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Field Measurements of Moisture in Building Materials & Assemblies: Part 2

BEST2 – Portland OR, 2010.03.12

Building Science Corporation
DMO Associates
FPInnovations

Introduction

- Handheld Meters
- In-situ Measurements
- Factors Affecting Measurement Accuracy
- Developing Species Correction Coefficients
- Species Corrections for some “Different” Materials
- Interpretation of Measurements

BEST2 Field Measurements of Moisture 2

Moisture Measurement in the Building Industry

- Handheld Meters
  - Survey & assessment
    - Dielectric (Capacitance & Power-loss type meters)
    - Conductance a.k.a. Resistance (Pin type meters)
- In-situ monitoring installations
  - Research Development & Demonstration
  - Detailed investigation
  - Early warning systems
    - Wired
    - Wireless

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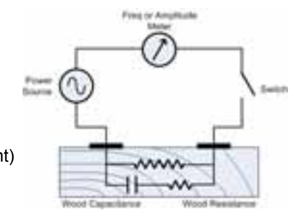
Dielectric Meter Function & Theory

- C = KA/4pd

  Where:
  C = Capacitance
  A = Surface area of the plates (constant)
  K = Dielectric constant (fn of wood MC)
  d = Distance between the plates (constant)



- Transmit electromagnetic wave into wood and measure
  - Energy Stored (*dielectric constant*) – Capacitance Meter
  - Energy Lost (*dielectric loss factor*) – Power loss meters

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Factors Affecting Dielectric Meters

- Species
  - Mostly Density
  - Less so cell structure
- Moisture gradients
- Surface moisture

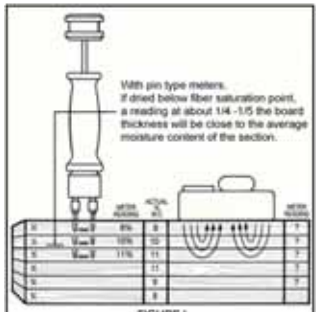


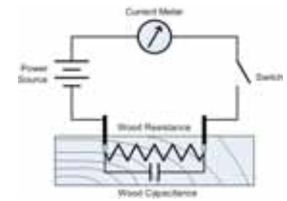
FIGURE I

PIN TYPE METERS VS. SURFACE TYPE METERS. (HYPOTHETICAL DRAWING OF 8/4 BOARD WITH VARYING LEVELS OF MOISTURE.

Resistance Meter Function & Theory

- r = RA/L

  Where:
  r = resistivity of material (fn of wood MC)
  R = resistance
  A = area for conduction (constant)
  L = length of path (constant)



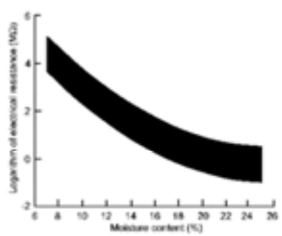
- Apply a constant (DC) voltage and measure current

Electrical Resistance vs Moisture Content

- Uncorrected (i.e. Douglas Fir) MC can be calculated from measured electric resistance:

$$Log(MC_u) = 2.99 - 2.113 \times \left(Log\left(Log(R_w)\right)\right)$$

where
MC_u = Uncorrected MC
R_w = Wood resistance (ohms)



- Equation is based on a large set of data collected by US-FPL
- Equation can significantly underpredict MC if it is over 40%

Factors Affecting Resistance Measurement

- Species
- Temperature

  } We'll get to this in a few minutes

- Moisture Gradients

  } Refer to BEST1 & Building Science Judgement

- Circuit Design
- Algorithm
- Electrodes

  } Hmm…..

In-Situ Moisture Monitoring Today

Wireless Systems

Image: GE

Linear Systems

Image: Detec

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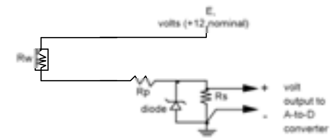
Resistance Measurement Circuits

- All variations on the same thing



- When measuring lower MCs (higher Wood Resistance), there can be complications:
  - Electrical noise
  - A-to-D Impedence

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Resistance Measurement Algorithm

- Wood is a Dielectric material in which ions move to the +ve or –ve electrode based on their charge
  - ASTM D4444 – The true conductivity of a material exhibiting simple anomalous dispersion is defined by Murphy and Morgan **(1)3 as the “infinite-frequency conductivity,”** which can be obtained by extrapolation of the DC conductivity curve to the point of voltage application.
- Polarization can occurs when measuring too long or too frequently for the ions to diffuse when the charge is removed
- We usually measure only 1 per hr
  - In some materials for research applications a short measurement every 5 minutes will work
  - OFTEN see problems with measurements made every 60s or faster

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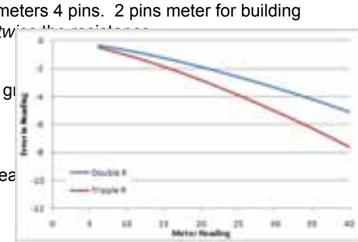
Resistance Measurement Electrodes

- Material
  - Readings across copper & zinc pins change as charge continues
  - Corrosion!
- Number of Pins
  - Many older meters & panel meters 4 pins. 2 pins meter for building applications generally *read tw*
- Grain Direction
  - Resistance perpendicular to g
- Pin Spacing
  - ideally 12.5x pin diameter
  - double spacing increases mea



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Resistance Measurement Electrodes

- Insulation
  - Allows measurement of gradient
  - Must be abrasion resistant
- Depth
  - if non-insulated, deeper = more contact area = lower R
  - effect is small (& mostly ignored)
- Pin Contact
  - if extended installation, predrill to avoid fiber relaxation & ratcheting

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Comparing Readings

- Ask not “which one is right?” rather ask “why are these different?”
- Moisture Gradient
- Surface Moisture
- Temperature Correction
- Calibration
- Species Correction

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Species & Temperature Correction

- MC readings can be corrected for measured temperature and identified species using the Garrahan eqn:

$$MC_c = \left(\frac{MC_u + 0.567 - 0.0260T + 0.000051T^2}{0.881 \times 1.0056^T} - b\right)/a$$

where,
t = the temperature of the wood in Celsius,
MC_c = the corrected moisture content,
MC_u = the uncorrected meter reading, and
a and *b* are constants for specific species at 23.8 C

- Equation is based on an extensive study by Forintek Canada, now a division of FPinnovations

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Species Corrections

- One of the most common moisture measurement questions: ***“Where do I get species corrections?”***
- Moisture Meter manufacturers
  - Important if default is not Douglas Fir!
- Published
  - USDA FPL workshop (1988),
  - Journal of Bldg. Enclosure Design, BEST1
- Research Labs
  - USDA Forest Products Laboratory (US)
  - Forintek div of FPinnovations (Canada)
- Develop them yourself…?

Species	a-coefficient	b-coefficient
Eastern Hemlock	0.904	-0.051
Sitka Spruce	0.853	0.398
Norway Spruce	0.702	0.818
Western White Spruce	0.828	-0.621
Eastern White Spruce	0.702	0.818
Black Spruce	0.820	-0.378
Red Spruce	0.723	-0.024
Red Pine	0.730	0.793
Eastern White Pine	0.821	0.556
Wester White Pine	0.969	-0.391
Ponderosa Pine	0.849	0.233
Lodgepole Pine	0.835	-0.545
Jack Pine	0.749	0.467
Alpine Fir	1.070	-2.950
Balsam Fir	0.900	0.350
Western Red Cedar	1.019	-0.455
Eastern Yellow Cedar	0.922	-0.751
Trembling Aspen	0.910	2.750
Hybrid Coefficients		
Western Hem-Fir	0.838	0.693
Spruce (Canadian Maritmes)	0.748	0.139
Northern Alberta Pine	0.792	-0.039
Northern Alberta Fir	0.985	-1.300
Douglas-fir	0.838	0.693

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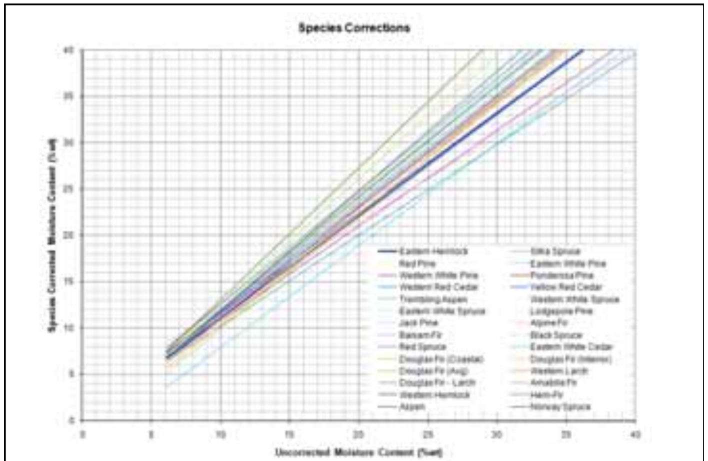

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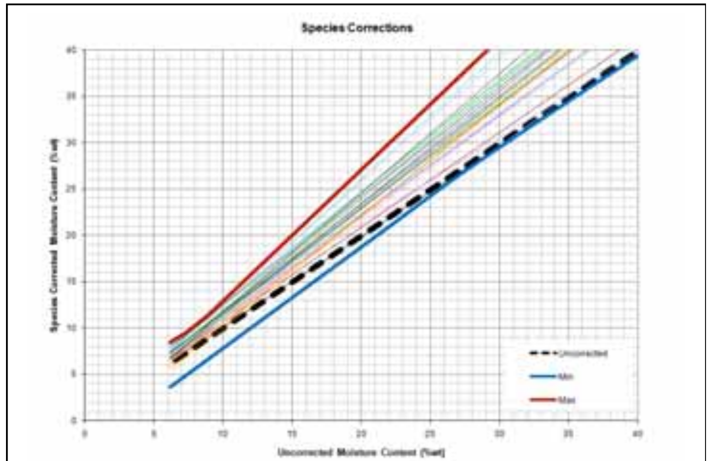

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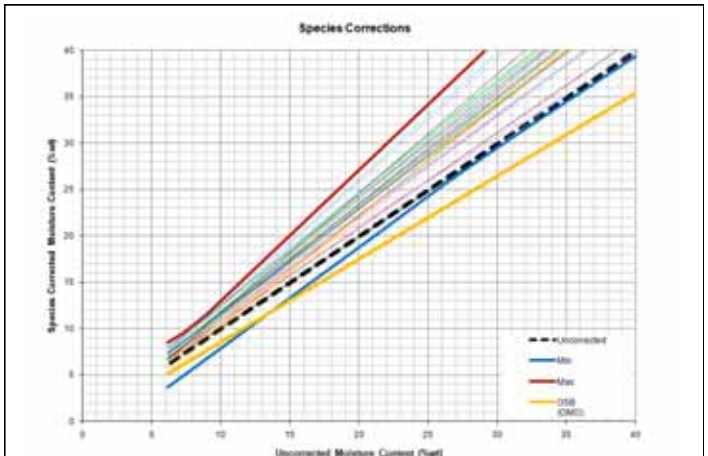

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DIY Species Correction

- ASTM standards
  - D 2915 "*Practice for Evaluating Allowable Properties for Grades of Structural Lumber"*
  - D 4442 "*Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials*"
  - D 4444 "*Laboratory Standardization and Calibration of Hand-Held Moisture Meters*"
  - D 4933 "*Guide for Moisture Conditioning of Wood and Wood-Based Materials"*
- Adapt approach depending on
  - Availability of Materials
  - Type of Materials
  - Time available
  - End use of correction

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Material Collection & Specimen Preparation

- ASTM D2915 – sample size is determined by statistical analysis
  - Usually requiring collection of more than 30 material samples (e.g. 2x4s?)
  - Difficult to satisfy in building applications
  - Try to collect at least 5 samples then cut a min of 10 specimens from each
  - Test 2 specimens from each material sample at each of 5 MCs
- ASTM D4444 – specimen size
  - Sufficient for direct measurement region of the meter w/ min extra
  - Free of irregularities (knots, decay, resin concentrations, etc.)
  - But… sample size must be big enough that change in mass can be registered by scale

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Specimen Conditioning

- Oven Dry weight should be determined after testing
  - Determine OD weight from extra samples – basis to check MC targets
- ASTM D4444 – Specimen Conditioning
  - Recommends use of humidity chambers w/ salt solutions (Ref ASTM D4933) to bring specimens to 5 EMCs between 7 - 21%wt

[illegible]

Nominal RH (%)	Salt	Relative Humidity (%) at Temperature (°C) 10	20	25	Solubility (g/100 mL)
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]		[illegible]		[illegible]
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]			[illegible]	[illegible]
60	[illegible]			[illegible]	[illegible]
70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

  - For building projects we typically place specimens in a ~98% RH chamber (i.e. supsend them above distilled water) and bring specimens to EMCs of 10, 15, 20, 25 & 30%wt

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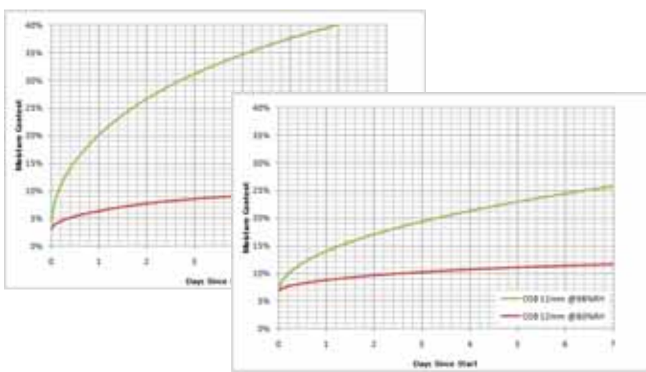
Conditioning in High RH Chamber?



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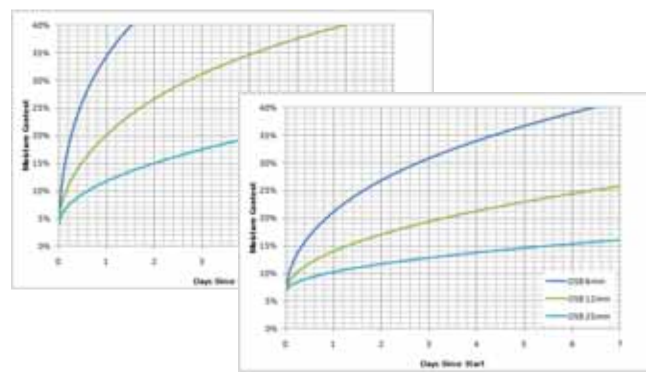
Conditioning in High RH Chamber?



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Conditioning in High RH Chamber

- Advantages over ASTM D4444 method
  - Can reach target MCs faster
  - Don't have to deal with salts
- Challenges
  - Avoiding condensation requires excellent temperature control
  - Mold growth can be an issue esp. if there is condensation



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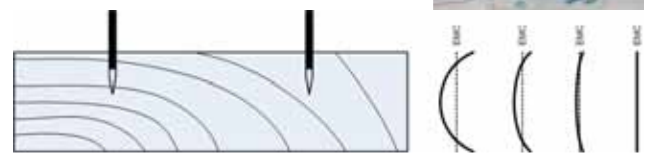
Packaging, Equilibrium & Measurement

- At target mass remove from chamber
- Package to prevent moisture loss
- Periodically measure
  - Mass to be sure there is no loss
  - MC to see that has reached stability

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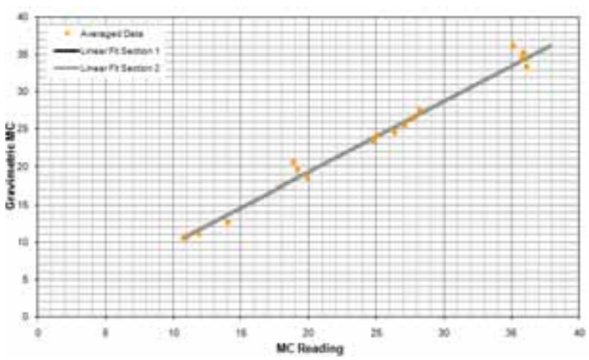
Regression to Get Species Correction



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Species Corrections for "Different" Materials

- OSB
- Borate Treated Wood
- ACQ?

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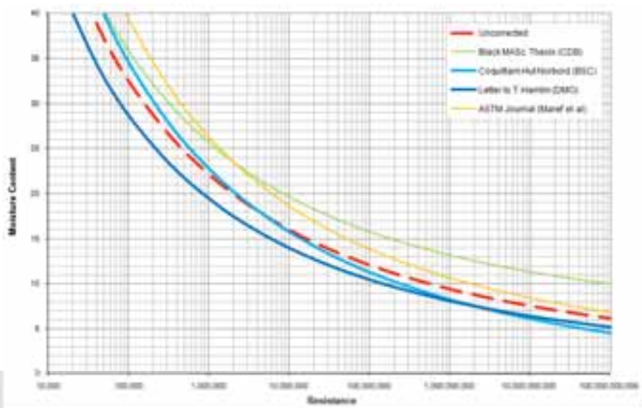
OSB



Borate Treated Wood

- Borate treatment alters electrical conductivity
- Borates are water borne treatments and are not intended for use with liquid contact
- Borates help control mold, decay, and termites
- Two treatment levels
  - Native North American Termites (ex. 2.7 kg/m^3)
  - Formosan Termites (ex. 4.5 kg/m^3)

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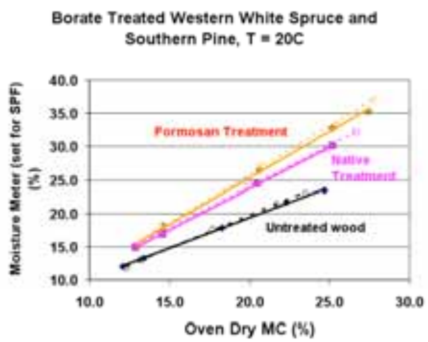
Borate Treated Wood: DC type meters read high



All readings were pinned to a depth of 25 mm into the edge of treated lumber specimens, meter set for SPF.

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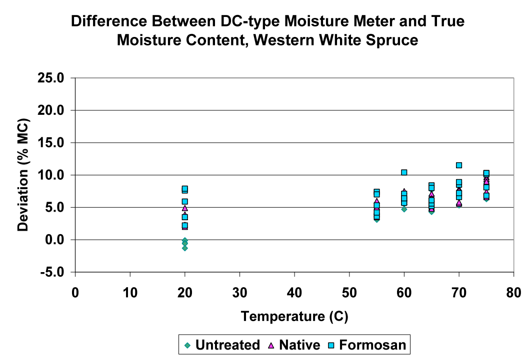
DC-type Meter Deviations, High Temperatures, Set for SPF



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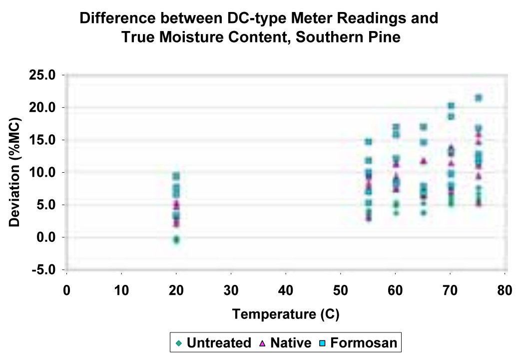
DC-type Meter Deviations, High Temperatures, Set for SPF



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Conclusions – DC-type Moisture Meter- Borate Treated Wood

- Wider range of measurement was possible
- Deviations
  - can be large
  - regular with high temperature
- Can western white spruce & southern pine be combined?
  - Similar enough at room temperature
  - At high temperatures, these two species appear to be different
- On this basis, an analysis was done to provide “a” and “b” coefficients for the Garrahan Eq. For both conventional temperature and for high temperatures.

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DC-Type meter - Correction Coefficients for WWS & SP

Treatment	Species*	Temperature Range °C	Coefficients for Garrahan Equation a	b	Test Stdev % MC	Test Max Deviation %MC
None	WWS and SP	< 30	0.961	0.621	0.3	0.5
	WWS	>30	0.974	0.863	0.3	0.4
	SP	>30	0.903	1.410	0.3	0.5
Native	WWS and SP	< 30	1.179	0.404	0.6	1.2
	WWS	>30	0.930	1.731	0.5	0.6
	SP	>30	1.055	2.050	1.4	2.2
Formosan	WWS and SP	< 30	1.338	-1.597	0.7	1.1
	WWS	>30	1.008	1.166	0.4	0.6
	SP	>30	1.228	0.848	0.4	0.5

* WWS (Western White Spruce); SP (Southern Pine)

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DC-type Meter, Recommendations – Borate Treated Wood

- Set meter or correct readings to SPF then correct using Garrahan eqn. and a & b coefficients
- Species ID
  - Probably not necessary for temperatures in typical assembly locations
  - If temperatures are >30C, ID species or use conservative a & b coefficients for southern pine
- Variability
  - Possible to account for by adding up to 2 standard deviations to the calculated corrected estimate of MC

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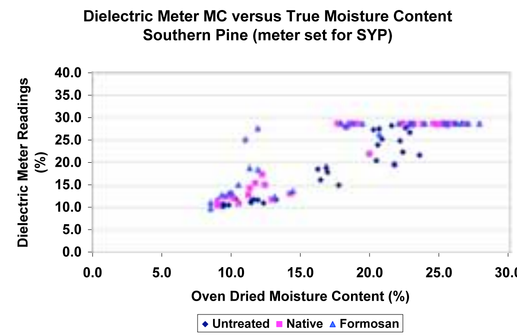
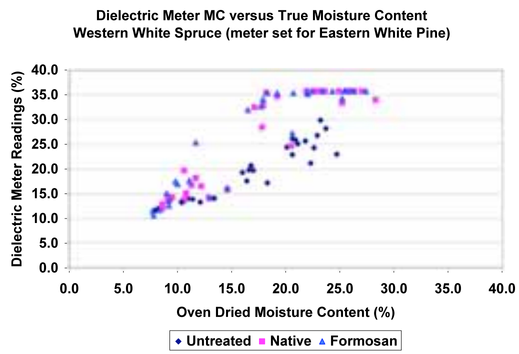
What about Dielectric Meters?

- Can we use capacitance and power-loss meters to measure MC in Borate treated wood?

Dielectric Meter – Southern Pine



Dielectric Meter – Western White Spruce



Conclusions – Dielectric Meter- Borate Treated Wood

- The data for these plots included measurements at 20, 55, 60, 65, 70, and 75 C
- The range of the meter selected was not wide enough
- Either the two species were quite different or the settings did not sufficiently correct for temperature and species
- Dielectric meters (as currently designed / calibrated) don't appear suited to use on borate treated wood!

ACQ?

- Early related work
  - HPO and the University of Toronto
  - Cooper at the Dept of Forestry
  - John Ruddick (formerly with Forintek)
- Don't yet know how to interpret meter readings from either DC-type or dielectric meters
- Suspect greater affect on reading from ACQ then Borate

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Interpreting the Measurements

- Mold & Decay
  - See paper from BEST1
- Shrinkage
  - An extension of BEST1 follows…

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Shrinkage – An Application of MC Field Measurement

- Wood structures more susceptible to shrinkage
- Shrinkage is a result of drying of wood from the fiber saturation level, between 25-30% of dry weight depending on the species.
- Shrinkage is assumed to be linear between fiber saturation and oven-dry conditions.
- Building codes require that wood at time of framing be a maximum of 19-20% so that shrinkage be kept to an acceptable limit based on experience with typical 1 – 2 storey housing.

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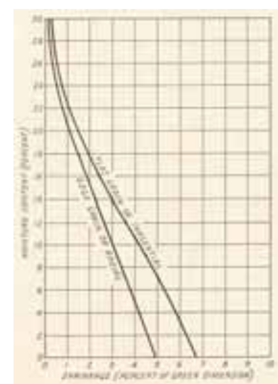
Typical Shrinkage Relationship

- Typical total shrinkage values for softwoods
- Tangential 5% to 9%
- Average for SPF ~ 7%
- Radial 2% to 5%
- Average for SPF ~ 4%



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Estimation of Building Shrinkage

- S = D • M • c

  where:

  D = dimension in direction of shrinkage (in. or mm)

  S = shrinkage (in. or mm)

  M = change in moisture content (%)

  c = shrinkage coefficient

  = 0.002 for shrinkage perp. to grain

  = 0.00005 for shrinkage parallel to grain

Concern about Building Shrinkage –Why ?

- For taller buildings we need to take precautions
- Wood framed buildings 4 to 6 stories are now being built
- Concern about total and differential shrinkage
- Total shrinkage affects plumbing, services, and egress design
- Differential shrinkage affects local slope in floors and discontinuities at threshholds.
- Rising Thrones

Shrinkage – Example for Lumber Joists

- Assumptions
  - Each wall has three plates, 2 at the top, 1 at the bottom, each 1.5” thick
  - Each wall has one floor, example 9.5”
  - Assume bottom sill plates have 3% higher initial moisture content because of construction moisture.
  - Assume wall stud height 8 ft. (96”)

Shrinkage Example – Lumber Joists (cont.)

Final MC		
	Costal	8-12
	Inland	6-10
	Dry Climate:	5-9
Assumed Final MC	8	(this example)

Element	length (in.)	Unit shrinkage	ΔMC for Initial MC of framing Lumber 15	20	25	30	Total Shrinkage per Element from 15	20	25	30
2 top plates	3	0.002	7	12	17	22	0.042	0.072	0.102	0.132
stud	96	0.00005	7	12	17	22	0.0336	0.0576	0.0816	0.1056
bot. sill plate	1.5	0.002	10	15	20	22	0.03	0.045	0.06	0.066
joist	9.5	0.002	7	12	17	22	0.133	0.228	0.323	0.418
Total shrinkage per storey (in.)							0.24	0.40	0.57	0.72
Total Shrinkage per building (in.)										
2	Storey						0.48	0.81	1.13	1.44
3	Storey						0.72	1.21	1.70	2.16
4	Storey						0.95	1.61	2.27	2.89
5	Storey						1.19	2.01	2.83	3.61
6	Storey						1.43	2.42	3.40	4.33

Shrinkage Example – Wood I-Joists

- Assumptions
  - Each wall has three plates, 2 at the top, 1 at the bottom, each 1.5” thick
  - Each wall has one floor joist, example 11” deep
  - Each I=joist has 2 flanges, 1.5” thick.
  - Assume bottom sill plates have 3% higher initial moisture content because of construction moisture.
  - Assume wall stud height 8 ft. (96”)
  - Assume initial and final MC conditions in example

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Shrinkage Example – Wood I-Joists (cont.)

		MC Range			MC Range	Initial MC
Final MC	Costal	8-12	Product	S-Dry Lumber	13-22	var
	Inland	6-10		Engineered Wood	4-12	12
	Dry Climates	5-9		Glulam	7-15	15
				Panel Products	4-8	6

Assumed Final MC	8	(this example)
Assumed Final MC flanges	8	(this example)
Assumed Final MC web	6	(this example)

Element	dimension (in.)	Unit shrinkage	ΔMC for Initial MC of framing Lumber 15	20	25	30	Total Shrinkage per Element from 15	20	25	30
2 top plates	3	0.002	7	12	17	22	0.042	0.072	0.102	0.132
stud	96	0.00005	7	12	17	22	0.0336	0.0576	0.0816	0.1056
bot. sill plate	1.5	0.002	10	15	20	22	0.03	0.045	0.06	0.066
flanges I-Joist	3	0.002	4	4	4	4	0.024	0.024	0.024	0.024
OSB web	8	0.0002	0	0	0	0	0	0	0	0
Total shrinkage per storey (in.)							0.13	0.20	0.27	0.33
Total Shrinkage per building (in.)										
2	Storey						0.26	0.40	0.54	0.66
3	Storey						0.39	0.60	0.80	0.98
4	Storey						0.52	0.79	1.07	1.31
5	Storey						0.65	0.99	1.34	1.64
6	Storey						0.78	1.19	1.61	1.97

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Differential Shrinkage

- Platform construction.
- Desire to keep each floor level and flat.
- Differential shrinkage between the interior core and the enclosure to be avoided.
- Choice of materials.
- Don’t mix steel columns in the interior with wood load bearing walls on perimeter.
- Minimize overall shrinkage by staging critical systems that would be affected with an eye out for moisture in the wood framing.

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Thank You for your Interest

- Any Questions?

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