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Field Monitoring and Simulation of a Historic Mass Masonry Building Retrofitted with Interior Insulation

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BUILDINGS XII CONFERENCE
DECEMBER 1–5, 2013

Background

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Background

- Interior insulation retrofits of mass masonry
  - Significant increase in R-value
  - Utilizes existing building stock
  - Potential risks: freeze-thaw, corrosion of embedded metal, embedded wood structural members
  - Presentation is not a primer on the subject
- Boston-area academic institution; existing solid masonry building; interior insulation retrofit
- BSC was asked to provide monitoring—assessing risk associated with retrofit
- Intended to inform future retrofit projects

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Project Overview

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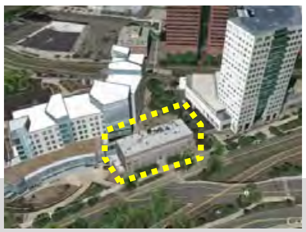
Building Location & Geometry



Cambridge, MA (DOE Zone 5A)
Original construction 1917
On National Historic Register

Renovation 2010-2011

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Interior Insulation

2-3 layers solid brick
Interior hollow clay tile
Painted on asphaltic coating

3 to 3-½" Open cell spray foam (0.5 PCF)
Thermal bridging through studs
Overall ~R-10.6 (nominal ~R-11 to R-13)

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Monitoring Locations

South (Front Elevation) North (Rear Elevation)

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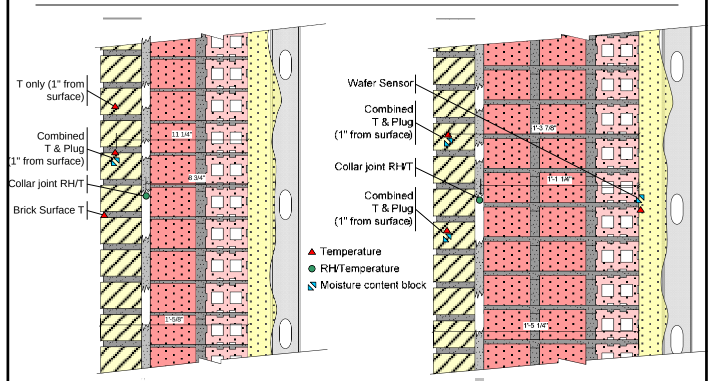
Wall and Instrumentation Setup



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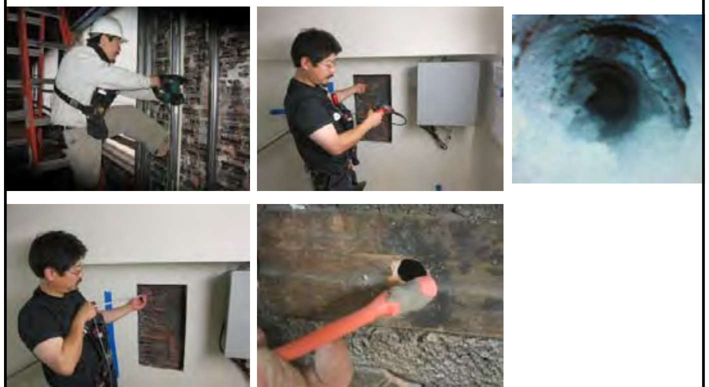
Masonry Instrumentation



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Results

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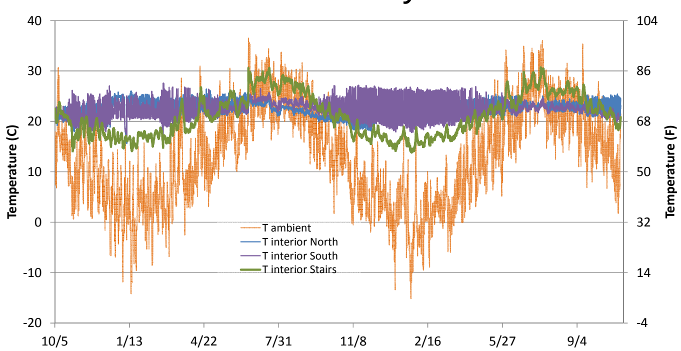
Interior/Exterior Boundary Conditions



- 2 years' data collection
- Wintertime interior RHs ~10-20%—overventilation?

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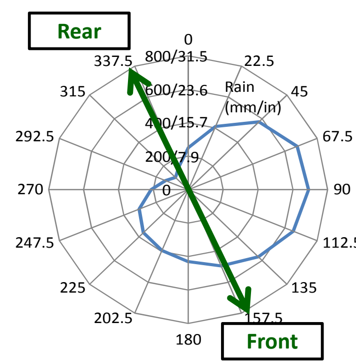
Driving Rain Data (Calculated)



- Monitoring did not capture worst driving rain orientation
- Rear ("north") side low driving rain exposure

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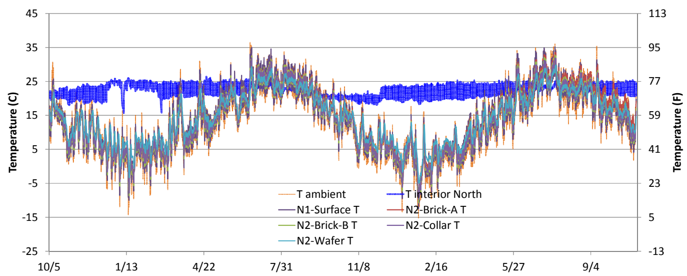
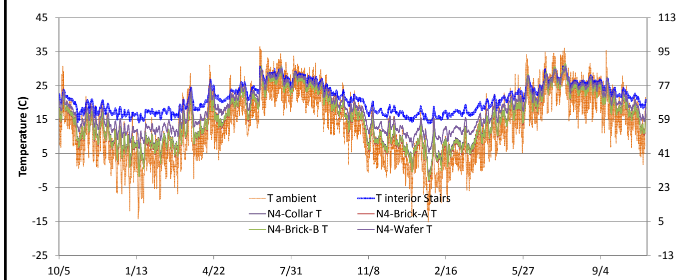
Wall Temperatures (North Insulated)



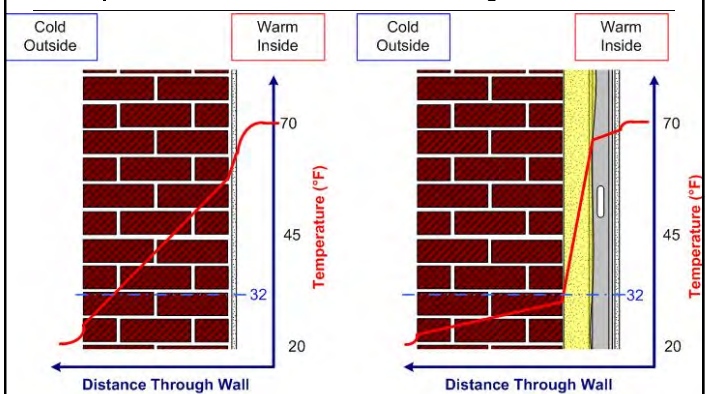
- North side insulated walls, various locations through thickness of wall
- South similar at night; added solar gain during day

Wall Temperatures (North Uninsulated)



- North side uninsulated walls: temperature gradient through thickness of wall

Temperature Gradients through Wall



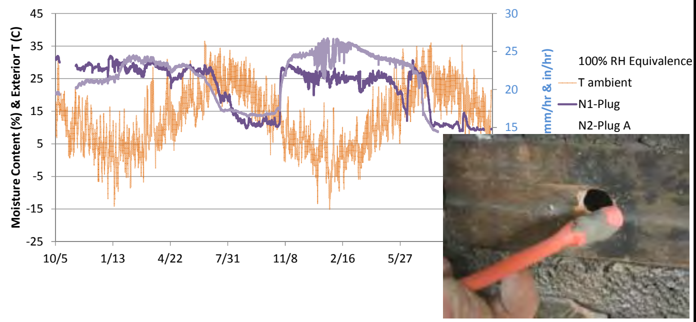
Freeze-Thaw Cycles in Wall

Table 1. Number of Freeze-Thaw Cycles (Through 23°F/-5°C) within Wall Assemblies

Location	# Occurrences	Location	# Occurrences
Ambient Air Temperature	34	N1 (Thin)-Collar Joint	8
		N2 (Thick)-Collar Joint	5
N1 (Thin)-Surface	11	N3 (Parapet)-Collar Joint	2
S1 (Thin)-Surface	12	N4 (Uninsulated)-Collar Joint	0
		S1 (Thin)-Collar Joint	0

- # of cycles through 23 F/-5 C
- Insulation associated with greater number of freeze-thaw cycles
- Surface behavior vs. one wythe inward
- Control of moisture levels is critical for durability
- Critical degree of saturation (S_{crit}) (Fagerlund)

Masonry Moisture Sensors-North Insulated



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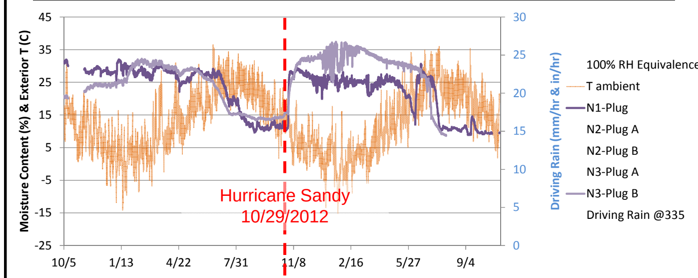
Masonry Moisture Sensors-North Insulated



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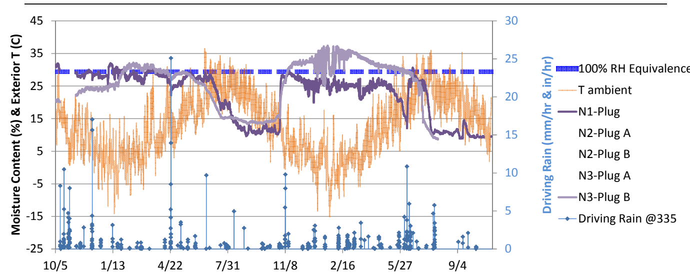
Masonry Moisture Sensors-North Insulated



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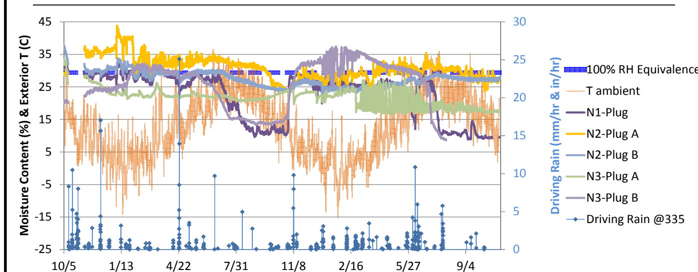
Masonry Moisture Sensors-North Insulated



- Some sensors show seasonal cycles, rain event response; others less responsive
- Placement? Exposure? Sensor installation/wall?

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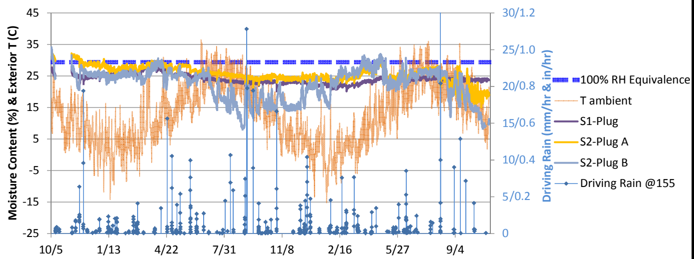
Masonry Moisture Sensors-South Insulated



- Tighter correlation with driving rain (S2-Plug B)
- Others less responsive

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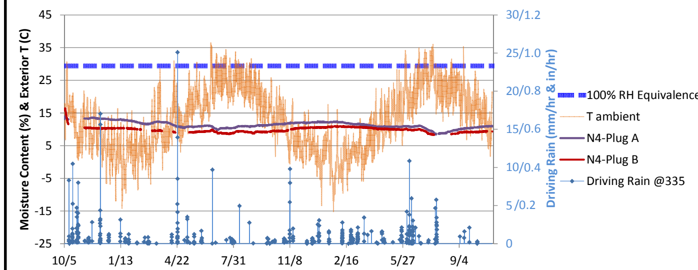
Masonry Sensors-North Uninsulated



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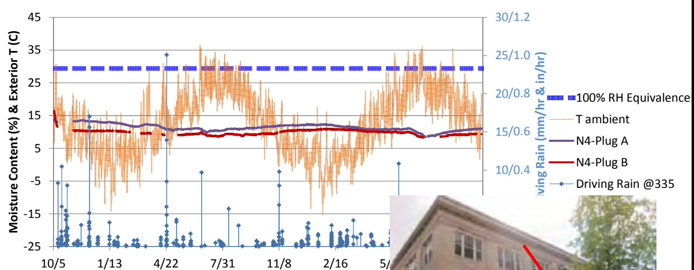
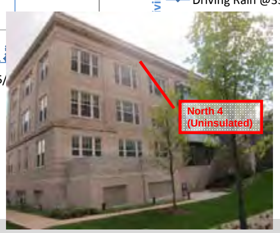
Masonry Sensors-North Uninsulated



- Sensor placement



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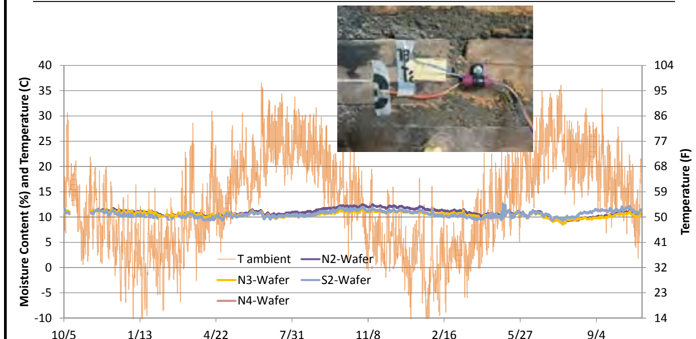
Insulation-Masonry Interface “Wafer”



- Dry conditions at interface with open cell foam
- But interior wintertime RHs ~10-20%

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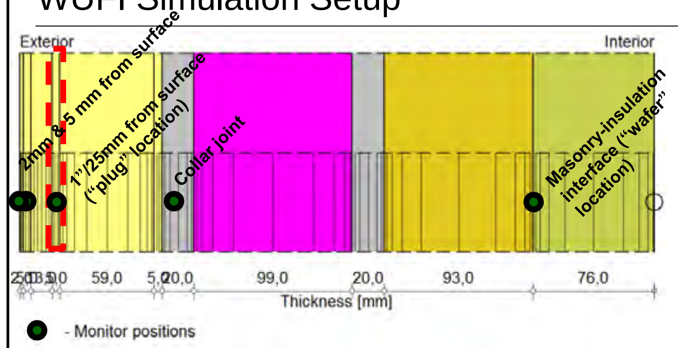
Hygrothermal Simulations

WUFI Simulation Setup



- Clay block and mortar joints modeled as solid (vs. air spaces)—small effect in sensitivity analysis

Hygrothermal Simulation Summary

- Good temperature correlation to measured (simulations biased low)
- Moisture response of simulation (outer wythe)
  - South dries faster than north
  - Uninsulated dries faster than insulated
  - Shows sharp response to individual driving rain events—not seen in monitored data
- Moisture content of outer brick layers
  - At typical rain exposures, low risk of freeze-thaw
  - Assumes outside consultants S_{crit} measurement

Instrumentation Choices

Instrumentation Choices & Issues

- Variability of moisture responses
  - Instrument time response
  - Variable rain exposure/concentration
  - Built-up masonry wall assemblies
- RH vs. Wood MC vs. Brick MC
  - RH and wood MC sensors much below range needed for S_{crit} resolution

RH (%)	Wood MC (Weight %)	Face Brick MC (Weight %)	Notes
50%	~9%	0.02%	Lower limit of resolution for wood surrogate sensors
80%	16%	0.09%	Reference water content (W_{ref} or W_{80})
90%	20%	0.19%	
95%	24%	0.38%	
100%	29%+	4.3%	Free water saturation (W_f)
100%	n/a	5-7%	Critical degree of saturation (S_{crit}) for face brick samples

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Instrumentation-Spatial Resolution

- Freeze-thaw damage occurs in a thin layer—instrumentation is larger than this dimension
- Options: gravimetric samples? Impedance meters? Nuclear magnetic resonance (NMR)?

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Thermal Bridging

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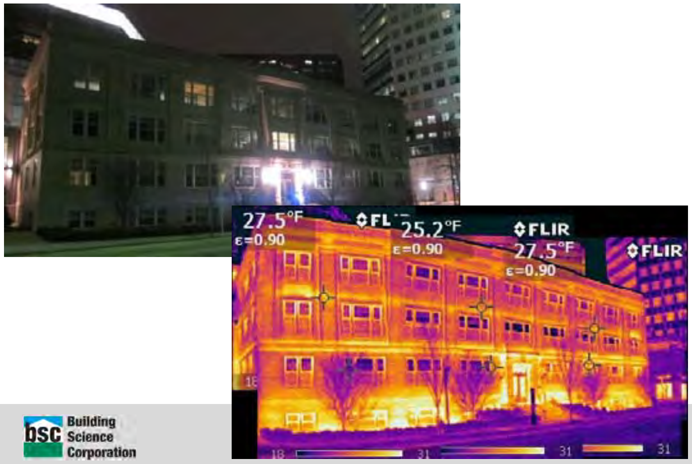
Thermal Bridging at Slab Floors



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Thermal Bridging at Slab Floors

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Thermal Bridging at Slab Floors

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Thermal Bridging at Slab Floors

- Typical Insulation Levels
  - R-10.6 for 10 foot wall (RSI 1.9)
  - R-3 for 1 foot floor slab (RSI 0.5)
  - R-8.6 overall opaque R value (RSI 1.5)
  - 19% loss from nominal value
- Higher Insulation Levels
  - R-25 for 10 foot wall (RSI 4.4)
  - R-3 for 1 foot floor slab (RSI 0.5)
  - R-15 overall opaque R value (RSI 2.6)
  - 40% loss from nominal value

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Conclusions

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Conclusions

- Insulated wall experiences cold temperatures (and more freeze-thaw cycles)
- Insulated wall shows higher moisture contents
  - Less effect of insulation/more effect of rain exposure
- Moisture levels in wall
  - Some remained close to constant
  - Others responded to driving rain, drying in summer
- Hygrothermal simulations
  - Good temperature correlation
  - Moisture response low correlation—sensor response, driving rain exposure, masonry wall non-uniformity

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Conclusions

- Hygrothermal simulations: low risk of freeze-thaw damage
  - Assumes S_{crit} value found in testing (by others)
- Choosing instruments for masonry wall monitoring
  - Direct measurement of critical moisture levels?
  - Current instruments—general patterns?
  - Direct measurement of driving rain on walls

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Questions?

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Christopher Schumacher (data acquisition system)

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