one part per million (10^{-6})
- 1000 microstrain = 0.1%
Running Freeze-Thaw Cycles

- Minimum 8 cycles
- Sometimes more to “draw out” damage
Dilation (Growth) of Samples

- 25C / 1hr
- 15C / 3hr

Microstrain vs. Water Saturation graph.