Kohta Ueno

November 16, 2017

# Insulating Load-Bearing Masonry Buildings

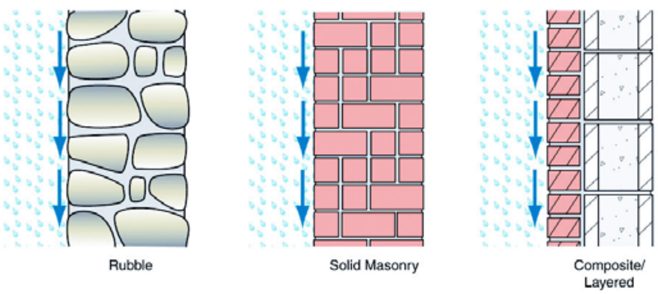
Building Science Corporation

AIA New Hampshire

# Overview



## Mass Walls (Rain Control)

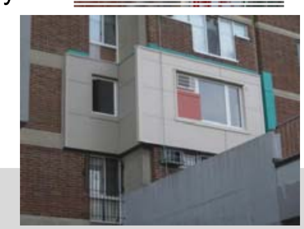



- Moisture is absorbed/safely stored during rain
- Moisture re-evaporates/dries while warmer
- No “drainage plane”



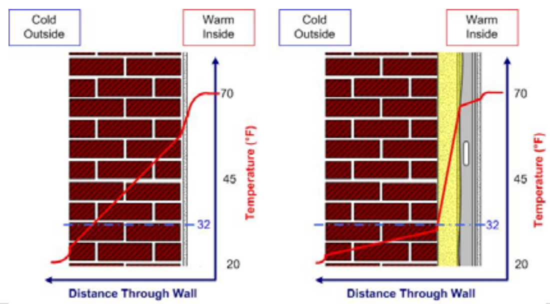
## Inside or Outside Insulation?

- 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



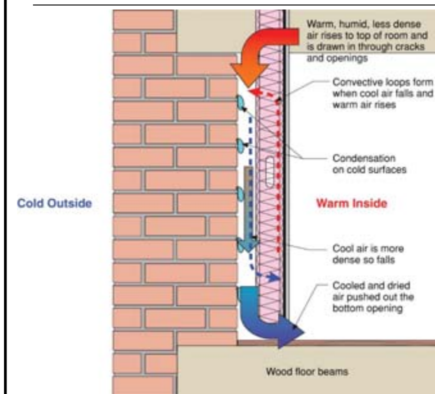
## Cold Climate Risks

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






## Cold Climate Risks: Condensation

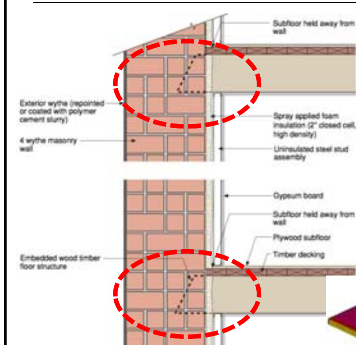


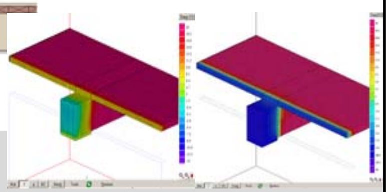

- Requires perfect workmanship at air barrier—around penetrations, etc.
- Made worse by air gap behind insulation
- **NOT RECOMMENDED**



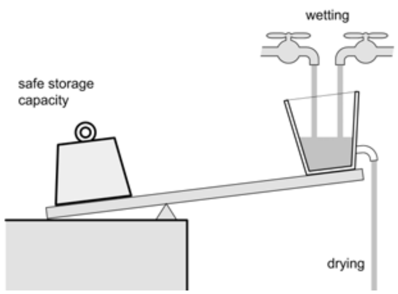
## Condensation Risks

## Embedded Wood Member Risks



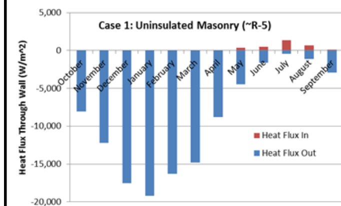
## The Moisture Balance

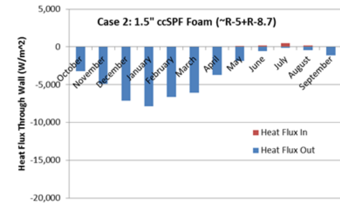



- Large storage capacity (mass wall)
- Drying decreases with insulation
- Design should reduce/control wetting to compensate



## Do We Need to Insulate Mass Walls?

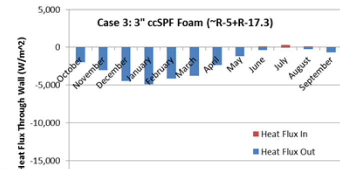



Climate: Burlington, VT

Case 2 (add 1.5" ccSPF, R-8.7) ≈ 60% reduction in heat flow through walls vs. uninsulated case

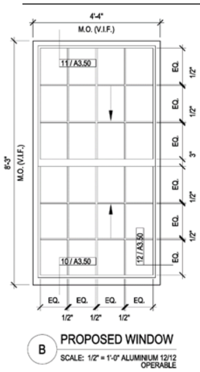
Case 3 (add 3" ccSPF, R-17.3) ≈ 75% reduction in heat flow through walls vs. uninsulated case




Mass vs. no mass → Adds ~R-1



## Window Heat Loss in Context

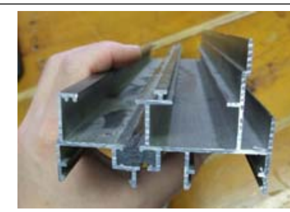



- Large windows (4' x 8'), high glass %
- Can't change frame profile (historic)
- Aluminum, double, low E: U≈0.5 (center of glass U-0.30)
- R-2 holes in R-20 walls

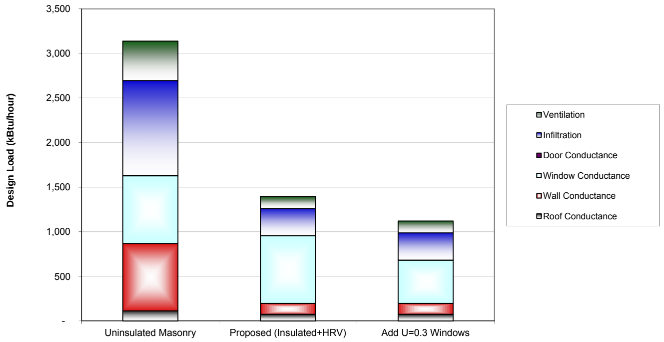


## Window Heat Loss in Context

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



## Wintertime Heat Loads by Component

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## Retrofit Approaches

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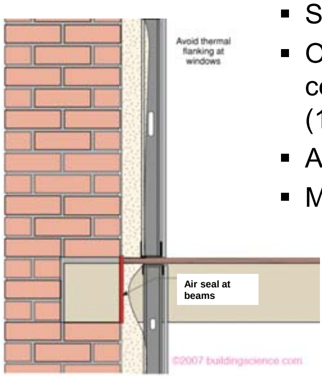
## Recommended Approaches




- 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

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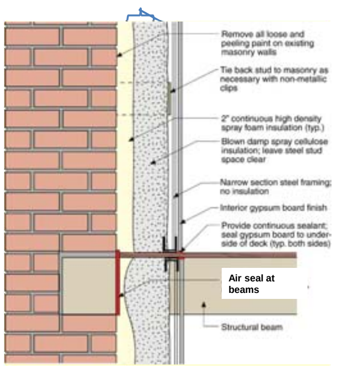
## Hybrid Wall Insulation Assembly

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## Rain Control

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

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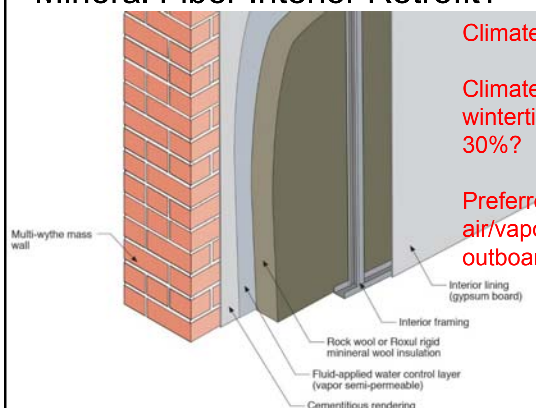
## Non-Foam Options?

- 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

Climate Zone 5-wintertime RH under 30%?

Preferred approach: air/vapor control outboard of stud wall

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# Problem Items

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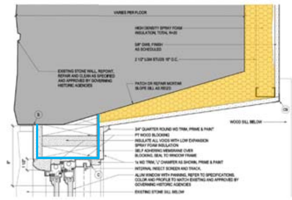
## Tapered Window Openings

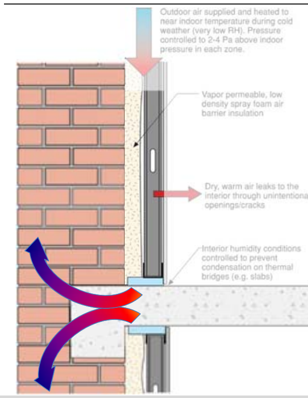


Minimum ~R-5 for thermal comfort (radiant surface temperatures)

Leverage spray foam for air barrier continuity to window opening

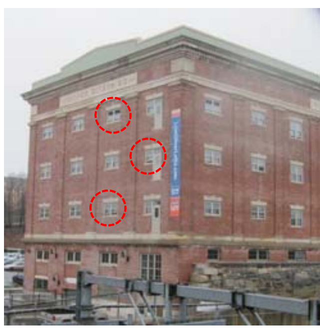


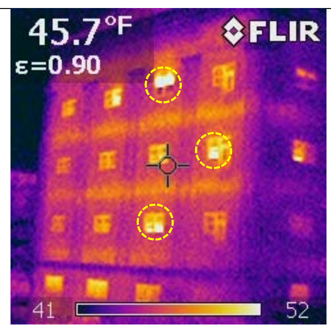
## Thermal Bridging at Slab Floors






## Thermal Bridging at Slab Floors

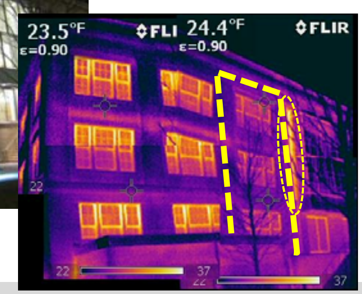





R-20 for 10 foot wall
R-3 for 1 foot floor slab
R-13 overall R value



## Thermal Bridging at Slab Floors



## 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

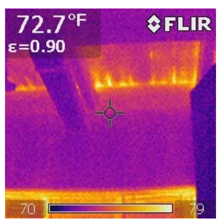


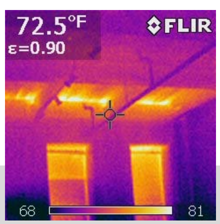
## Interior Brick Exposed to Exterior

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

Source: CBD-23. Air Leakage in Buildings



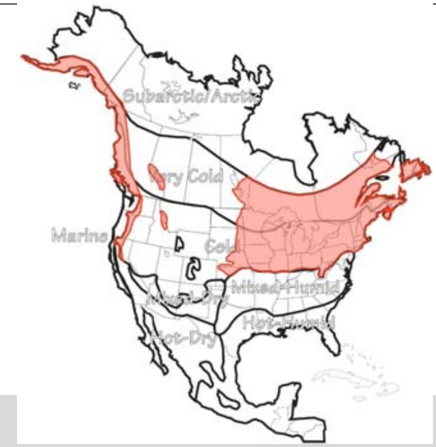
# Assessment Steps

## Where is the Building?





## Where is the Building?






## Freeze-Thaw Risk Assessment Process

In order of importance:

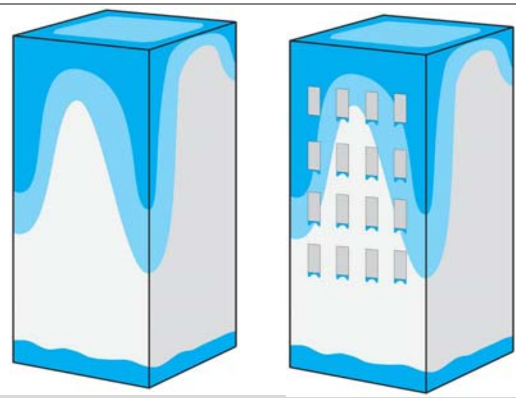
- 1. Site Visit Assessment
- 2. Materials Tests & Modeling
- 3. Site Load Assessment
- 4. Prototype Monitoring
- 5. Retrofit and Repair (execution)
- 6. Maintenance and Repair



## 1. Site Visit

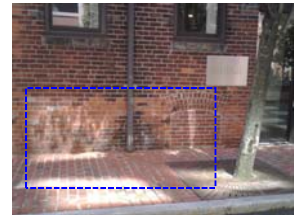
- Most important!
  - Walk around exterior and interior of the building
- Rain leaks?
  - Large/small, often/rare
- Freeze-thaw damage
  - parapet, chimney, at-grade, below windows

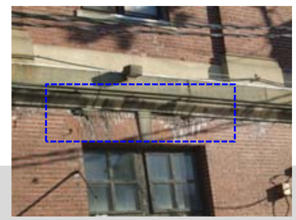
## Site Assessment: Where is it Wet?



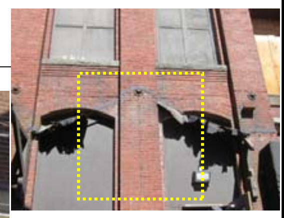


## Site Assessment: Where is it Wet?



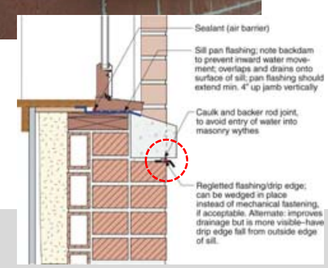


## Water Concentrations



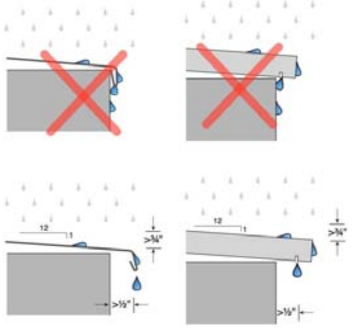


## Windows (Water Concentration)



## Drip Edges

- Minimum projection of drip edge

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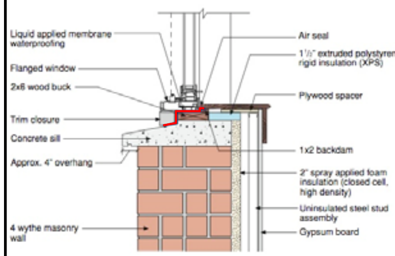
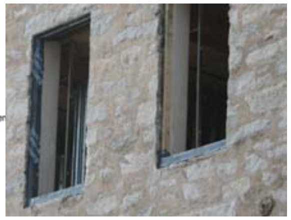
## Windows (Potential Rain Entry Point)



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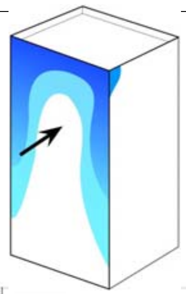
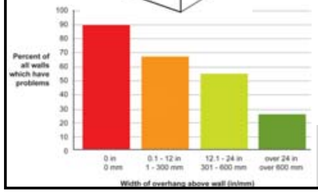
## Roof-Wall Interface



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## Existing Damage

- Where is it?  Still active or not?

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## Existing Damage

- Map damage—can correlate to exterior drainage issues?
- If you can identify the source, you can fix it

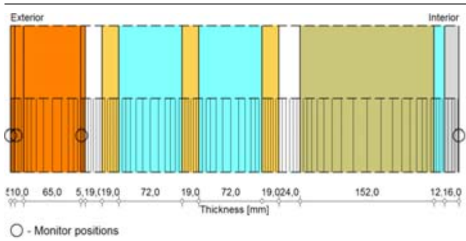


## 2. Materials Tests & Modeling

- 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 ($S_{crit}$)
  - More details in following section
- WUFI modeling
  - Requires knowledge, experience, comparison to measured data, and real experience



## Hygrothermal Simulations



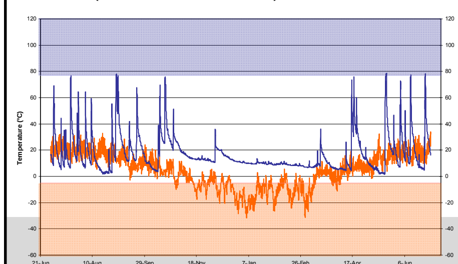

- Brick
- Mortar
- Terra cotta
- Air Space
- Plaster
- ccSPF
- Air Space
- Gypsum Board

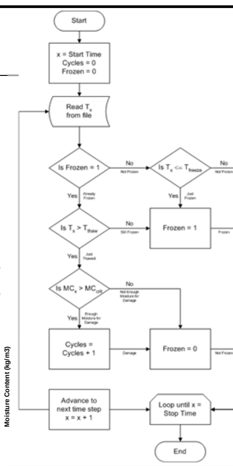
- Simulate existing (uninsulated) wall
- Simulate retrofitted (insulated) wall
- Vary rain loading—sensitivity analysis



## Assessment

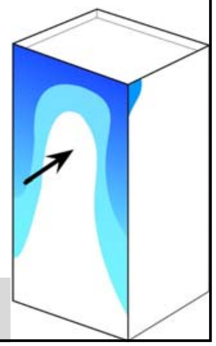
- Freeze Thaw Event
  - Brick must have higher moisture than Critical Degree of Saturation
  - Brick must freeze/thaw (<23 F and >32 F)





## 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 $S_{crit}$

- Critical Degree of Saturation ($S_{crit}$)
  - 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 $S_{crit}$



## Preparing Test Specimens (Brick Slices)

## Saturation Moisture Content

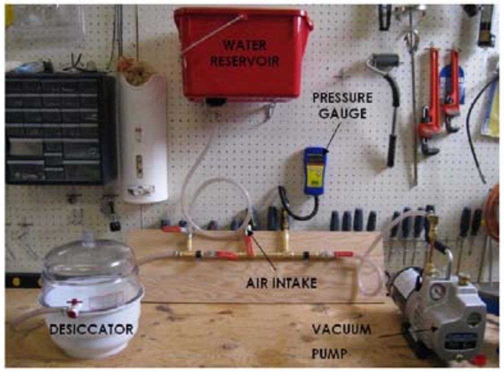



Image: P. Mensinga, UofW BEG

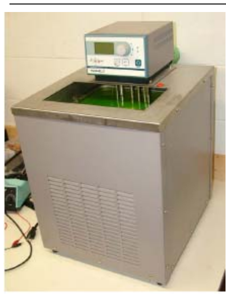


## Measuring Dimensions (Dilation)

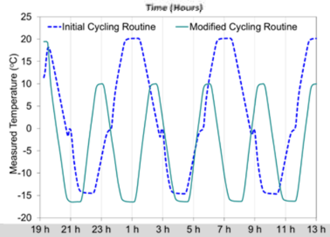
- Small dilation ~200 to 3000 microstrain
- One microstrain=one part per million ($10^{-6}$)
- 1000 microstrain=0.1%



## Running Freeze-Thaw Cycles

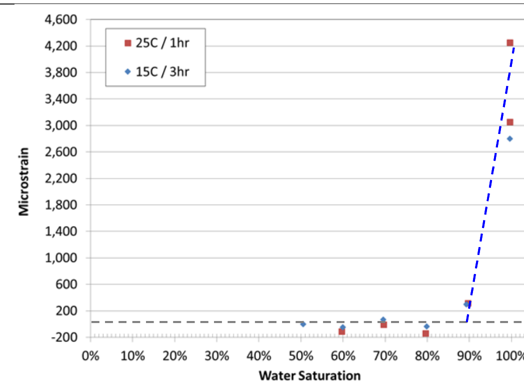


- Minimum 8 cycles
- Sometimes more to "draw out" damage




## Dilation (Growth) of Samples

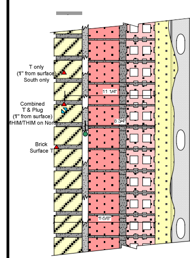


# Current Research



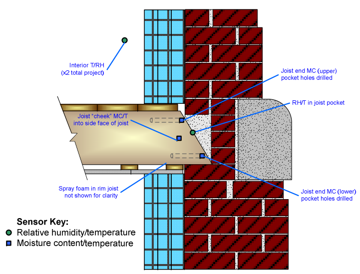
## Masonry Temperature/Moisture

- “Prototype monitoring” (Step 4)





## Embedded Joist End Monitoring







# Questions?

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This presentation will be available at:
http://www.buildingscienceconsulting.com/presentations/recent.aspx

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building America U.S. Department of Energy

## Document Resources

- Building Science Digest 114: Interior Insulation Retrofits of Load-Bearing Masonry Walls In Cold Climates
  http://www.buildingscience.com/documents/digests/bsd-114-interior-insulation-retrofits-of-load-bearing-masonry-walls-in-cold-climates
- Building Science Insight 047: Thick as a Brick
  http://www.buildingscience.com/documents/insights/bsi-047-thick-as-brick/
- CP-1013: Assessing the Freeze-Thaw Resistance of Clay Brick for Interior Insulation Retrofit Projects
  http://www.buildingscience.com/documents/confpapers/cp-1013-freeze-thaw-resistance-clay-brick-interior-insulation-retrofits/view
- BA-1105: Internal Insulation of Masonry Walls: Final Measure Guideline
  http://www.buildingscience.com/documents/bareports/ba-1105-internal-insulation-masonry-walls-final-measure-guideline/view
- BA-1307: Interior Insulation of Mass Masonry Walls: Joist Monitoring, Material Test Optimization, Salt Effects
  http://www.buildingscience.com/documents/bareports/ba-1307-interior-insulation-mass-masonry-walls/view
- Interior Insulation Retrofit of Mass Masonry Wall Assemblies Workshop
  http://www.buildingscienceconsulting.com/services/documents/file/BSC%20TO2%201_3%20Final%20Expert%20Meeting%20Report.pdf



## Document Resources

- CP-1301: Field Monitoring and Simulation of a Historic Mass Masonry Building Retrofitted with Interior Insulation
  http://www.buildingscience.com/documents/confpapers/cp-1301-field-monitoring-simulation-historic-mass-masonry-retrofitted-interior-insulation/view
- Thermal Performance of the Exterior Envelopes of Whole Buildings XII: Field Monitoring and Simulation of a Historic Mass Masonry Building Retrofitted with Interior Insulation
  http://www.buildingscienceconsulting.com/presentations/documents/2013-12-04_Ueno%20Buildings%20XII.pdf
- Canadian Building Digest 2. Efflorescence
  http://www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/building-digest-2.html
- Canadian Building Digest 138. On Using Old Bricks in New Buildings
  http://www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/building-digest-138.html
- Green Building Advisor: Insulation Retrofits on Old Masonry Buildings: Building Science Podcast
  http://www.greenbuildingadvisor.com/blogs/dept/building-science/insulation-retrofits-old-masonry-buildings-building-science-podcast
- Green Building Advisor: Insulating Old Brick Buildings
  http://www.greenbuildingadvisor.com/blogs/dept/musings/insulating-old-brick-buildings