Critical Freeze-Thaw Saturation Measurement of In-Service Masonry

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R. Van Straaten, P.Eng., RDH Building Science Inc.

T. Trainor, M.A.Sc., RDH Building Science Laboratories

C. J. Schumacher, M.A.Sc., RDH Building Science Laboratories

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Greetings from the co-authors

Randy Van Straaten

at home, finishing his PhD

Trevor Trainor

arrives in Clearwater tomorrow

Outline

- → Quick Review
  - → Critical Freeze-Thaw Saturation
  - → The Overall Process
- → Addressing Some Issues
  - → Material Sampling Methods
  - → Measurement Repeatability and Reproducibility
- → Growing Confidence in the Approach

A Quick Review

Freeze-Thaw Risk-Assessment
using Critical Saturation

The Critical Saturation Approach (to Freeze-Thaw)

→ Fagerlund (Lund University, 1970s)

→ *No such thing* as a freeze-thaw resistant material!

→ There is a *critical degree of saturation* , S_{crit}

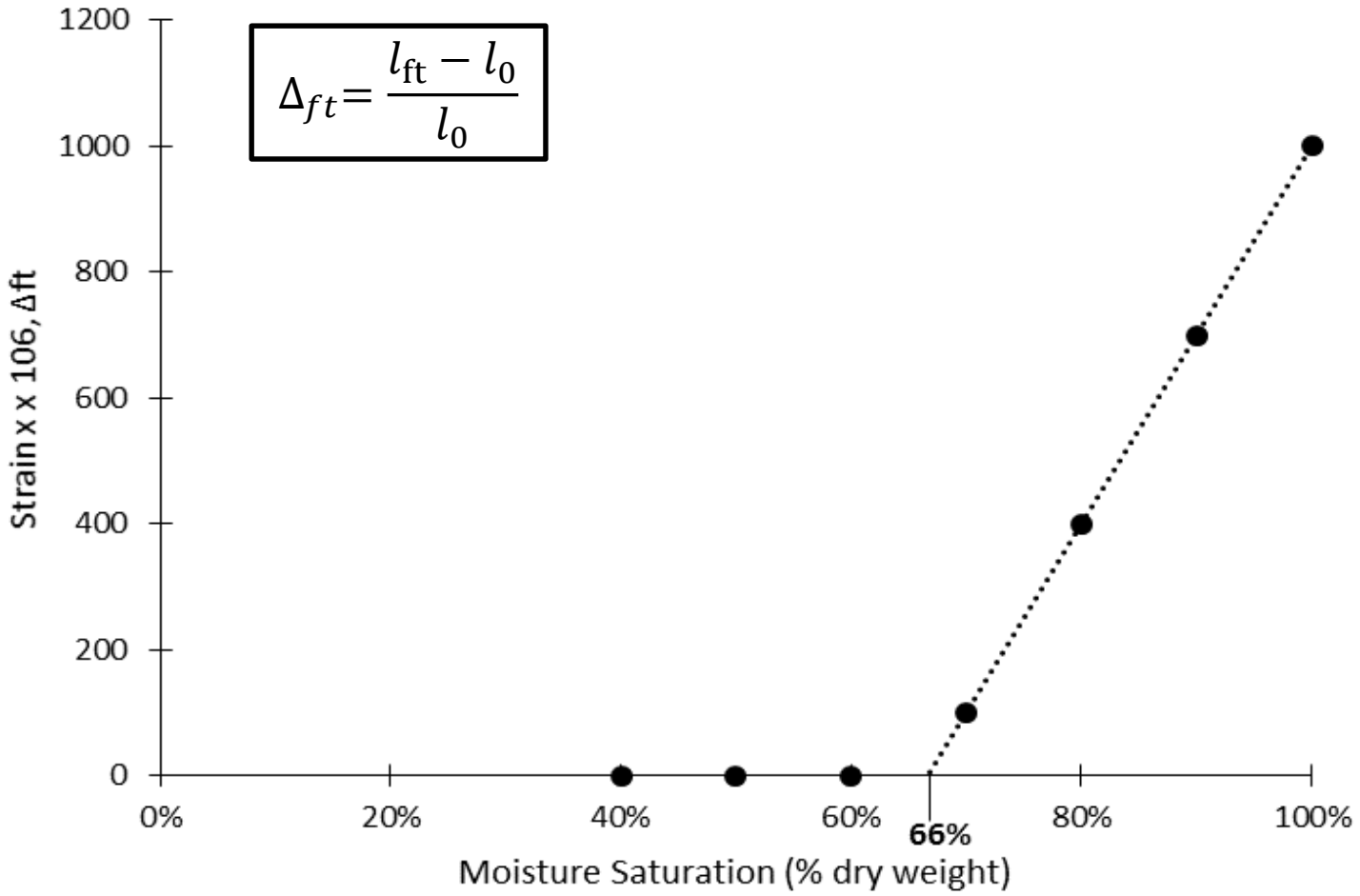
→ Below S_{crit} no freeze-thaw damage will occur regardless of number of freeze-thaw cycles

→ Above S_{crit} damage is measurable after only a few cycles

The Critical Saturation Approach (to Freeze-Thaw)

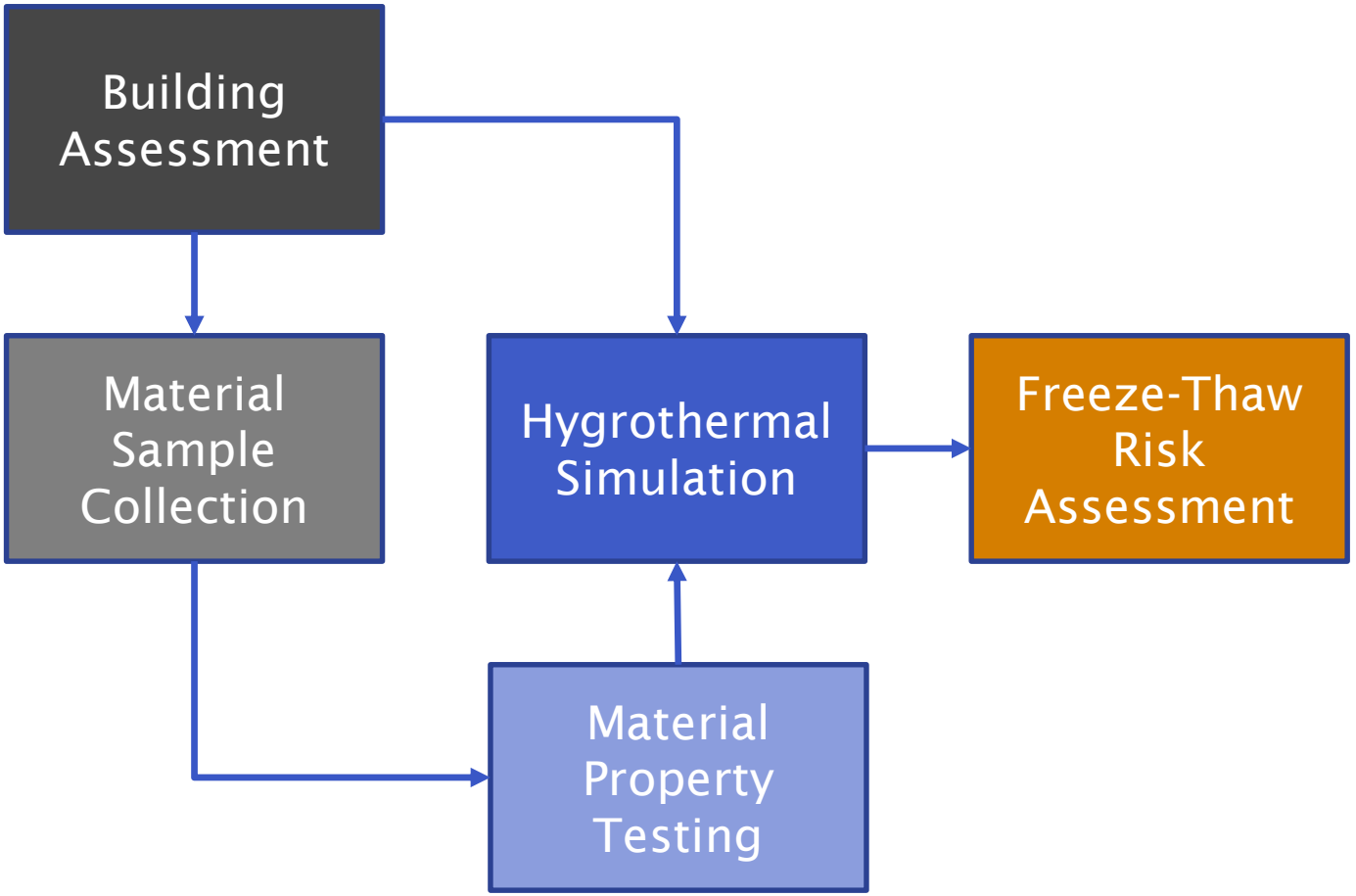
→ Fagerlund (1977) porous, brittle materials below a certain moisture content level can be freeze-thaw cycled repeatedly without any measureable damage

$$\Delta_{ft} = \frac{l_{\text{ft}} - l_0}{l_0}$$



The Overall Process

→ Using the Critical Saturation approach to assess the Freeze-Thaw Risk associated with a real building



Building Assessment (the Four Cs)

→ Construction

→ Condition

→ Concentrations

→ Connections

Material Sample Collection

→ Represent range of important masonry materials on site

- → Number of different types of units?
  - › Face brick, infill brick, backup brick, block, tile
  - › Stones in the field, at trim, accents (e.g. quoins)
- → Number of samples of each type?

Material Property Testing

Hygrothermal Simulations

→ Density

→ Liquid Water Uptake

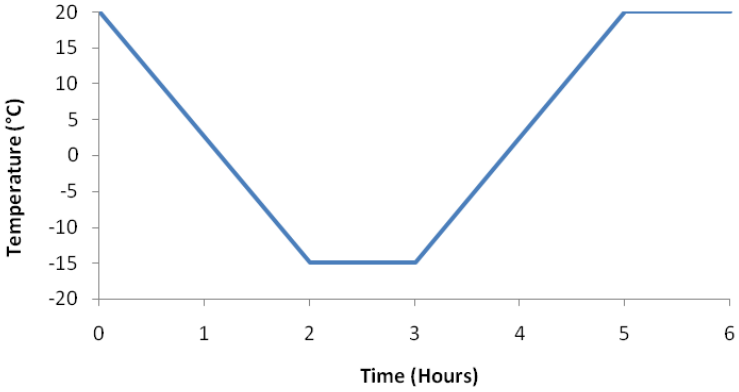
→ Moisture Storage Fn

→ Reference MC

→ Free Water Saturation

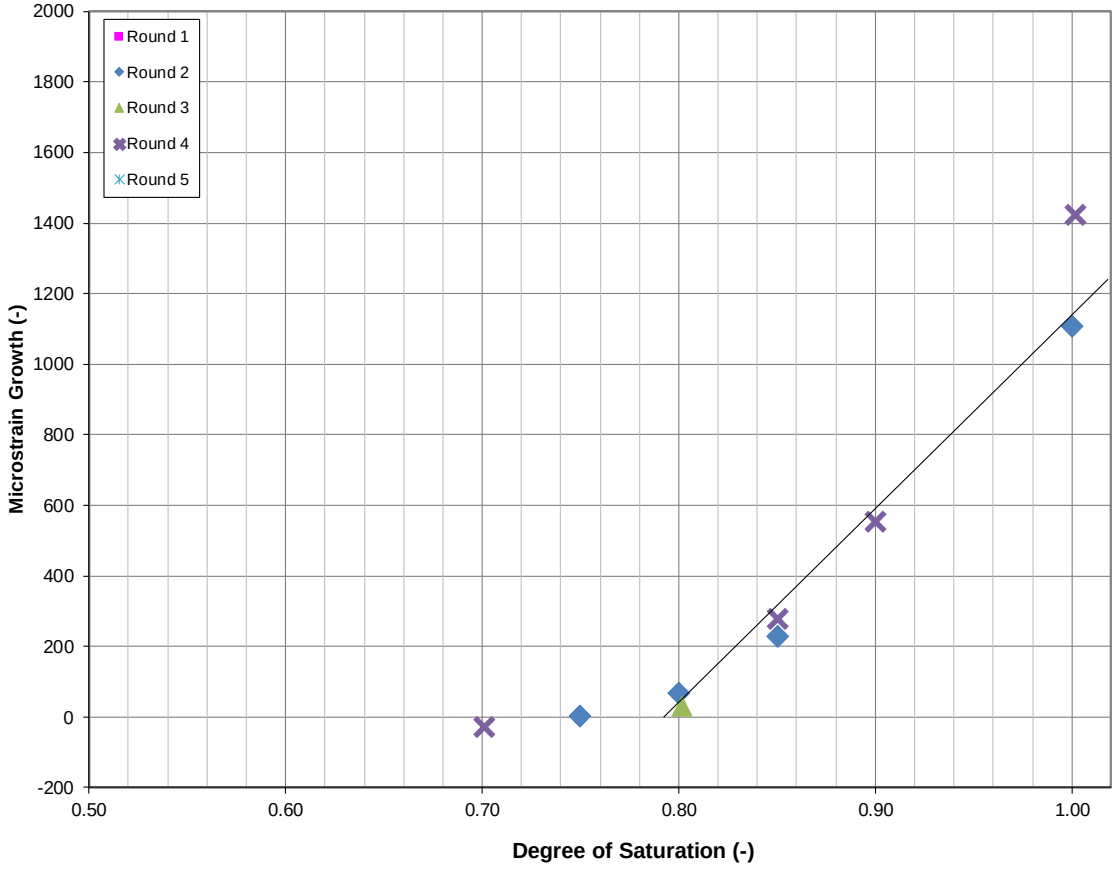
→ Vacuum Saturation

→ Vapor Permeability



Freeze-Thaw Risk Assessment

→ Critical Degree of Saturation



Hygrothermal Simulations

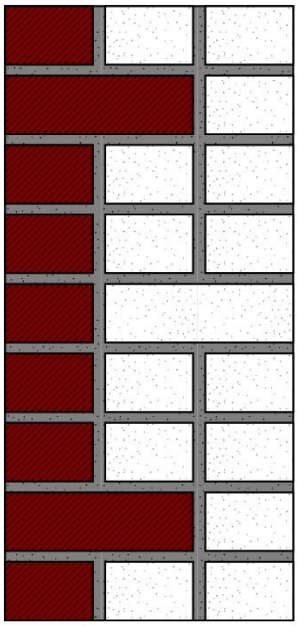
→ Using multi-year weather data from the building locale

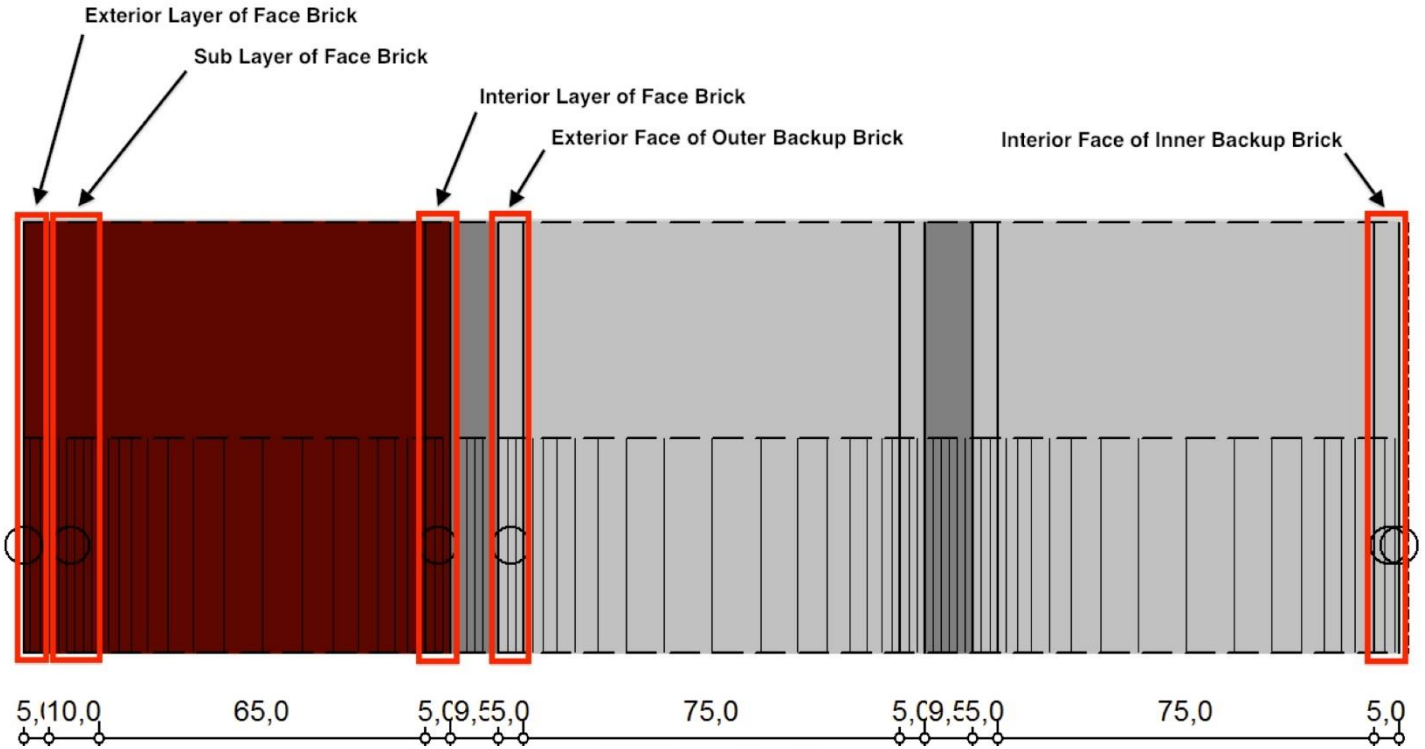
→ Model each different construction and exposure

→ Introduce moisture leaks to reflect connections

→ Parametric evaluation of moisture loading

→ Calibrate to existing then consider retrofit





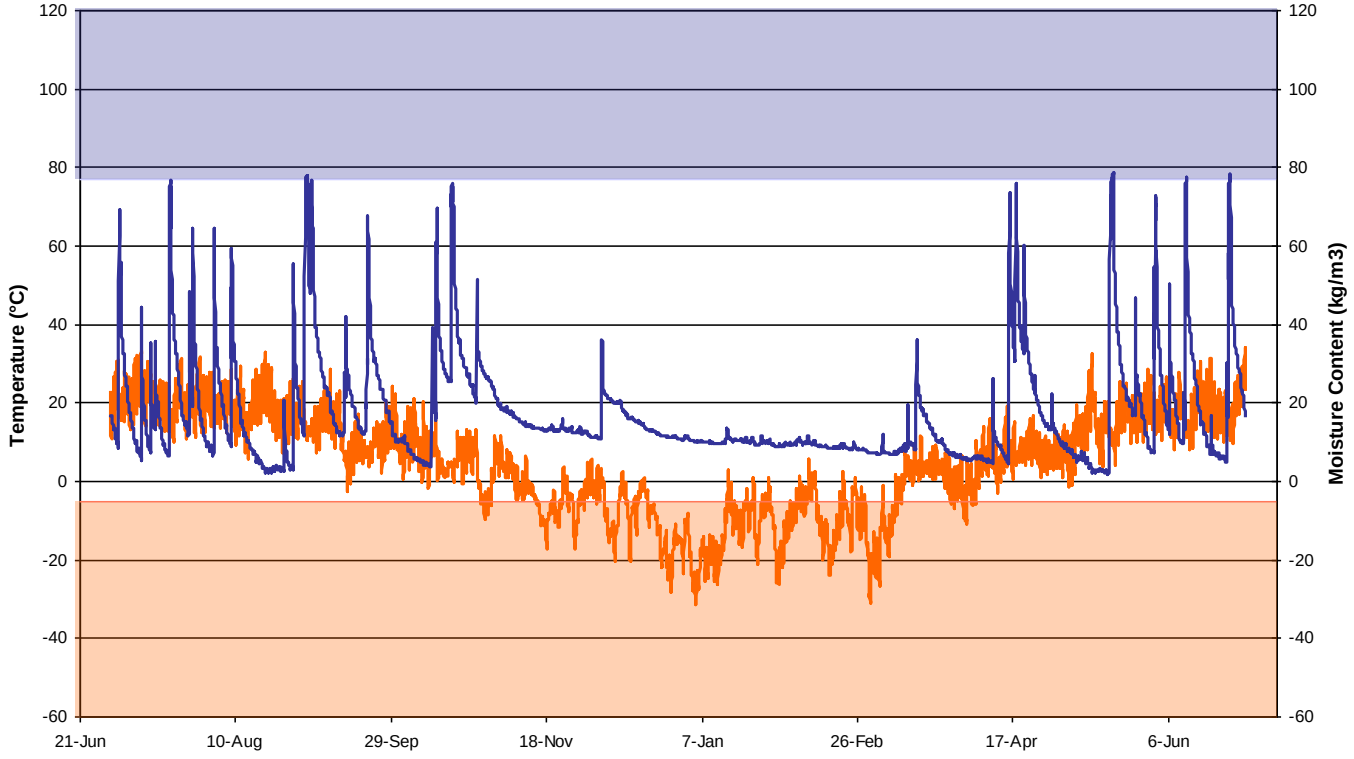
Freeze-Thaw risk assessment

→ Freeze-Thaw Cycle

→ Material temperature cycles below -5˚C (23˚F) and back up above freezing

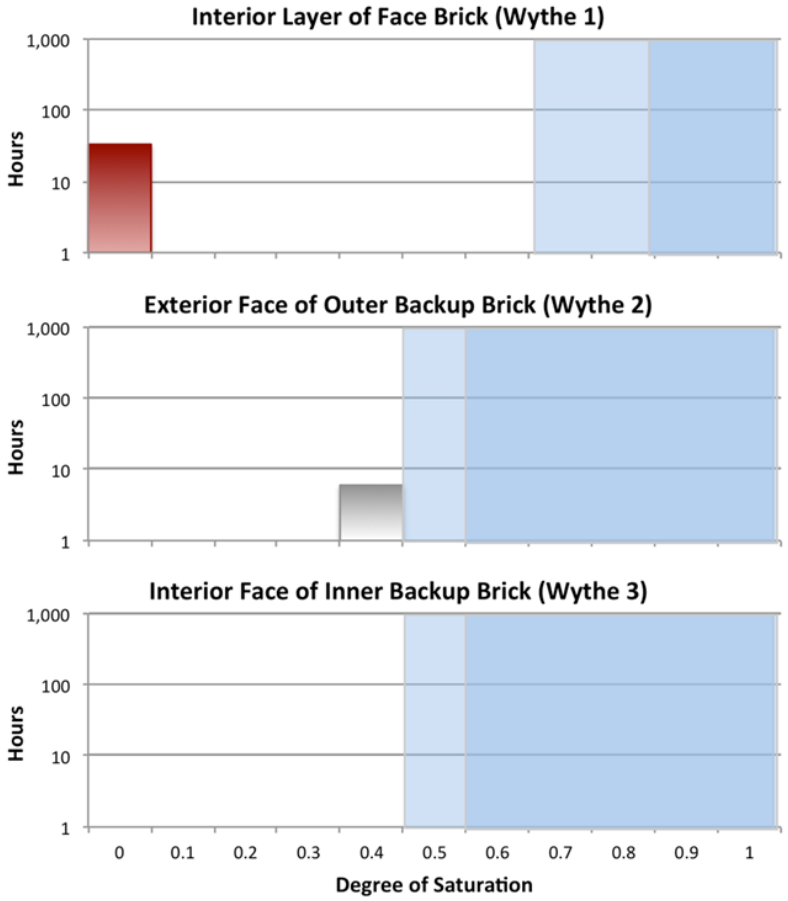
→ Damaging Freeze-Thaw Cycle

→ Freeze-thaw cycle occurs while material moisture content is above the critical degree of saturation

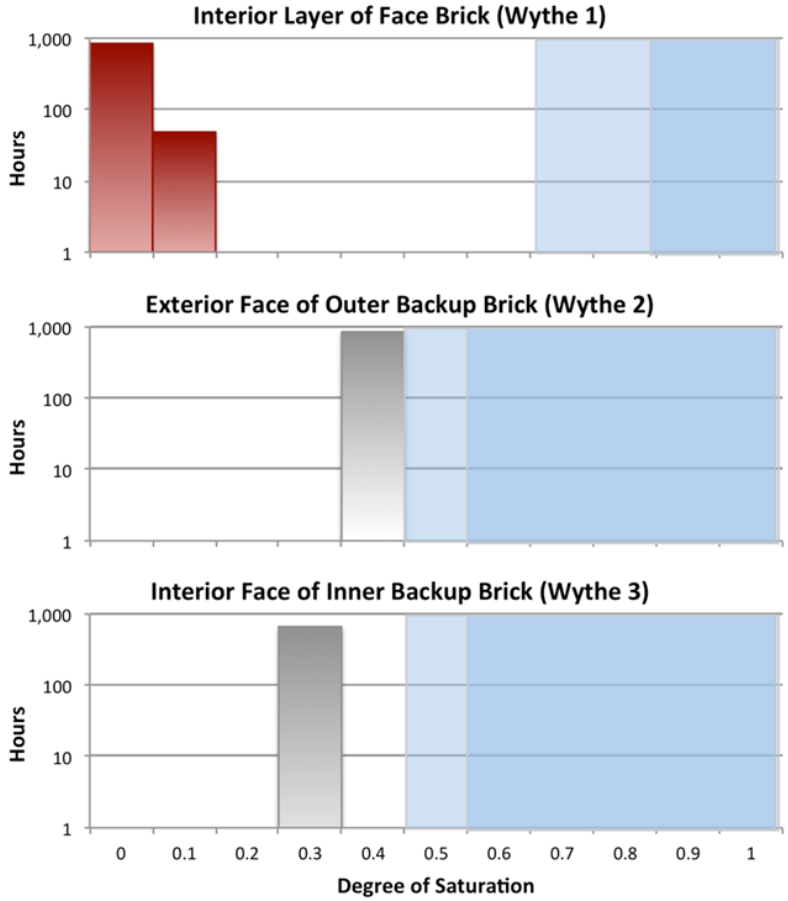


Freeze-Thaw risk assessment

Consider degree of saturation (moisture content) during hours when temperature is below -5˚C (23˚F)



Existing wall w/ high rain exposure



Retrofit wall w/ high rain exposure

Addressing Some Issues

Material Sampling

Sampling Challenges

- → coordinate sampling locations
  - → New mechanical openings
  - → New wheelchair access
  - → New elevators / stairs
  - → Areas on “blind sides”
  - → From attic stock
  - → Units that can be replaced by attic stock
- → Don’t only sample damaged units that will be replaced
- → Does the sampling consider enough areas to be truly representative ?

Sampling Challenges

Course removal of a large area of wall is easy for a contractor but destructive and, in most cases not acceptable to owners

Careful removal of individual units is possible and preferred

Field Sampling of Masonry Units

Bulk Sampling

→ Retrieve a large number of samples (10-100/type)

→ More samples improves population representation

→ Pre-screen whole units back at the lab (A-value tests)

  → liquid transport coeffs

  → surrogate for other moisture transport and storage properties

→ Time consuming and expensive

Non-Destructive Field Testing

→ Pre-screen units in-situ on the wall assembly

→ Reduces number of samples collected (4-12/type)

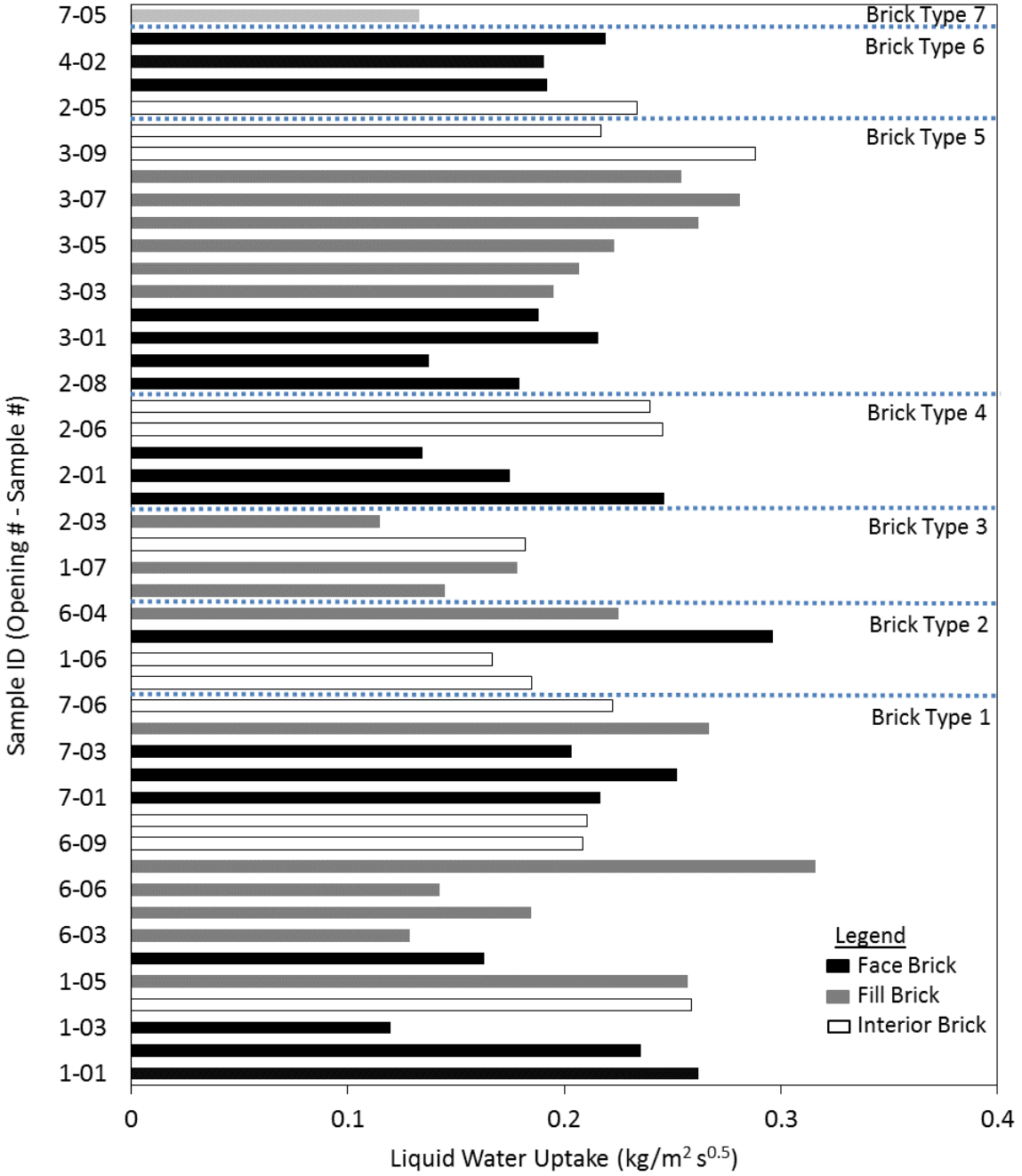
→ Pre-screen by assessing rate of drying or "drying slope" as an in-situ surrogate

→ Requires experience to interpret results

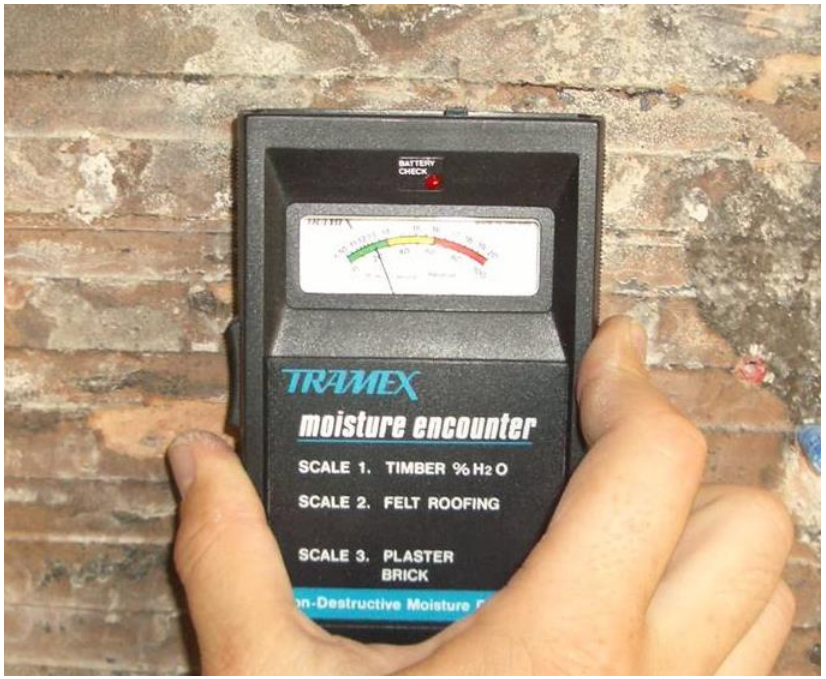
Bulk Sampling Example

→ 1 bldg., 47 bricks
(ID: location-number)

→ 7 types
(by type of clay,
frogs, stamps, etc.)



Non-Destructive Field Testing Procedure



→ Identify candidate locations and bricks

→ Measure starting MC

→ Spray 15 ml of water

→ Measure “redistribution” MC at 2 minutes

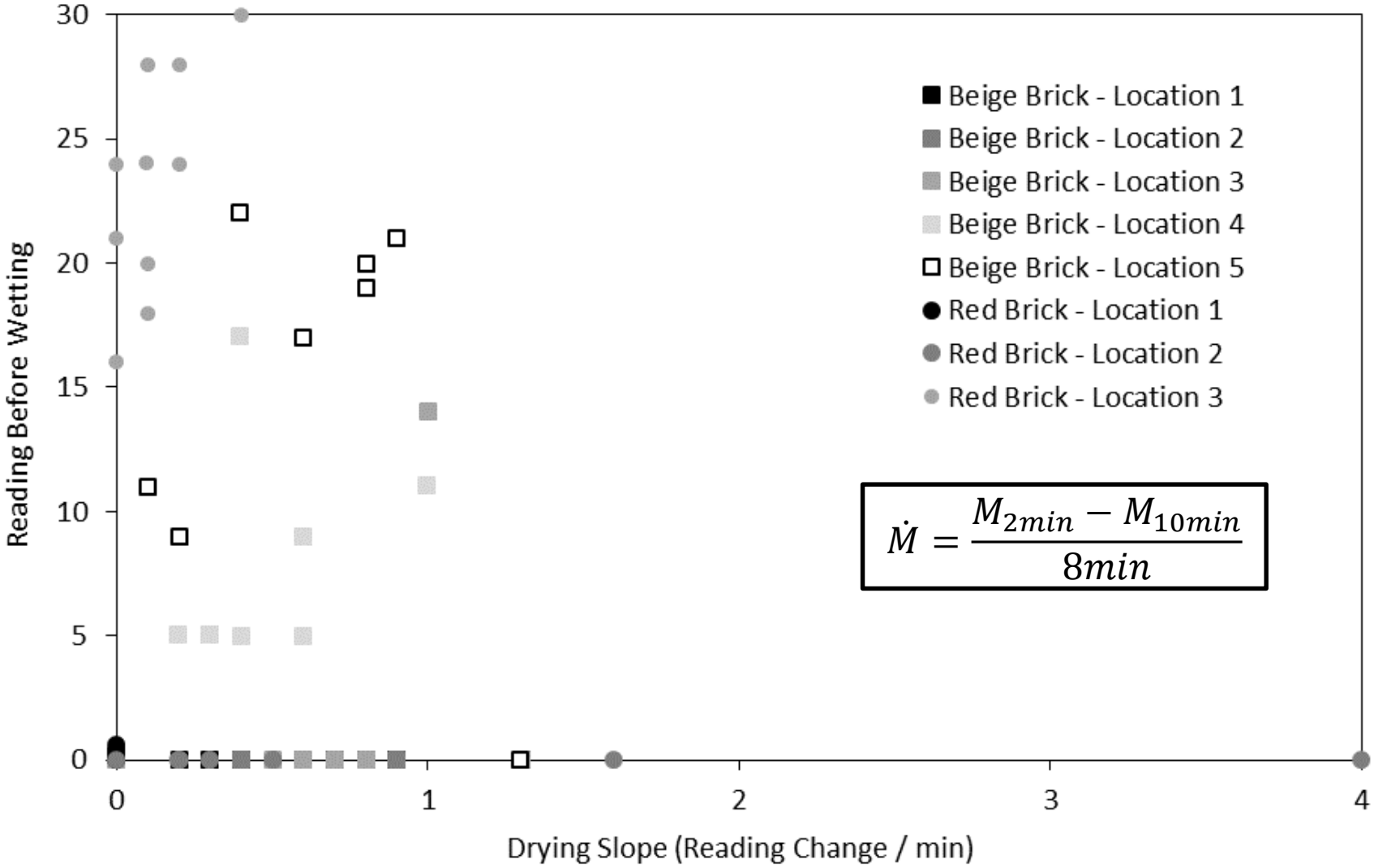
→ Measure “drying” MC at 8 minutes

→ Calculate drying slope and group candidate bricks

→ Identify final sample units

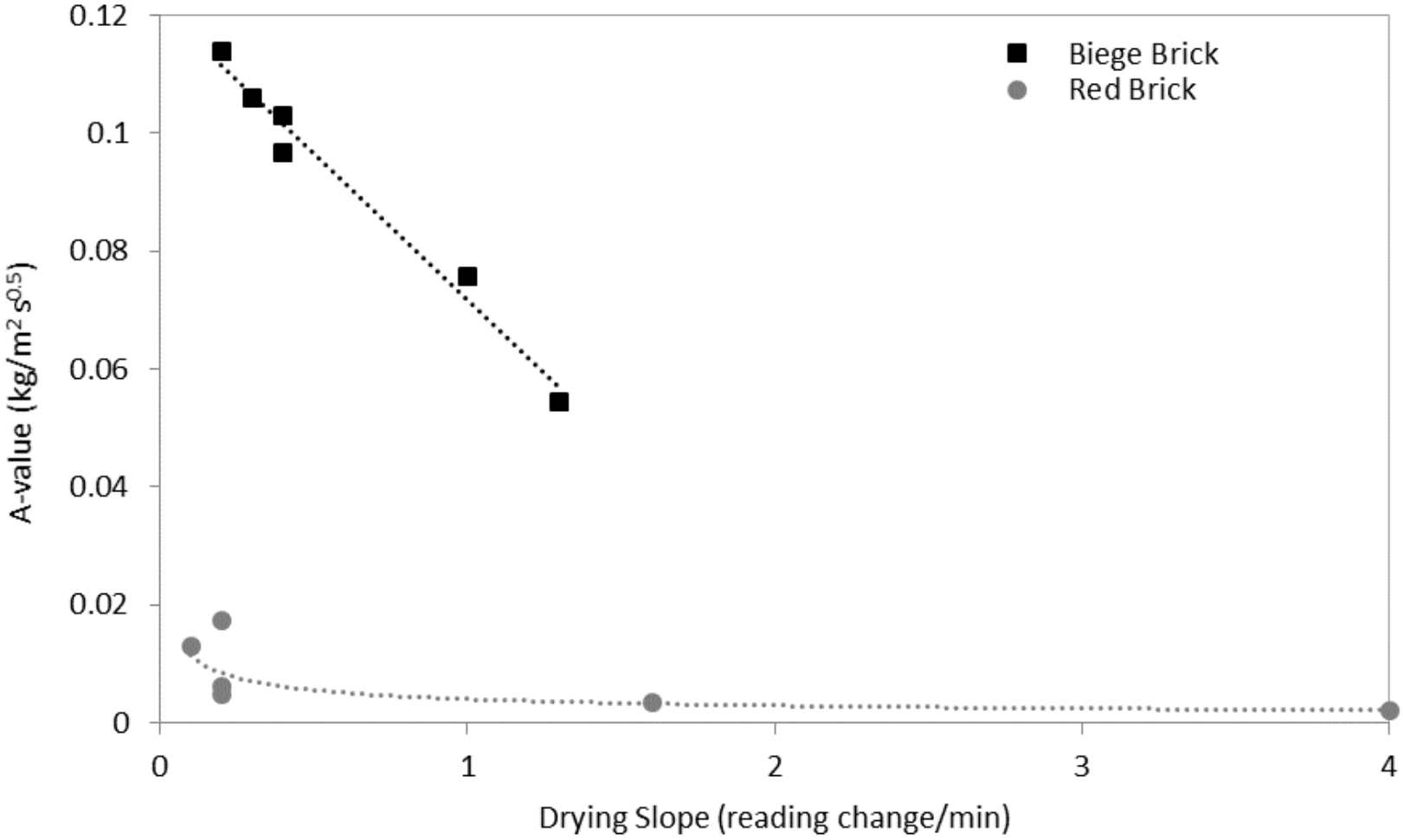
Non-Destructive Field Testing Example

1 owner, 2 bldgs., 2 types of brick, limited sampling
Initial moisture meter reading and drying slope measurements



Non-Destructive Field Testing

Comparison of water uptake and drying slope for selected bricks



Addressing Some Issues

Measurement Repeatability
and Reproducibility

Measurement Challenges

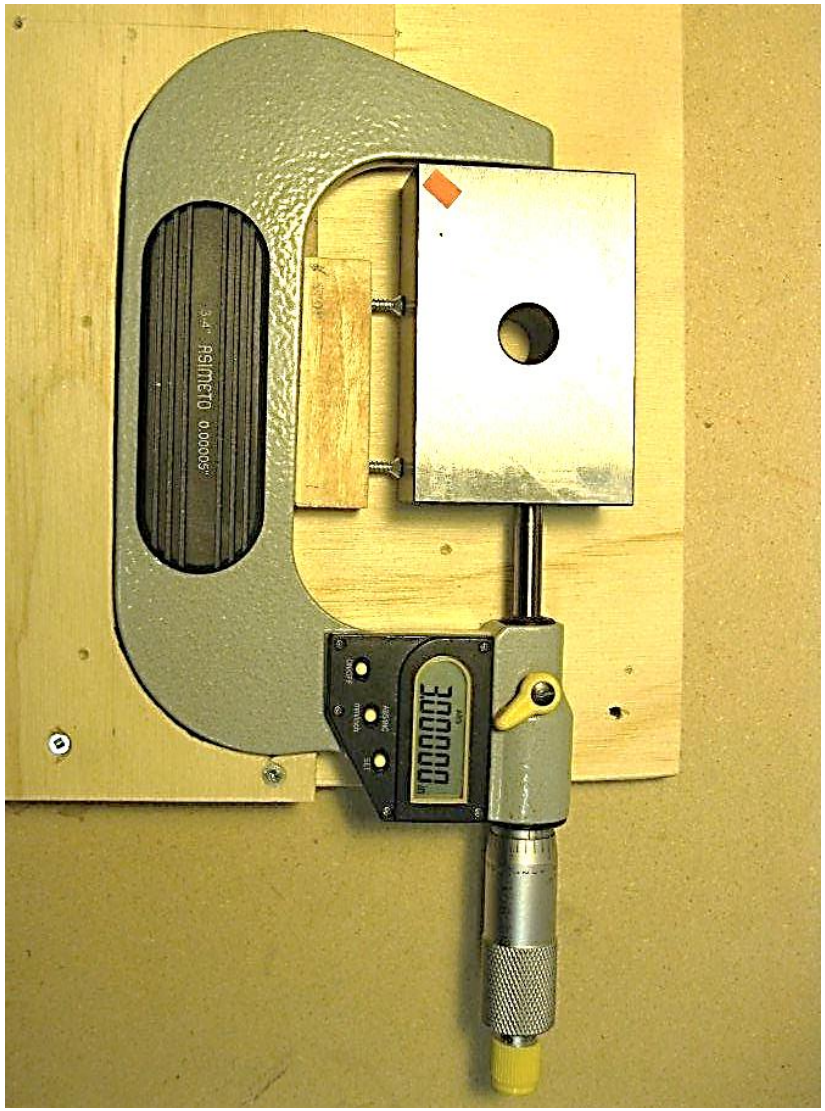
→ Length measurement figures highly in the determination of the critical saturation

→ Multiple measurements on a given sample are averaged to reduce uncertainty

Concerns:

→ Repeatability of measurement on a single sample

→ Reproducibility from one lab tech / engineer to another (Length & Critical Saturation)

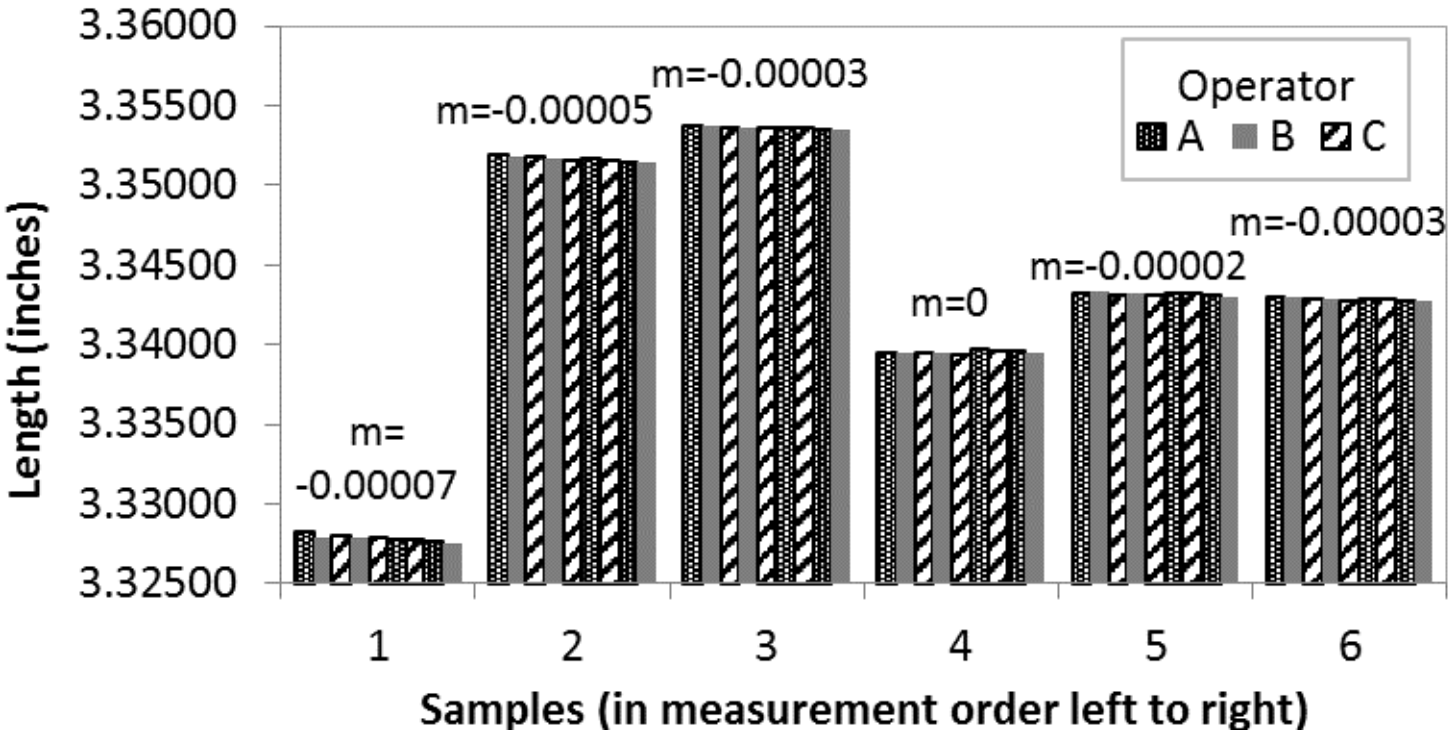


Sample Slice Length Measurements Repeatability

Repeated length measurements of six limestone slices

→ 1 initial measurement then 8 more following immediately

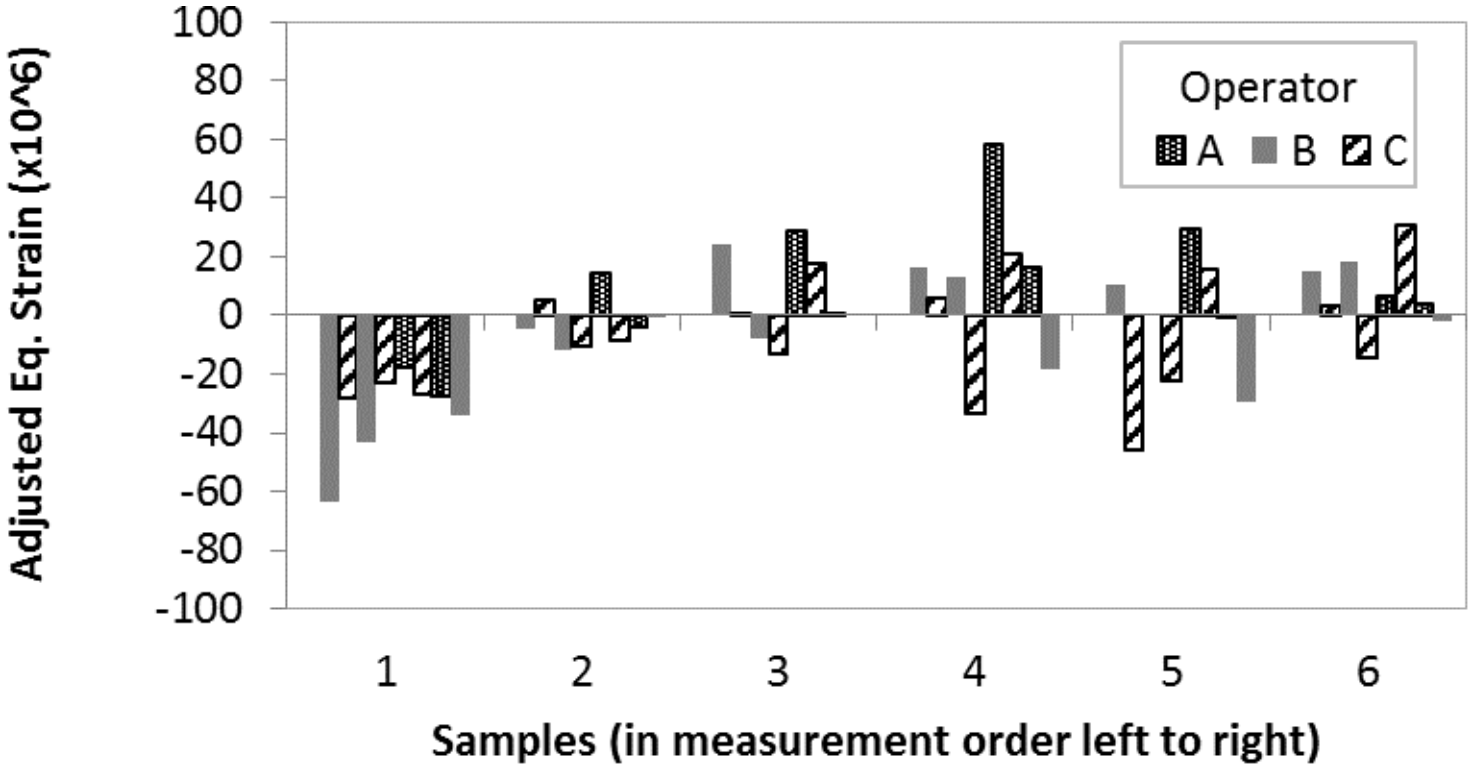
→ 3 operators taking care to use the same procedure (placement, number of clicks on the micrometer ratchet, etc.)



Sample Slice Length Measurements Repeatability

Accounting for rate of wear:
adjusted equivalent strain relative to first Operator A measurement

$$\Delta'_{eq} = \frac{l_n - m(n-1) - l_1}{l_1}$$



Length Measurement Procedure

For Initial Length (before F/T):

→ Make repeat measurements until consistent within +/- 0.00005 in.

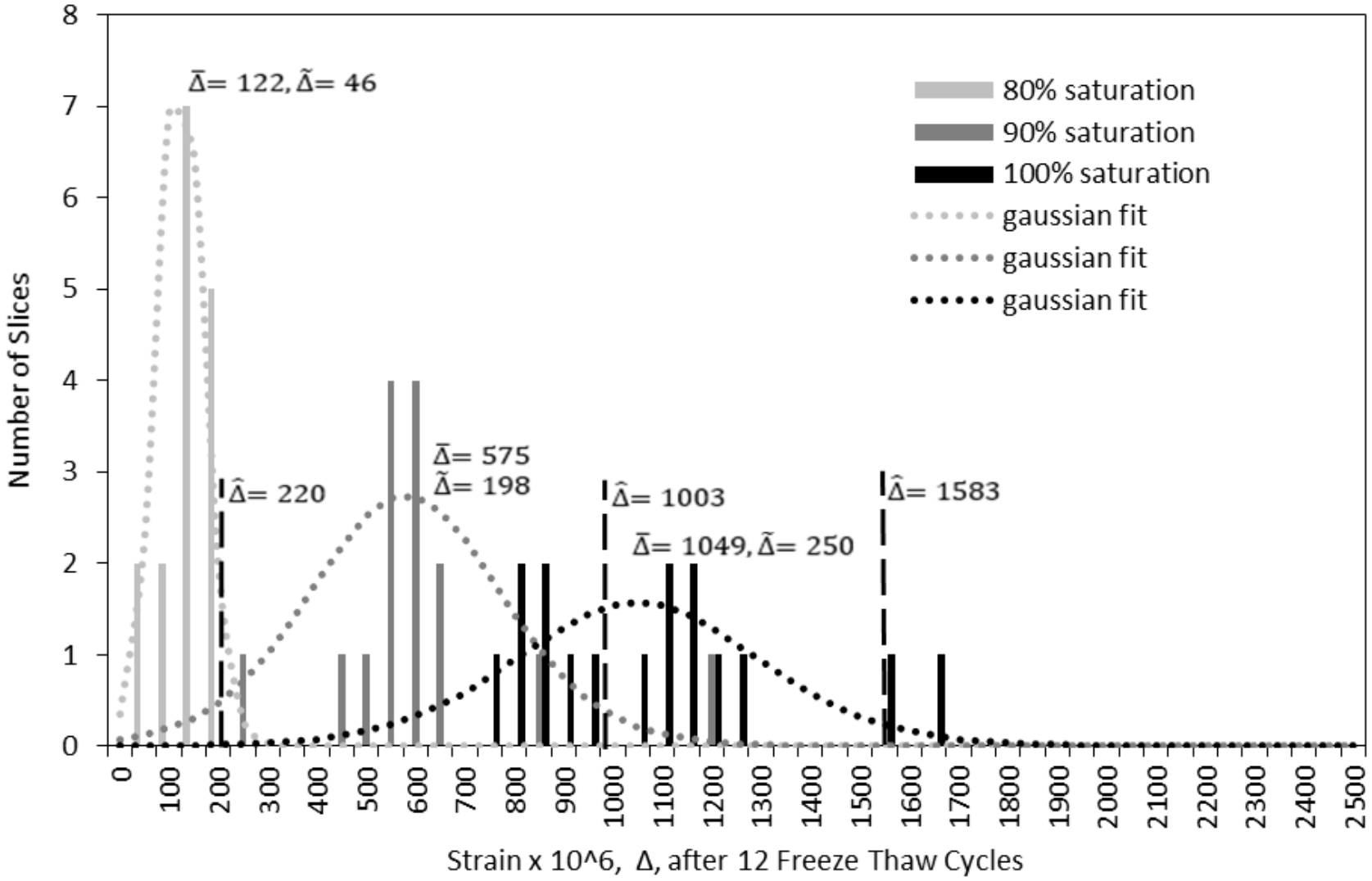
→ Intent is to displace loose material at the surface

For Final Length (after F/T):

→ Make a single measurement being careful seat the micrometer slowly

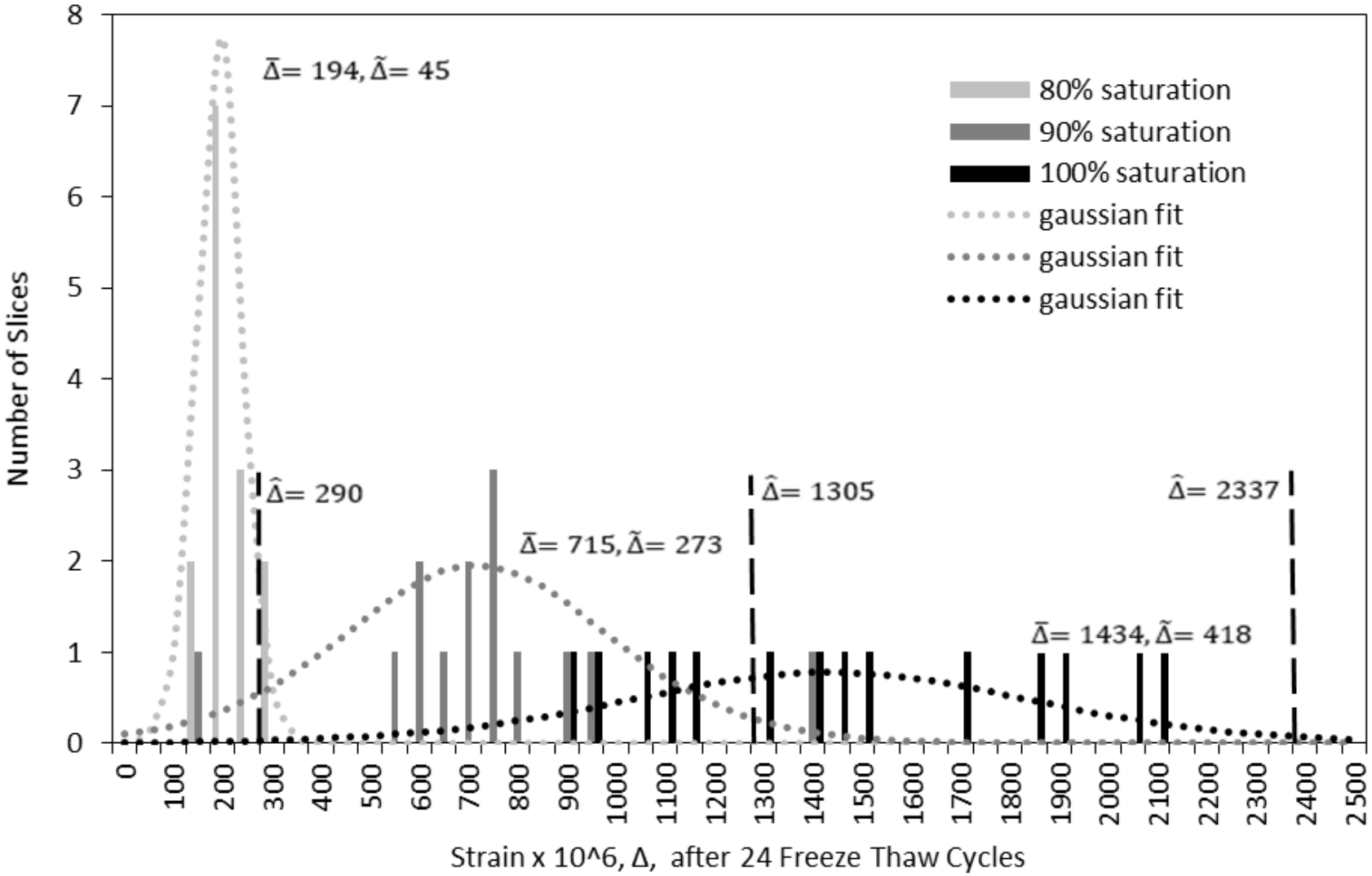
Within-Lab Critical Saturation Measurement Reproducibility

Histogram of slice dilation after 12 cycles (total of 48 slices)



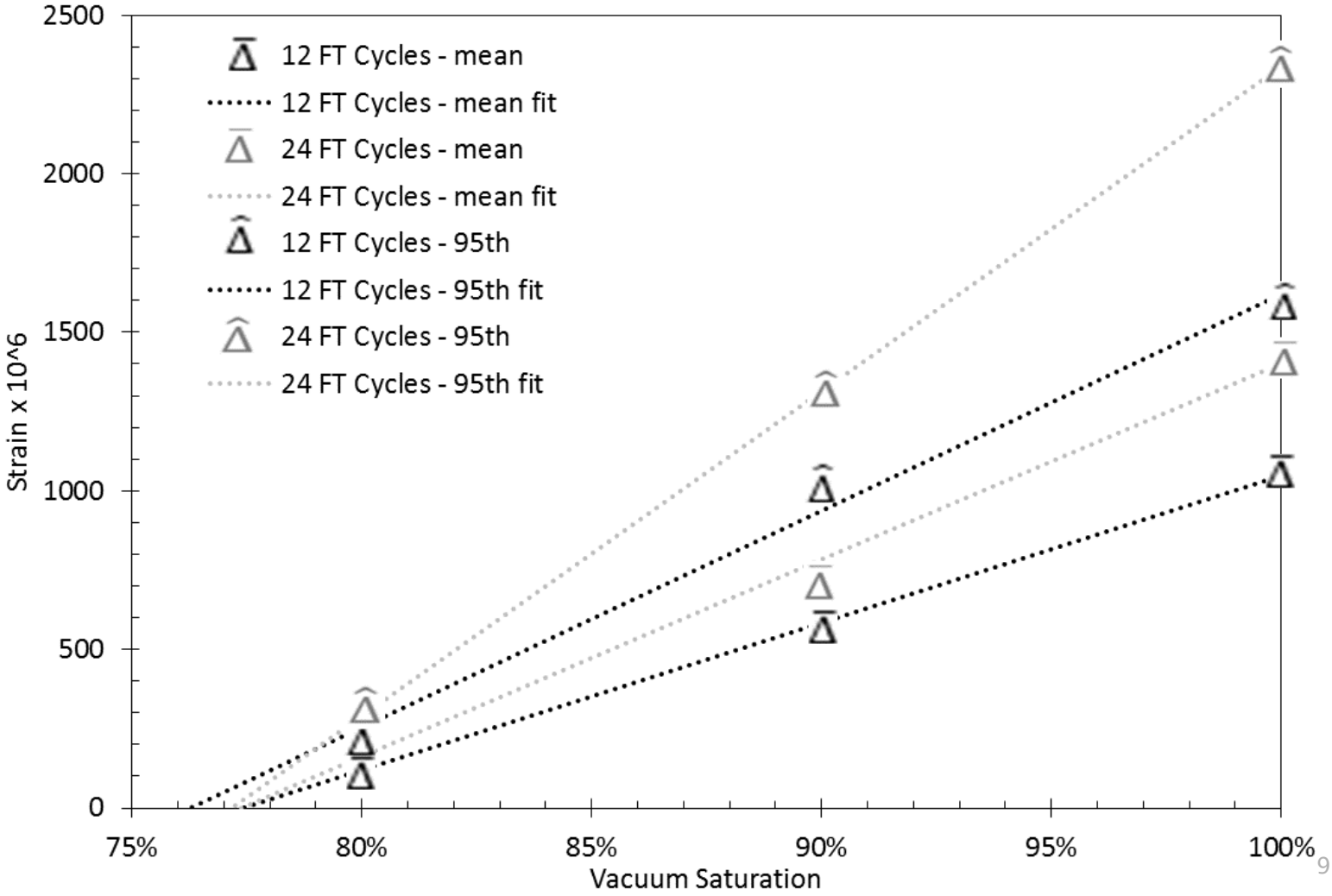
Within-Lab Critical Saturation Measurement Reproducibility

Histogram of slice dilation after 24 cycles



Within-Lab Critical Saturation Measurement Reproducibility

Mean and 95th percentile strain after 12 and 24 freeze-thaw cycles



Within-Lab Critical Saturation Measurement Reproducibility

Table 1. Critical Freeze-thaw Saturation Measurements

	12 Freeze-thaw Cycles			24 Free Thaw Cycles		
Operator	# of Saturation Samples	Mean	95th Percentile	# of Saturation Samples	Mean	95th Percentile
All Data	16	77.4%	76.3%	14	77.4%	77.2%
A	4	76.5%	74.8%	2	77.0%	76.3%
B	12	77.4%	76.5%	12	77.6%	77.3%

→ Repeatability and reproducibility tests show

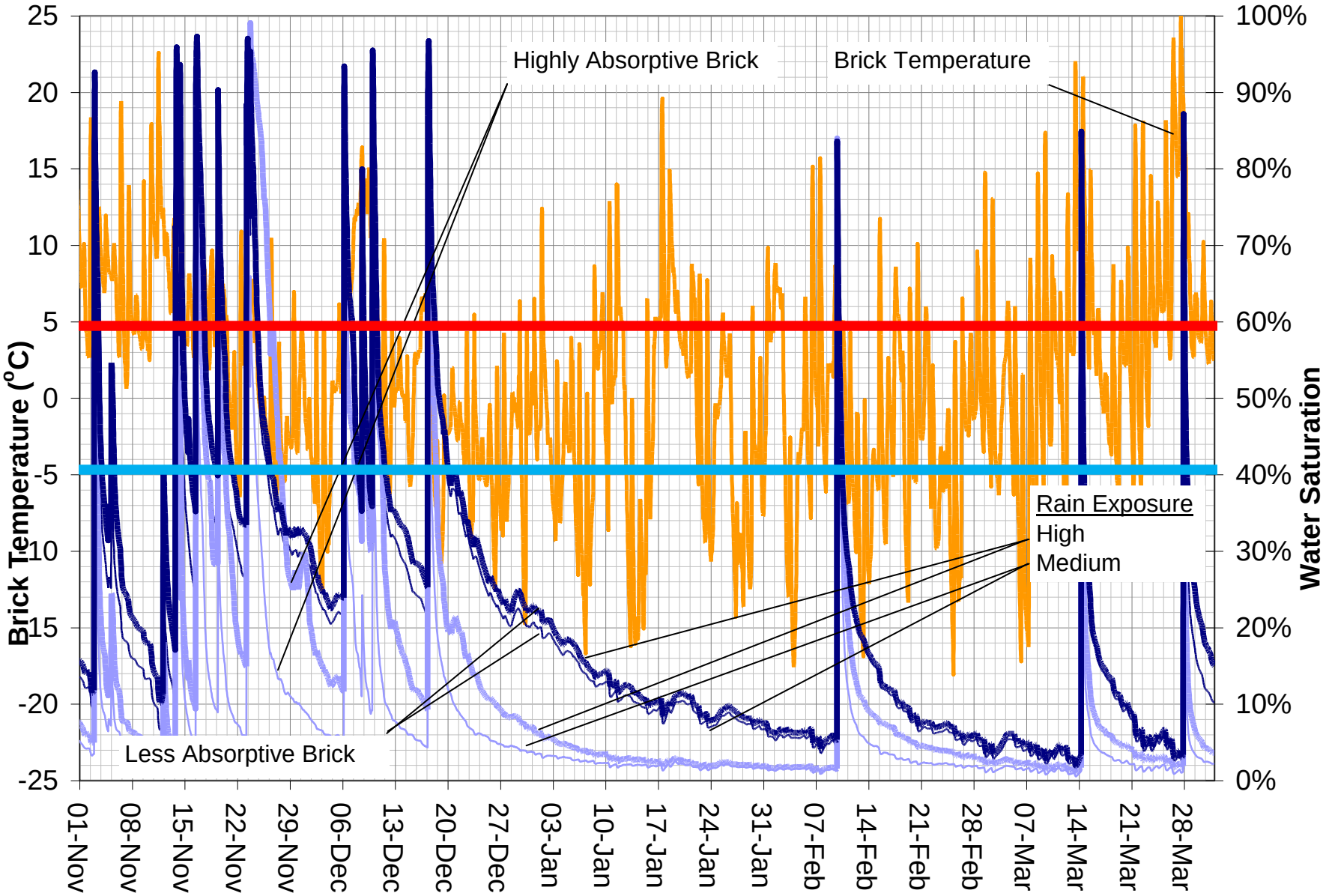
- → Measurement method allows good repeatability from one length measurement to the next
- → Measurement and analysis methdos excellent reproducibility of length measurement and Critical Saturation from one operator to the next

Growing Confidence

In the Critical Saturation Approach
to assessing Freeze-Thaw Risk

Armoury to Recreation Center Conversion, VT

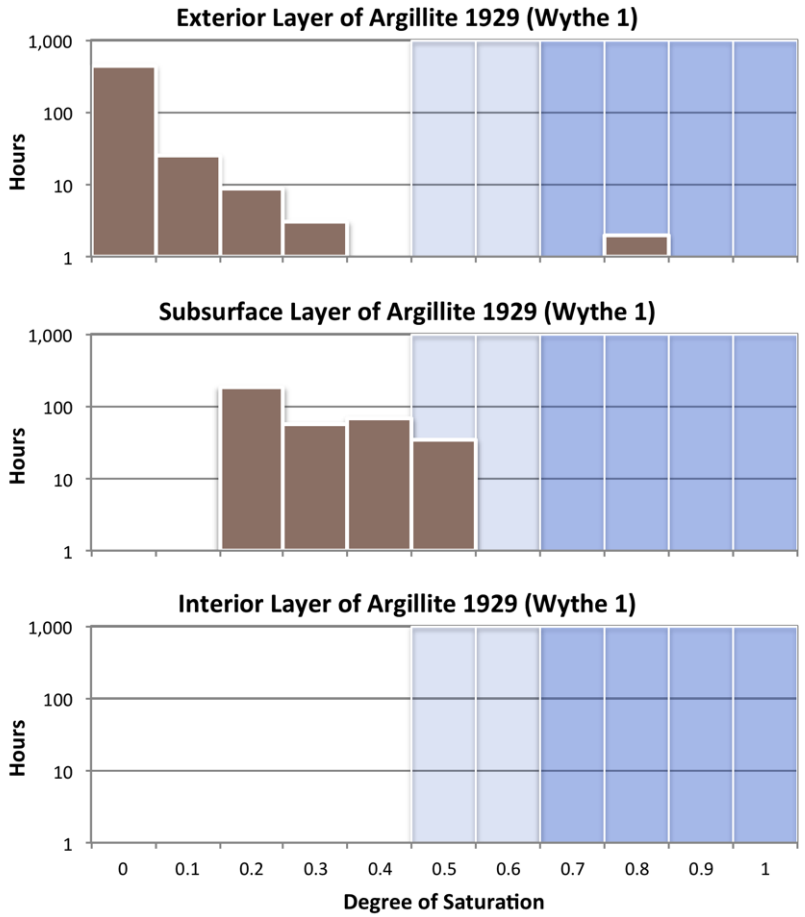
Armoury to Recreation Center Conversion, VT



Armoury to Recreation Center Conversion, VT

Chemistry Lab to Business School Conversion, NJ

Chemistry Lab to Business School Conversion, NJ



Predicted moisture distribution during freezing temperatures, Existing Wall Assembly, Argillite Stone, High Rain Exposure, Southwest-facing

Historic Armoury Building, NS, Canada

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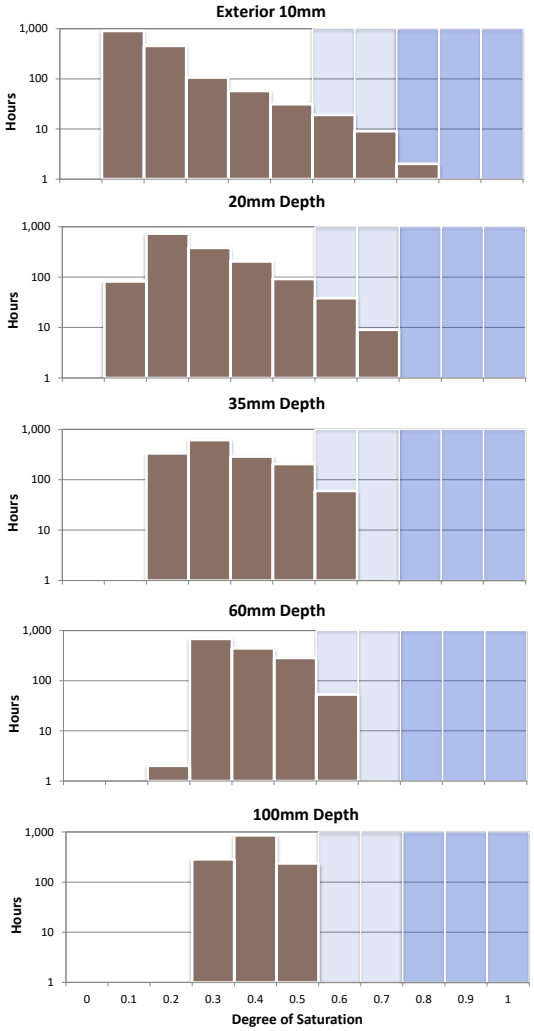
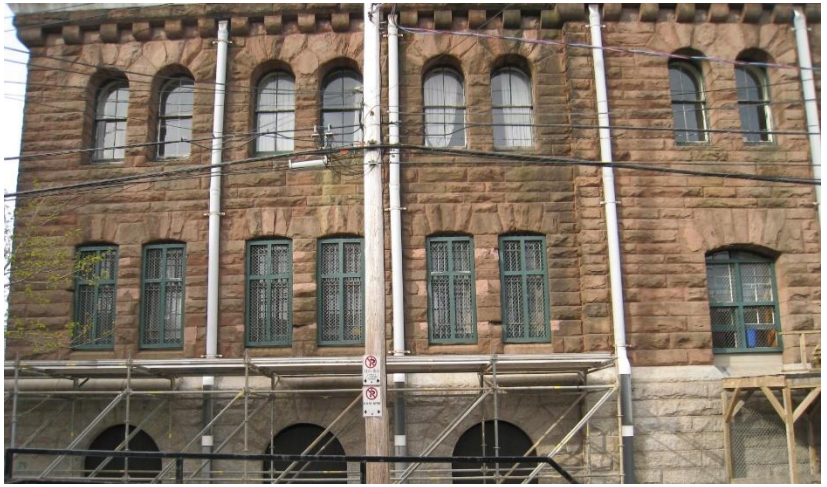
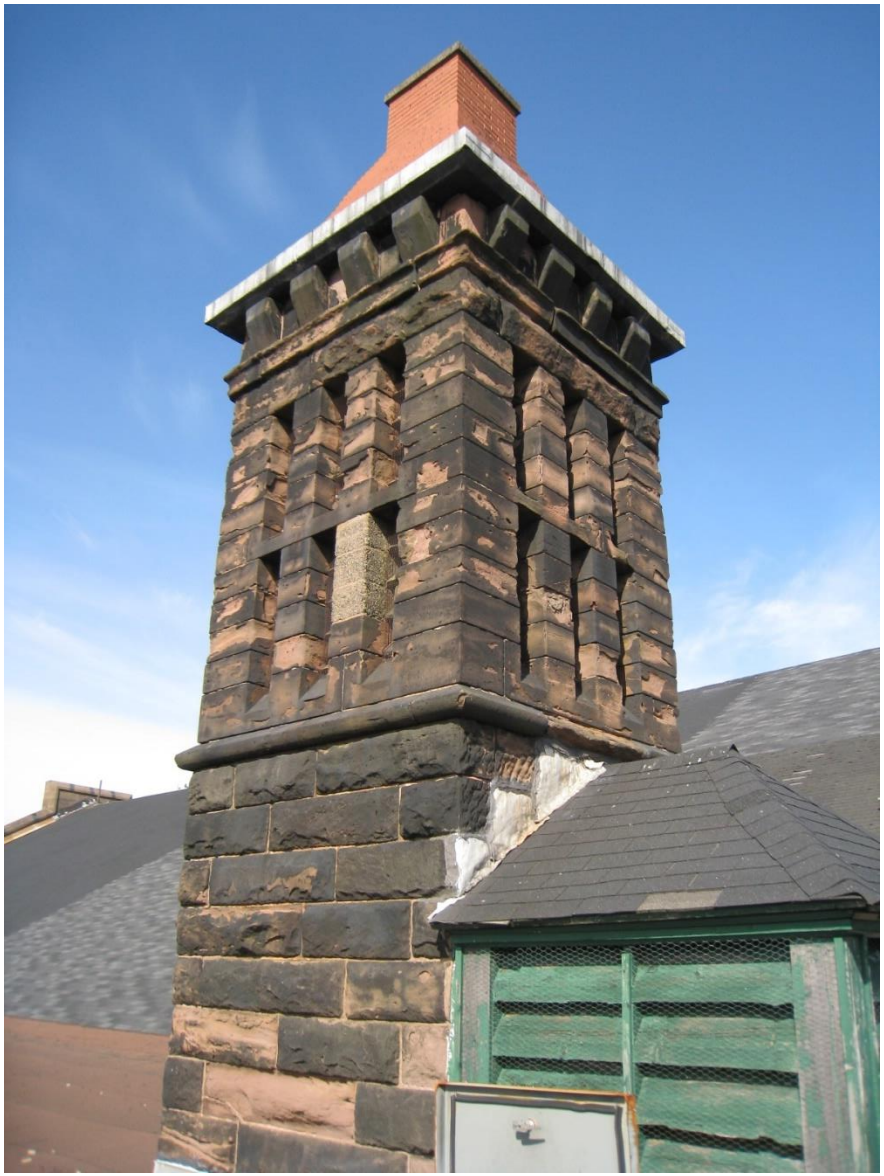


Predicted moisture distribution during freezing temperatures, Existing Wall Assembly, Sandstone, High Rain Exposure, North-facing



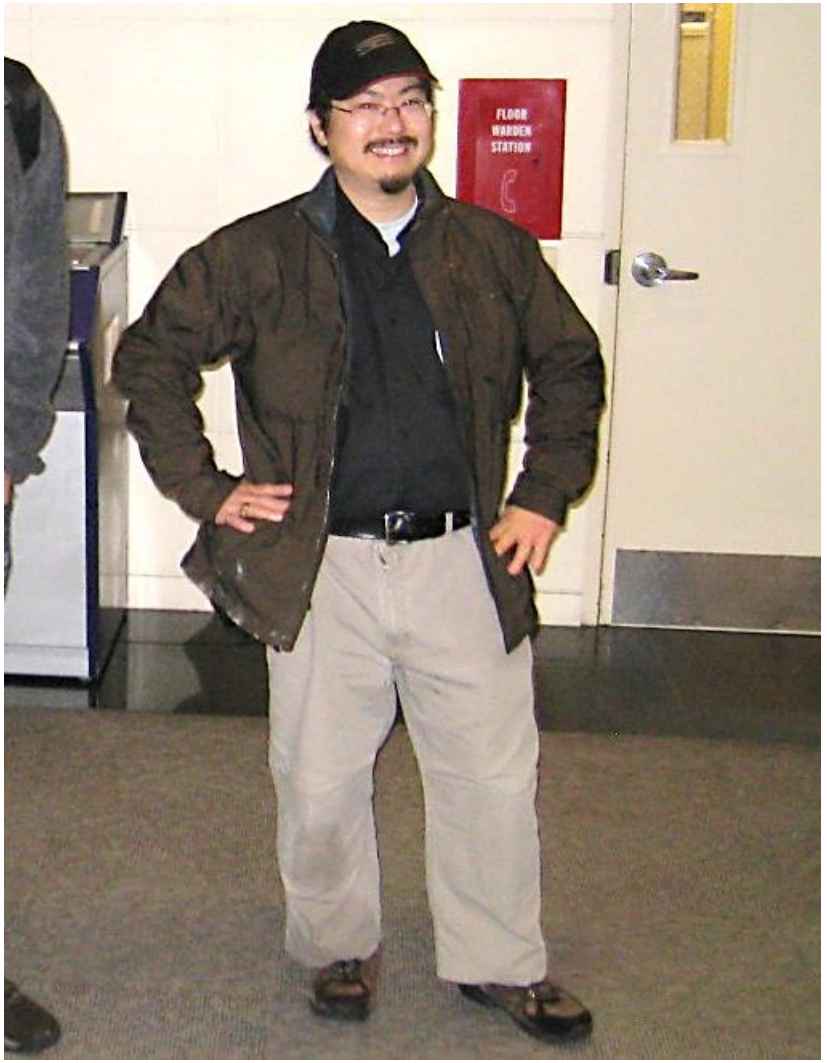
Historic Armoury Building, NS, Canada



Acknowledgements

→ Kohta Ueno of BSC

- → Collaboration on numerous projects
- → Site documentation
- → Sample collection
- → Logistics
- → Pier review
- → Etc…



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→ www.rdh.com

→ www.buildingsciencelabs.com

OR CONTACT US AT

→ rvanstraaten@rdh.com

→ ttraintor@rdh.com

→ cschumacher@rdh.com

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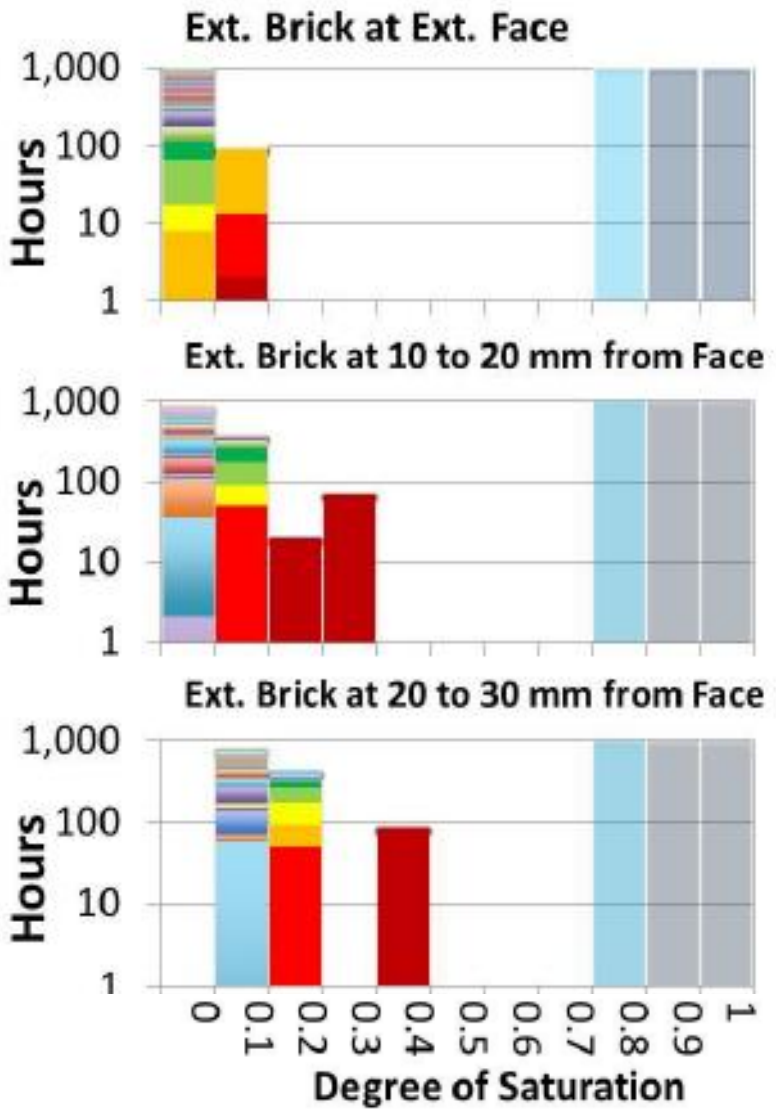
Another example

Existing wall before insulation



Retrofit wall with insulation