FIELD MEASUREMENTS OF MOISTURE IN BUILDING MATERIALS AND ASSEMBLIES: PITFALLS AND ERROR ASSESSMENT

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Abstract

Moisture meters are becoming ubiquitous in their use on building sites by building inspectors, supervisors, installers of flooring finishes, and other building specialists in their forensic work. The point of their use on construction sites is to enable their users to identify and avoid excessive built-in moisture or to determine why a moisture problem has developed. When things go badly and building scientists are called in to investigate failures moisture meters are essential tools to assist in the early stages of an investigation. The trouble is that many users are novices in their use and in the interpretation of readings provided by a moisture meter.

There are several families of tools available to enable practitioners to apprise themselves of the amount of water stored in materials and to judge whether the levels measured pose a risk to the assembly once completed. These tools include handheld resistance-based and capacitance-based moisture meters and others.

This paper will provide some of the background to the accuracy of handheld moisture meters and some of the pitfalls in their use and interpretation. Unless they are in the hands of a knowledgeable user, they should not be used solely as the basis for undertaking major remediation works without more detailed investigation.

1 Background

Increasingly, moisture meters designed for industrial use in the wood industry are being used for field investigation of structures by persons who do not have the experience in their use or an understanding of their limitations. As part of the background in their use, it is important to understand the purpose for which they were developed and the basis for the extensive research that underpins their use.

Measurement of the moisture content of lumber has been of prime importance to the wood industry for many years. Lumber producers need to know that their kiln operations

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achieve the target moisture content for KD lumber – more drying than necessary is costly for the extra energy needed, reduced productivity at the kilns, and increased levels of shrinkage and warp. Also, shipping lumber to distant markets that contains more water than desired (hence shipping weight) cuts into profit margins. Finally, drying (whether by kilns or air drying) is needed to avoid sap stain of wood having high moisture, and to arrest either incipient or new decay from progressing while it is in storage or being shipped.

To meet these needs, particularly for wood industries that depend on speedy delivery to markets often across long distances, moisture meters have been developed based on the relationship between the electrical resistance or dielectric properties of wood and its moisture content. From these initial developments, meters have also been developed for other materials and applications, based on the same principles.

Research on the factors that influence the resistance or dielectric properties of wood is extensive. Yet, there is a lack of appreciation for the uncertainty of the measurements made. It is one thing to accept a certain degree of variation in lumber that is kiln dried as a shipment. It is another matter to use these meters in the field to interpret whether there is or is likely to be moisture damage. Particularly egregious is the case where a code-imposed limit is required to be met by builders of wood framed buildings and an inspector dogmatically decides that the moisture meter readings above the limit indicate a structure is too “wet” to proceed with. Or, that on the basis of probing a few locations in an existing building, with a fixation on a code-imposed or unofficial understanding of the consequences of moisture retention, a building inspector decides that the envelope is in trouble and must be remediated, often at great cost.

The purpose of this paper is to assist those not fully informed in wood moisture measurement and to provide a summary of the factors that influence moisture content readings. We will also discuss how this information should influence the measurement in the field and interpretation of the findings using these types of meters. The paper expands upon discussion and information provided in other guidelines [13].

Figure 1: DC-resistance moisture meter (on left) and dielectric moisture meter (on right)
2 Why Measure Moisture Content?

Building codes in the US and Canada, and indeed in many other countries, specify that lumber be dry at the time of installation in buildings. The definition of “dry” lumber in the North American context (as defined by the National Lumber Grades Authority [NLGA]) is wood having a maximum moisture of 19% on a dry weight basis. This is a typical moisture content that air-dried lumber can achieve in covered, outdoor storage. This requirement is derived from a long history of scientific research and experience involving good practice by the construction trades.

The justification for the 19% specification does not seem to be recorded. However, it has long been recognised in the lumber industry that once logs have been sawn into lumber, if drying conditions are poor or the lumber is close-piled, there is opportunity for fungal infection and staining which may degrade its appearance and render it to be less marketable.

The following quotation was taken from an early edition of the Wood Handbook (1940 revision) [1] in a discussion of storage of lumber at yards (p 205)

“Lumber that has a moisture content higher than 20 percent is likely to become stained or decayed when piled solidly. On the other hand, lumber, even though at a moisture content of less than 20 percent, when not properly protected against the weather is apt to stain or decay.”

This was at a time when the majority of wood was air dried and had become exposed to spores of decay fungi during exposure before sufficient drying. Today, we recognise that while existing decay may continue until the wood is dried below 20%, re-infection of kiln dried (normally sterile) wood by decay fungi will not occur unless the moisture content approaches the fibre saturation point (typically 28-30% MC) [2]. The 20% rule is now considered to provide a “reasonable margin of safety against fungal damage” [3]. In other words, there is a built in safety factor of some unknown amount in that recommendation.

Despite those requirements, builders have not always used dry wood. Traditionally, green wood has often been used but construction practises made allowances for sufficient drying to take place of the finished building assemblies.

From a forensic point of view, measurement of moisture content of wood and other materials is incidental to the main question having to be answered. For whatever reason questions were raised that required an investigation, the main goal is to decide whether or not there is a potential problem, and to decide what to do about it if there is a problem. The use of moisture meters is an aid to develop some understanding of the condition of a structure without further destructive investigation.
2.1 Industry Drying Practices

It is useful for persons investigating the health of a building assembly to know a little bit about the nature of the basic material they are dealing with. Most commercial lumber used in construction is from softwoods, i.e., from conifers that do not lose their foliage on a yearly basis.

North American softwood lumber producers use large, batch-loaded kilns to dry lumber under controlled conditions of temperature, relative humidity, and airflow. Variables such as species, initial moisture content, dimension, and other characteristics, affect drying times. Even after taking all of these variables into consideration, wood remains a complex material to dry. Natural variations in grain pattern, density, and the amount of sapwood/heartwood result in a certain amount of variability in the final moisture content. For these reasons, end users must expect and be prepared to accommodate for a certain amount of variability in the final MC. In fact although the NLGA grading rules specify 19% as the required upper limit for average moisture content, there is an allowance for up to 5% of the pieces in a charge to be in excess of this level. This is to reflect the variability in the material and the difficulty in drying all pieces to the same final MC.

Virtually all kilns in the softwood construction lumber industry are of the heat-and-vent (or conventional) variety. Heat-and-vent dryers used in the drying of dimension lumber are large chambers with forced air circulation systems and controlled temperature and relative humidity systems. Drying schedules may employ maximum temperatures of 82 to 88°C (180 to 190°F) in conventional kilns and up to 115°C (240°F) in high-temperature kilns. These temperatures are sufficient to kill all insects and any other organisms that might be present in the wood.

Computerised controls are used in most dry kilns to monitor and control the drying conditions and to collect some data on the moisture content (MC) of the material in the process. There are no practical systems available to accurately measure the moisture content of wood in a dry kiln. Kiln operators have data/tools available to assist in determining the end point for drying, but, for the most part, accurate measurement of MC cannot be conducted until after the wood is removed from the kiln.

Moisture content sampling at the planer mill is the point in the process where the most accurate and greatest quantity of information can be gathered. Many of the larger softwood mills employ in-line moisture meters to monitor the MC of every piece of lumber processed. If well calibrated and maintained, such instruments can provide average estimates of the MC to within plus or minus one percent of the “true” mean batch MC of most species. Spot checks with handheld moisture meters are also usually conducted at various points in the dressing (surfacing), grading, and packaging process. Mills rely on such information to verify conformance with MC specifications and provide feedback to the dry kiln operator. Sampling of final MC by the oven-dry method may provide accurate information on an individual board basis but it is impractical for obtaining an accurate picture of the condition of the entire load.
These practitioners know their materials, they know their sources, and they understand the drying processes involved. Significant variability can still be found from piece to piece within a kiln charge depending on how the drying actually took place. But these variations gradually reduce in protected lifts of material as moisture gradients decline and diffusion takes place within the stack during subsequent periods of storage and transit.

2.1.1 Historic versus Current Building Practices

In the past, construction practices were forgiving to both higher initial MC’s and wetting that occurred during the building process. Construction scheduling was slower than today and permitted gradual drying of the standing wood frame structure. Use of lumber subflooring permitted drainage of moisture that impinged on the partially completed structure and prevented ponding of water on floors. Lumber wall sheathing was very permeable to both air and vapour movement and resulted in rapid drying of excess moisture in the wall cavities. Also, low levels of insulation permitted greater heat loss that contributed to more rapid drying after construction.

With the application of lath and plaster finish for the interior, a wet process, drying was needed before the final finish plaster coat was applied. This was commonly done after a longer period of time when sufficient drying and building settlement had occurred to allow any shrinkage cracks to be manifest and to be repaired before the final finish coat and paint were applied. These building practices are not now commonly employed in North America.

Currently, dry rather than wet practices for interior finishes are used; use of plywood and OSB panels for floor, wall and roof sheathing, and the use of power tools all provide for greater flexibility, ease of assembly, and speed of construction. Faster construction times are encouraged by the costs tied up in purchasing the land, and the labour and materials for construction.

In quite recent times, there has been concern about the degree to which construction moisture is being locked in to wood framing at the time of construction. In 1991 CMHC published a report of a study they had commissioned Forintek to undertake to assess this issue across the country [4]. The moisture content of framing in wall studs and plates of over 515 houses under construction were assessed at 10 regional centres and at 4 different seasons of the year. In some parts of the country, S-GRN lumber was used predominately and high moisture levels were measured. When S-DRY lumber was used, moisture contents tended to be lower, but at some sites, even this lumber was found to contain moisture contents above fibre saturation (fibre saturation is considered to be approximately 30%). Bottom wall plates had higher moisture contents than wall studs because they were more vulnerable to absorbing rainfall due to their position and less surface area exposed for subsequent drying.
This discussion helps define the potential initial moisture conditions that building assemblies may have experienced by the time of construction and from which changes will have taken place prior to investigation by a building inspector or forensic engineer or architect.

### 2.2 Consequences of Drying IN SITU -- Shrinkage

We have touched on building practices that were used in the past to deal with shrinkage-induced effects related to drying. It is worth pointing out that whether lumber framing conforms or does not conform to the regulation concerning moisture content in the building codes, shrinkage effects still have to be accounted for in construction. The equilibrium moisture content (EMC) finally attained by lumber in the building may be 8% or lower depending on its location in the building and the climate.

The transverse shrinkage of green lumber as it dries to its end point EMC can be as much as 4.5%. Dry lumber meeting code requirements will experience significantly less shrinkage but it still can be expected to shrink in the order of 2%. The consequences of shrinkage are nail popping leading to loss in air tightness (and drywall plaster popping), differential settlement leading to drywall cracks, floor squeaks, and building height settlement leading to potential problems with vertical plumbing stacks. These problems are normally associated with the initial drying-out period as lumber dries to its EMC. Our current building practices can accommodate for these effects. Probably the most important concern is the need for more careful attention to installation of air barriers and vapour barriers. This caution is to alert the reader to one type of change that affects how the heat, air and moisture performance of wood assemblies can be affected.

How to judge that excessive moisture may be the cause of or may contribute to problems down the road? To make these judgments it is essential that the person undertaking the investigation knows about the likely behavior of the “system” he/she is investigating.

Generally, if the desired moisture is 19-20% dry weight basis with no more than 5% of a shipment in excess of this level, it is considered “dry” because once installed in a building and protected, the MC will gradually decline and dry. It has been a long established practice that this is a safe level at which wood would not promote mold growth and encourage decay. The tolerance on exceeding the limit is to acknowledge the presence of other permitted species in the kiln charge that dried at a different rate.

Of course once that lumber is installed in a structure, the rate of drying becomes dependent on the assembly that is quite different from that in a protected close piled lift. How that drying proceeds depends on the environment surrounding the individual pieces which is a function of the building practices during construction and the makeup of the building assembly.
With the above sections as introduction, we will now summarize some of the factors that influence the accuracy of the estimate of moisture content that will be obtained using commercial moisture meters in a field inspection setting. Our primary emphasis will be on resistance based meters, but both they and dielectric based meters are tools that serious investigators will need to use, often at the same location.

3 DC-Resistance Based Meters

Essentially, DC-resistance based meters are ohm meters that have a scale or output calibrated for some reference species of wood. The reference species used by many manufacturers in North America is Douglas-fir, using a relationship that was obtained by the USDA Forest Products Laboratory (James 1963). This was most likely old growth Douglas-fir and the relationships developed would be specific to that material. Initially, moisture meters produced were calibrated for that species only. When used to measure the moisture content of other species, a correction was required. Extensive calibration studies were undertaken for numerous species to enable an industry standard resistance based moisture meter to be used throughout the industry and tables were published to allow these Douglas-fir calibrated, DC-resistance meters to be used by lumber producers [5, 6]. Since then extensive research has been done to allow the use of these meters down to a wood temperature of -20 °C and lower. This was necessary since significant errors were found for frozen wood [7]. Data from many studies have been recast into one correction equation for various species and wood temperatures from -20 to 120 °F [8].

Meters are now available that allow individual species and wood temperatures to be selected. These meters have been programmed to automatically compensate for species and temperature effect. The relationships programmed into the meters are, in most cases, based on the various research papers listed in the bibliography. Those having the capability of selecting for specific species and temperature, and that have been properly calibrated using appropriate sampling techniques, are more likely to give readings that are closer to the mean moisture content of the wood than others.

3.1 Electrical Circuits in Wood

When good contact is made between the pins of a DC-resistance meter and a piece of wood, a path is provided for current to flow between the two pins. In the equivalent electronic circuit of Figure 2, wood, as a dielectric, can be represented as a simple parallel circuit including a resistance and a capacitor. In this idealized circuit, when current is first turned on, electrons flow through the wood as idealized as a resistor and charge begins to accumulate in the capacitor. As charge continues to build the apparent resistivity drifts. This analogy hides the complexity of actual current and ionic flow in this natural dielectric material [15]. The movement of free ions is slower than that of electrons and they move toward one or other of the pins and the current flow diminishes with time as they accumulate at the interface between the pin surface and the wood.
This mechanism explains the low conductivity (e.g. high apparent resistance) of wood and the fact that the resistance increases with temperature [9].

![Figure 2: The Equivalent Circuit](image)

When no charge is present the ions tend to diffuse randomly, however in the presence of an electric field ions move towards and accumulate around the electrodes, causing the material to become polarized. While this phenomenon has little effect on short, one-time measurements made with hand-held analog MC meters, it can have significant effect on longer, continuous measurements or periodic in-situ measurements using such instruments. Digital commercial MC meters are designed take the measurements over a very short fixed period of time and at a low applied voltage to minimize polarization. Periodic in-situ measurements will be discussed later in this paper.

### 3.2 Use of Handheld Meters – 4 or 2 pins and orientation

The pins should be inserted parallel to the grain and in a region away from defects such as knots, pitch pockets, or decay. When interpreting measurements in material containing a moisture gradient, insulated pins should be used. These are specially coated with a non-conducting material and shaped to resist abrasion when being driven in. The tips are not insulated and the MC reading taken is relevant to the wood in the region and depth to which the pins have been driven. For thinner materials, and where moisture gradients are not likely, non-insulated pins are typically used. Use of non-insulated pins provides one an idea of the upper level of moisture present, not the average if that is of interest, or of the moisture content in a particular veneer in plywood. For measuring moisture content of product having veneers, 4 pin tools are useful because one does not need to be concerned about the grain direction of the particular veneer being probed.
3.3 In-situ Measurements

In-situ measurements can be made by driving pairs of pins with lead wires into select locations. The moisture content at these locations can be measured by connecting the leads to the pins of a handheld meter as illustrated in Figure 3. In this case a pair of 19 mm (3/4 in.) stainless steel pins has been used as the in-situ electrodes. All but the tip and a band under the head have been coated with ceramic engine paint and cured in an industrial oven to provide an abrasion resistant, non-conductive (i.e. insulating) finish. Once the pins are installed the exposed solder joints are coated with insulating electrical tape to prevent the possibility of current flow through wet adjacent materials such as insulation. A thermistor can be installed in parallel to the moisture pins to allow for temperature calibration where necessary.

![Figure 3: In-situ pins connected to moisture meter using leads (on left) and close-up of thermistor and insulated pins (on right)](image)

In-situ measurements can be useful whenever periodic measurements must be made at the same location or wherever it will be difficult, too costly or too destructive to get to the measurement location at the time that the measurements are to be made. Using this approach, one can monitor the drying of construction moisture or moisture introduced by a wetting event. It can be used to permit periodic moisture content checks in problem areas after repairs.

3.4 Issues that Influence DC-Resistance Based Measurements

3.4.1 Species effects and temperature effects

An extensive series of studies at the Eastern and Western Forest Products labs in Canada (now FPIInnovations) and the USDA Forest Products Laboratory over many decades have led to a fairly reliable formulation to make corrections for meters that are
calibrated or designed for Douglas-fir and used at a setting appropriate for that species. This has been based on very extensive research over many decades in both the US and Canada.

Species is one factor that is known to have an impact on DC-resistance meter readings. Although specific gravity varies between species, the species effect on DC-resistance is also related to differences in the chemical (extractive) composition of the wood. In order to apply a species correction requires some knowledge of the species being tested. People in the wood industry know the trees they are machining and can even differentiate between individual species within a family of conifers. For example, some spruces can only be identified by examining both the wood and the bark of the tree. This has a direct bearing on the accuracy of estimating the moisture of lumber. At a sawmill site it is relatively easy to identify which species is being tested. In other circumstances there is much less certainty by persons outside of the wood producing industry. If species cannot be determined with certainty, the user must bear this in mind when considering the potential accuracy of readings that are obtained.

For any given moisture content, the apparent resistance of wood is dependent on the temperature of the wood - the higher the temperature the lower the resistance. Temperature corrections were first developed at the USDA by James [9] using 73 °F (23.8 °C) as the reference temperature. However several research studies have shown that this relationship makes corrections that severely over estimates the moisture content for wood at low temperatures, particularly for frozen wood. On the basis of extensive studies a relationship was provided that enabled a DC-resistance meters to be used more reliably over a wide wood temperature range. The single formula accounting for the effect of both species and wood temperature developed was [8]:

\[
MC = \left[ \frac{R + 0.567 - 0.0260T + 0.000051T^2}{0.881(1.0056)^2} - b \right] \frac{1}{a}
\]

Where:
\[MC = \text{corrected meter reading}\]
\[R = \text{meter reading}\]
\[T = \text{wood temperature} \ °C\]
\[a \text{ and } b = \text{species correction coefficients (calibration at 22.8}^\circ\text{C)}\]

While this relationship appears to be ungainly, it can be set up in a spreadsheet to provide corrections even on the job site. At least one manufacturer has incorporated this relationship in electronic based moisture meters that allow selecting for a specific species by code and temperature, and correctly interpreting the displayed reading. Species correction coefficients for a range of commercial species and species groupings (hybrids) are provided in Table 1.
Manufacturers supply meters for many areas of the world and for many different applications. Therefore, it is common to find meters that are pre-programmed with different correction factors than those described above. The references and material listed above are relevant to Canadian conditions. When sourcing or utilizing any moisture meter the user must be careful to get information on how the meter has been calibrated and what "on-board" calibrations are available for use outside of its base line condition.

Table 1: Species correction factors for resistance type moisture meters calibrated for Douglas-fir based on USDA data for that species (from [10])

<table>
<thead>
<tr>
<th>Species</th>
<th>a-coefficient</th>
<th>b-coefficient</th>
</tr>
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<tbody>
<tr>
<td>Eastern Hemlock</td>
<td>0.904</td>
<td>-0.051</td>
</tr>
<tr>
<td>Sitka Spruce</td>
<td>0.853</td>
<td>0.398</td>
</tr>
<tr>
<td>Norway Spruce</td>
<td>0.702</td>
<td>0.818</td>
</tr>
<tr>
<td>Western White Spruce</td>
<td>0.828</td>
<td>-0.621</td>
</tr>
<tr>
<td>Eastern White Spruce</td>
<td>0.702</td>
<td>0.818</td>
</tr>
<tr>
<td>Black Spruce</td>
<td>0.820</td>
<td>-0.378</td>
</tr>
<tr>
<td>Red Spruce</td>
<td>0.723</td>
<td>-0.024</td>
</tr>
<tr>
<td>Red Pine</td>
<td>0.730</td>
<td>0.793</td>
</tr>
<tr>
<td>Eastern White Pine</td>
<td>0.821</td>
<td>0.556</td>
</tr>
<tr>
<td>Western White Pine</td>
<td>0.969</td>
<td>-0.391</td>
</tr>
<tr>
<td>Ponderosa Pine</td>
<td>0.849</td>
<td>0.233</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>0.835</td>
<td>-0.545</td>
</tr>
<tr>
<td>Jack Pine</td>
<td>0.749</td>
<td>0.467</td>
</tr>
<tr>
<td>Alpine Fir</td>
<td>1.070</td>
<td>-2.950</td>
</tr>
<tr>
<td>Balsam Fir</td>
<td>0.900</td>
<td>0.350</td>
</tr>
<tr>
<td>Western Red Cedar</td>
<td>1.019</td>
<td>-0.455</td>
</tr>
<tr>
<td>Eastern Yellow Cedar</td>
<td>0.922</td>
<td>-0.751</td>
</tr>
<tr>
<td>Trembling Aspen</td>
<td>0.910</td>
<td>2.750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hybrid Coefficients</th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Western Hem-Fir</td>
<td>0.838</td>
<td>0.693</td>
</tr>
<tr>
<td>Spruce (Canadian Maritimes)</td>
<td>0.748</td>
<td>0.139</td>
</tr>
<tr>
<td>Northern Alberta Pine</td>
<td>0.792</td>
<td>-0.039</td>
</tr>
<tr>
<td>Northern Alberta Fir</td>
<td>0.985</td>
<td>-1.300</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>0.838</td>
<td>0.693</td>
</tr>
</tbody>
</table>

An example of the range of true moisture content for different species and species groups is shown in Figure 4.
Figure 4: Figure showing the correction to meter readings for a range of species at a calibration temperature of 22.8 °C.

For accurate measurement and interpretation, the temperature should be measured with a separate instrument by inserting a probe into the hole created by driving the moisture meter pins into the wood. The influence of temperature on the uncorrected meter reading is shown in Figure 5. Use of a typical handheld temperature gauge for this purpose is shown in Figure 6.
Figure 5: Showing the effect of temperature on meter readings for an example species (Douglas-fir)

Figure 6: Hand-held digital thermometer fitted with thermocouple probe to measure internal wood temperature
3.4.2 Moisture Gradients

In most applications in the field, moisture is seldom distributed uniformly. In studs, wall plates or floor joists, particularly in the exterior envelope where the greatest environmental differentials between inside and outside exist, there will be moisture movement. Consequently, it is necessary to assume that there are moisture gradients.

For lumber that is drying uniformly from all four faces and from a high MC level, depending on the rate of drying, the approximate average value is at about 1/5th to 1/6th of thickness when measured on the middle of the wide face. Under mild drying conditions (say air drying) or a piece of under initial uniform moisture, the distribution is assumed to be parabolic as shown in Figure 7. The higher the rate of drying, the higher the moisture gradient. In other words, the face of the lumber piece dries to a very low MC relative to the core.

Of course, if there has been subsequent wetting, the shell of the piece of lumber will be wetter than the core and a reverse distribution may be found. This alone may be of great assistance in understanding the circumstances leading to the distribution of moisture found in the assemblies being investigated.

Figure 7: Two possible moisture gradients, after kiln drying (dotted line), after rewetting (solid line).
Also, as the lumber acclimatizes in storage or in a building structure, the high gradients expected immediately after kiln drying will no longer exist. Instead, gradients specific to the environment actually experienced will predominate. It is thus necessary to understand the circumstances possible for the assembly being investigated and the likely history of the wood in the framing when measurements are being done.

In field applications, it is important to consider the location of the lumber being probed and its function. For example, a wall stud is usually subject to a temperature differential across its depth (in the thickness of the wall). It may be exposed to air in the cavity on both faces, but not to air on the edges, especially the outside edge.

When using a DC-resistance (pin) meter it is possible to insert the insulated pins to different depths to observe the change in moisture with depth. Touching the pins to the surface of the wood will give a reading that reflects the EMC of the wood under environmental conditions in that vicinity. You need to penetrate the exposed layers of wood cells to get to the material that accurately reflects moisture content in the piece near the surface. As you probe deeper, you will get an idea of that gradient.

Conventional symmetrical drying normally leads to a parabolic gradient (as shown in Figure 7 as a dotted line) and the mean MC will be found at a depth of about 1/5th to 1/6th of the thickness of the lumber if insulated pins are used. For a 38 mm piece of lumber (1.5 inches) that depth is about 6 to 7.6 mm (0.25 to 0.3 inches).

Not all cases involve symmetrical drying. For example the bottom plate of a wall may have sat in a pool of water during early construction. And because of contact with the subfloor will have dried very slowly from that contact plane. The gradient may well show greater and greater MC with depth from the top face down to its bottom. To determine if wetting has taken place, several readings should be taken. For a symmetrical distribution at least two readings should be taken. If only the edge of the lumber is accessible it is suggested that the two readings be taken at 6 and 25 mm depth and averaged. Also, if only the edge is accessible, readings can be taken at different vertical positions from the bottom to the top face. This allows us to simulate readings that would have been taken at different depths if the wide face had been accessible.

3.4.3 Wet Pockets

Very briefly, certain species are prone to a condition referred to as “wet pockets”. These prevent the establishment of a normal moisture gradient in lumber. The main softwood species used for construction that are affected are balsam fir and subalpine fir in the Spruce-Pine-Fir group, and hemlock that is part of the Douglas Fir-Hemlock marketing group. The problem is due to a bacterial infection in the living tree which does not affect wood strength or its color but does affect its liquid and vapour permeability. The permeability is reduced to the point where, wet pocket zones in a board may take 3 or 4 times as long to dry as normal wood. The infection is usually not widespread in a tree and therefore typically affects only portions of a board.
After a normal drying cycle of a kiln charge, it is possible to find localized areas in a board cross-section that may have MC’s as high as 30 to 50% MC while the rest of the wood is well below the target MC, (see Figure 8). If a high moisture reading is obtained using a resistance based meter, at least 3 or 4 additional readings along the member in question should taken to determine if a wet pocket is responsible for the high reading.

![Figure 8: Typical wet pocket in cross-section of a board from a species such as balsam fir or western hemlock.](image)

Small wet pockets are not a concern as they will eventually dissipate into the rest of the board and dry out. Wet pockets may be found when lumber is initially dried, but by the time the lumber ends up in a finished structure, the moisture gradients will be significantly reduced. In practice, deleterious effects have not been found by including wet pockets in lumber supplied; it is usually only a matter of time before the local wet pockets dry to the similar condition of normal wood.

### 3.4.4 High temperature Kiln Dried Wood

Normal maximum kiln drying temperatures range up to 71 °C (160°F) for a significant portion of the kiln schedule. Very high temperatures cause a change in the basic structure of the wood which results in a change in its resistivity. However, investigations into the effect of high temperature drying, with temperature ranging up to 100 °C (212 °F) or higher for a significant portion of the kiln schedule have not been found to have a significant effect [11].

### 3.5 Moisture Content of Treated Lumber

#### 3.5.1 CCA treated wood

Copper Chrome Arsenate (CCA) treated wood has been the most commonly available pressure-treated wood used in construction. This wood is dried and then pressure treated in a water-borne solution of chemical. Consequently, the presence of an S-DRY stamp on pressure treated lumber is not indicative of the moisture content after
treatment. The material is stored at ambient temperatures or heated for a short time and the chemical becomes fixed to the fibre in the wood and protects the treated portions from decay. The treatment adds water to the wood, but this is not normally considered to be a problem for exterior uses. For use in a building, kiln drying after treatment (KDAT) should be specified.

The moisture content of CCA-treated wood, when used in more severe conditions in the building envelope can be evaluated using the same procedures as for untreated wood. CCA-C treatment has been reported to be less conductive than for salt treatments. The error for treated southern yellow pine was about 2% MC in the range 12% to 25% [14].

### 3.5.2 ACQ and CA treated wood

Alkaline copper quat (ACQ) and copper azole (CA) have largely replaced CCA treated wood for exterior and other locations. They contain more copper than CCA, and are more corrosive to unprotected fasteners. They require use of hot dipped galvanized fasteners and connectors (or stainless steel). No information is currently available on the potential effect that these treatments have on the moisture content readings by either resistance based or dielectric based moisture meters.

### 3.5.3 Sodium Borate (SBX) treated wood

![Figure 9: Approximate relationship between oven dried moisture and moisture meter readings for borate treated Western White Spruce at room temperature at different treatment levels.](image-url)
Sodium borate treated lumber and sheathing has recently been introduced into the market in Canada and the U.S. This is also a water-borne treatment, but it is intended only for applications protected from rain. All borate treated wood should be specified as KDAT. The treatment will also prevent decay and be instrumental in reducing the risk of mould growth. A recent study available to the authors has shown that the resistance based meter reading was 2% to 4% higher over a 12-30% MC range for treatments intended for controlling native termites, and from 2 to 8% higher over that range for higher retention treatments intended to control Formosan termites. The apparent resistivity is strongly sensitive to the treatment level and species, and until that data is published in its entirety it is necessary to temper any readings taken on borate treated lumber or panel products, recognizing that measured moisture values can be considerable higher than actual moisture values as shown in Figure 9.

3.5.4 Fire-retardant-treated wood

Fire-retardant-treated or FRT wood is produced by either coating or pressure treating with chemicals. The majority of fire-retardant-treated wood used in construction is strictly surface coated. The interior of surface-coated wood is essentially unaffected and therefore the method of moisture measurement is unchanged from that for untreated wood. It is important to ensure that insulated pins in good condition are used to avoid any electrical contact with the fire retardant. In pressure-treated material, the presence of fire retardant within the wood will affect its resistivity and therefore a separate correction factor is required. At present, there is insufficient information to suggest how to interpret moisture meter readings in this situation. If moisture content data on such material is required, cutting small samples for an oven-dry determination is recommended.

In conclusion, while accurate estimation of moisture content is difficult in wood having some types of treatments, it should be noted that some of those treatments are done to protect the material in high MC conditions and that, despite measuring higher moisture than recommended for normal wood (even after correction for changes in resistivity), there is no justification for assuming that the treated portion of the structure is at risk. This does not mean that other portions of the structure are not affected by the source of that moisture.

3.6 Moisture measurement in other wood products

3.6.1 Oriented Strand Board [OSB]

OSB panels are produced by laying up parallel and cross mats of wood strands having a wafer-like appearance. The adhesive used is either applied in powder form or sprayed in liquid form as the strands are tumbled in a large drum prior to lay-up in mats. Lower density aspen and poplar are preferred for this product because these strands can more easily be made to conform to each other under heat and pressure. However higher density species such as southern yellow pine have also been used successfully. The high temperatures and pressures used also result in some densification of the material.
Industrial wax is applied to the wafers to allow better uniform adhesion of powdered adhesives to the wafer surfaces. This also imparts some water repellency to the finished product.

Due to the densification and the addition of wax and adhesive, the bulk density of OSB is higher than that of wood or plywood. The moisture content (dry weight basis) is about 3-4 % lower than for solid wood of the same species at the same conditions. Limited testing was conducted at Forintek to develop a correction factor for OSB. Existing temperature correction data for solid wood was used to develop corrections at other temperatures. Correlation coefficients for use with the previously noted equation in this paper were developed [a= 0.838, b=0.693]. It should be noted however that there is considerable variety in sources of supply and species used for this widely used product and these results only provide a rough guide for the correction that should be applied.

Finally, it should be noted that the calculation of bulk moisture content includes the weight of adhesive and industrial wax that is still retained after manufacture. The moisture content of the wood fibres would be somewhat higher, closer to that achieved by unprocessed wood. The addition of, say, 3% moisture to the corrected bulk moisture content is one way to account for these issues and to provide an estimate of the moisture actually experienced by the wood fibres in these products.

### 3.6.2 Plywood

Plywood panels are laid up with parallel and cross-ply layers of veneers that are rotary peeled from logs. After drying, sorting and grading, liquid beads of adhesive are deposited on each sheet or width of veneer on their way to the lay-up station. The pressure and temperature used by the presses in the production of plywood are lower than those used for production of OSB resulting in less densification. The adhesive forms a mostly discontinuous thin film that alters the liquid permeability of the product somewhat. The moisture reading obtained with a resistance-type meter is based on the most conductive path of the veneer into which the pins have been inserted. At high moisture levels, because of the possibility of liquid paths in the more open structure of veneers compared with solid wood (caused by lathe checks), somewhat higher than average readings may be obtained.

Because of the added mass of adhesive and slight densification, the bulk density of plywood is higher than wood from which it was derived. Consequently, at specific environmental conditions, the equilibrium moisture content of plywood based on bulk density will be about 2% less (dry weight basis) than would be achieved by the parent material based on oven drying determinations. More accurate readings can be obtained if care is taken to insert the pins from a resistance-type meter into the same layer of veneer. Grain direction has a small effect and it is advisable to take the average of parallel and cross readings.
The species of veneers used in the core may not be the same as that used on the faces. Consequently one is limited to using species and temperature corrections based on broad species groupings such as are provided in Table 1. Over the fibre saturation of plywood, the errors in estimation of moisture content are far larger than in solid wood. In part this is because of moisture gradients, and the makeup of the material.

### 3.7 Accuracy of Estimation of Moisture Content Using DC-Resistance Based Moisture Meters

There are limits to the accuracy with which the moisture content can be measured by any electrical means. All handheld electrical meters (DC-resistance and dielectric) are not considered to be reliable for measuring moisture content above the fibre saturation point (25 to 30%). Given the discussion in earlier sections dealing with a) species effects, b) temperature effects, and c) moisture gradients, an appropriate question to pose is what accuracy can be achieved when you think you know everything you need to know. The following example will try to answer that question.

In the study of moisture content of framing in houses under construction, field inspectors selected cutoffs, or cut pieces from longer lengths of framing lumber used for walls on buildings sites in 10 population centers across Canada [4]. The pieces were from 2 x 4 studs usually, and cut to be at least 50 mm long. They were bagged and shipped to the Forintek Laboratory in Ottawa for analysis. They were pinned at two depths (shell and core, at 9.5 mm and 25 mm into the edge of each piece), oven dried to determine their mean moisture content, and the species were identified. The meter readings were adjusted for species and temperature for comparison with the oven dried values.

Nine species were identified, although individual species could not be identified within the spruce genus on examination of the wood alone and these were grouped together. A comparison between the estimated and the oven-dried MC values for the spruces is shown in Figure 10 below.
The regression of samples having less than 30% MC had an $R^2 = 0.927$, and a root mean square error of 1.52% MC. This implies that with the best of information (excluding specific species in the group) the estimate of possible error over the range, roughly 10 to 30% MC, the true mean moisture content is within 1.5% MC of the correct value roughly 68% of the time. Over 30% MC (over fibre saturation) the scatter is considerable, although there were only 40 specimens in that region. Estimating the average MC at high levels of moisture is dubious – all one can say is that the wood is wet. If more than two moisture readings had been taken for each specimen, it may have been possible to secure a more reliable estimate, even for values over fibre saturation.

It was noted that when the pine and fir samples were added (N=391), for the 10 to 30% range, $R^2 = 0.835$ and the RMSE was 2.4% MC. The estimate of error in moisture content above 30% was in the order of 8 to10% MC. Of course, better results will be obtained if specific species can be identified.

**Key Points – on use of DC-resistance based moisture meters**

- Care must be taken to ensure that moisture readings are obtained from sound, clear wood and special precautions should be taken with species that are prone to wet pockets to not presume general wide spread moisture on the basis of readings in one locale.
Proper pinning depth is important to ensure a good estimate of average MC. Of course, due to expected moisture gradients these should be evaluated as the gradient may provide information as the source of wetting.

Moisture meters can provide good estimates of the actual moisture content of wood provided that moisture levels are under fibre saturation (about 30%) and the species can be identified and the temperature at the pinning location is known.

Moisture gradients must be investigated to help in determining the source of wetting, if possible, and to assess if drying to safe levels and if destructive investigation is warranted.

Meters can be used on composite products such as plywood and OSB. But much less information is available about the variability of readings taken. In part this is due to the complexity of the materials and partly due to scarcity of the data.

4 Capacitance Based Moisture Meters

While most of this paper has concentrated on the use of DC-resistance type moisture meters, this is not meant to minimize the potential for the use of meters based on dielectric properties of wood. As noted earlier, some mills employ dielectric based meters on line for all lumber produced, and with proper calibration accounting for the species and the moisture gradients typically present at the manufacturing stage, estimates of moisture content can be made within +/- 2% of true levels [12].

For on site investigations, the value of a dielectric type meter lies in the ability to use it as a scanning device to detect locations where higher than expected moisture contents may be detected. It is a nondestructive contact instrument in contrast to the DC-resistance based moisture meters that must insert pins into the material being assessed. By setting the threshold value of a dielectric based meter in a location that is not expected to be “wet”, one can then scan the surface of a wall to locate areas that may be of greater interest to investigate carefully. By attaching the meter to an extendible pole, upper walls and ceilings can also be quickly examined. In reality, based on this description, a dielectric meter is an essential tool for pre-screening and the DC-resistance based meter is essential for obtaining, to the extent that is possible, a good estimate of the moisture content of the material being assessed and the distribution of that moisture within the material.

Dielectric meter readings are affected by the temperature of the wood but the correction is less than half of that required for resistance based meters [12]. For pre-screening purposes, it would not be necessary to attempt corrections. Things such as meter application pressure, surface condition of the wood, and the presence of knots do have a minor impact on meter reading. If, however, the intent is to use this meter to pre-screen material the effect of these variables can be neglected. The main variable which must be accounted for is specific gravity. Since specific gravity varies between species this is usually referred to as a species correction. Specific gravity can be determined through a laboratory test but for most applications a species average from the Wood
Handbook (1) is sufficient. Many meters of this type have the ability to be adjusted for the specific gravity of the material.

The prime drawback to the use of a dielectric meter is that its normal calibration assumes the lumber has a typical parabolic moisture gradient and that the average moisture content is the property of interest. This may not always be the case. Some meters are available that generate two selectable electric fields, one - typical for assessing the average moisture of lumber, and another – generate a weaker field to assess the moisture of the near surface material in lumber. Effectively this is an attempt to assess gradients. We do not have experience with these meters as yet. Most of these meters are heavily influenced by surface moisture content. A moisture gradient involving either a very wet or very dry surface will cause MC estimates to be over or underestimated respectively.

As with DC-resistance meters, the limitations dielectric moisture measuring technology should not be considered as a reason to not take advantage of this technique. Indeed, meters combining both functions have come on the market in recognition of both the limitations and the capabilities of each type of instrument.

5 General Procedure for On Site Investigation

To assess the general moisture content of a stud in a wall, two sampling locations with a moisture meter are recommended. Readings taken at a level of about 300 mm and at mid height, approximately 1200 mm, should give a fairly good estimate of the basic moisture content of the vertical members in that elevation of the building, at that storey level (see Figure 11).

Figure 11: Suggested approximate locations for meter measurements to obtain average moisture contents in studs and wall plates [13]
Interior wall studs are more likely to be representative of the lumber as it was delivered to the site and then dried somewhat in place. These are usually only enclosed with gypsum wallboard and are not subjected to significant temperature gradients. As a result, drying is readily permitted and the moisture content of interior studs is less critical to durability. Exterior wall studs and plates are the more critical elements to evaluate, since they are generally more exposed to the weather and are constructed to be resistant to moisture flow. Consequently, obtaining the moisture content of one or two interior wall studs of the same size as those in the exterior walls may give the assessor an idea about whether there was excess moisture in the lumber to start with.

The bottom plates are likely to be the wettest of the framing lumber in the building and should be checked more rigorously. These pieces should be checked for core and shell moisture content and at several points along their length. Headers, rim joists, built up columns or other assemblies with a large mass of wood are slow to dry when wetted. Boards in areas where drying is inhibited by impermeable flashing or peel and stick membrane, should also be checked.

It is unlikely that high moisture conditions in interior wall framing at time of installation will lead to conditions that encourage decay. These walls generally dry rapidly because there are few or no barriers to inhibit vapour transmission. The major consequence of tolerating higher moisture levels in the interior load bearing members is that more settlement and shrinkage of the interior will take place relative to the exterior shell of the building. This is not expected to be a significant effect although the total shrinkage of the whole building must be accounted for in the design of the plumbing and sewage distribution system.

If the intent of the measurements is to assess whether it is acceptable to proceed with the construction, it is recommended that a minimum of 4 studs be evaluated in each exterior wall elevation. As far as the number of storeys that should be assessed, in most cases (from our experience) the bottom storey will be the wettest even though it will have been constructed first. A small amount of ad hoc evaluation may be helpful to determine where attention should be focussed with regard to detailed MC measurements in the building.

In summary, when it is found that higher than desirable moisture levels have been detected, adequate sampling is required to provide a solid basis for a decision to delay construction or undertake some additional measures. It is recommended that, for the studs in any particular wall with moisture readings at two depths at each location, measured at two heights, and for four studs in the wall, a total of 16 readings be obtained. The same level of sampling should be done for the bottom wall plates. This should give the builder and assessor sufficient information to form an opinion on the degree of additional drying that may be required before proceeding. The builder and assessor can only make decisions of this nature, at the time of inspection. It may well
be decided that significant portions of the framing can be closed in and to only leave unfinished those sections which require longer natural or induced drying.

5.1 Interpretation of MC Measurements in the Field

The issue of high moisture content in construction lumber is not new. Wood frame construction, as practised for almost two centuries now, has always had to incorporate measures to mitigate the effect of moisture. Given the variability in climatic conditions across North America and the large seasonal changes experienced in northern climates, it is difficult to put forward a general rule on what degree of wetness might be tolerable over time. Judgement is needed, particularly with respect to the type of construction, the scheduling and degree of protection provided. Some factors that builders and inspectors may consider when they encounter framing that exceeds code requirements are discussed below.

5.1.1 Species Identification

The average person will not be able to recognize the species of a piece of lumber. Generally, wood anatomists can, with the help of a magnifying glass, a penknife, and an examination of a large enough piece with grain deviations and knots. Even then some particular genus of spruce, for example, may not be possible to identify without seeing the bark of the tree as well. Where does this is leave the building inspector or forensic specialist?

First of all, the grade stamps help identify the marketing group, and in some cases the specific species being marketed. For example SPF signifies the spruce-pine-fir group which includes up to 4 species of spruce, and an assortment of pines and firs. When more specific or individual species are marketed alone this makes the task easier. Even so, this may take some doing if grade stamps are not visible even if a portion of a wall or assembly is exposed. In the event that nothing is known about the material in the wall, looking at some other portion of the house say the basement, where there may be partitions and some exposed wood, may reveal what some of the material was graded as. A shipment for floor joists would not be a good indication as to the species group used in wall assemblies simply because they come from larger trees and may well have originated from another manufacturer/supplier. Also, sometimes knowing the regional construction practices and sources of supply can help pin things down. On the whole, stud grade material is often used in constructing walls and, as they are relatively over designed, there is less benefit from and interest in marketing specific species. On the other hand, framing lumber of the same size which is used in higher stress applications such as roof trusses and wood I-joists may well be sorted by species or at least be more predominant in one species.

Accredited grade stamps for Canadian lumber are to be found on the Canadian Lumber Standards (CLS) Accreditation Board web site (Membership Information), and corresponding grade stamps for lumber produced and graded in the U.S. are located on the American Lumber Standards Committee, Inc. web site (Accredited Agency List).
In a critical investigation, particularly one in which some destructive examination has been done to reveal the underlying structure, grading agency inspectors can be called in to examine and more accurately identify the species of lumber used in a particular structure.

5.1.2 Climatic Factors
The climatic conditions are extremely important. Conditions in most of the country will often favour the maintenance of or promote drying toward an acceptable moisture level. Unfortunately, because unfavourable conditions - either being too wet, or too humid, or too cold can occur in all locations, the builder must exercise caution. The weather conditions in some areas are so unpredictable that protected construction is the only way to lower the risk of delays. Undertaking construction practices that minimise the risk is another part of the solution. For example, using exterior insulation changes the thermal gradients and results in warmer stud cavities. With judicious consideration of vapour resistance of materials making up the wall, it is possible for excess moisture to dry to the interior.

5.1.3 Type of Wall System
Some completed wall systems are more amenable to drying than others. Partially completed walls will be more amenable to drying and this should be taken advantage of when possible. Many wall systems built in colder climates are built with a vapour barrier located over the interior surface of the framing, just behind the interior gypsum board lining. Therefore the majority of drying of moisture after the installation of the vapour barrier can only take place toward the exterior. Advantage should be taken of all conditions that could provide drying to the interior before the vapour barrier is installed. The polyethylene vapour barrier also serves to protect the gypsum board from moisture in the wall. The paper faces are particularly vulnerable to supporting mould growth when exposed to high humidity. Drainage capability behind the main weather barrier and the choice of materials used affects the ability of a wall to dry out. This must be left to the builders and designers to consider for each type of system they employ.

5.1.4 Orientation
The orientation of walls affects their drying rate. North facing walls and walls that are shaded from the sun by other buildings can be expected to dry more slowly. These walls are of particular concern and may have to be treated differently compared with east, west or south facing walls that receive more solar energy. In other areas, walls more exposed to wind-driven rain may require special consideration.

The builder and inspectors must also keep in mind that loading of exterior cladding by rainwater can contribute to, or reduce the ability of the backup wall to dry out. Stucco cladding is a wet process and, until it has set, cured and been finished; it may reduce the ability of the inner wall to dry to the outside. A solar driven moisture wave front toward the interior of the wall is not unusual, but the effect can be minimised by use of a ventilated cavity. Sequencing of construction in addition to location and orientation is critical when assessing the moisture content that can be safely retained in the framing.
5.1.5 Indoor Climate

It is not expected that interior conditions in northern climates will have much effect on exterior wall performance when a vapour retarder is installed and an air barrier system is used to minimize air movement. However, if these construction details are not properly addressed, the moisture content of the lumber framing becomes more critical. The level of seasonal moisture storage may be safe for a building with a lesser initial moisture content. Should the initial moisture content be high at time of closing, the addition of further moisture might prevent drying in a timely fashion.

Air conditioning in the summer can do much to reverse the flow of moisture in a wall. Here, it almost goes without saying, its makeup and design will affect the tolerance of the wall to these conditions.

5.2 Key Points - on factors that influence interpretation of field measurements

▪ Bottom plates are likely to be the wettest of the framing lumber in the building and should be checked more rigorously.
▪ For vertical members, meter readings should be taken at various heights and depths to assess average MC and moisture distribution.
▪ There is no hard and fast rule to recommend at what moisture content lumber and other materials in the standing frame may be protected against deterioration.
▪ The local climatic conditions, particularly wind-driven rain, can affect the likelihood of drying in a reasonable timeframe.
▪ The type of wall, its materials and design, ultimately affect the decision as to what must be done in cases where excess moisture exists.
▪ The orientation of walls in relation to solar gain, and in relation of the prevailing direction of wind-driven rain, plays a major role and should be accounted for in design and predictions on time required before closing.
▪ The indoor environment and whether or not it is air-conditioned must also be considered.

6 Summary

With regard to the use of DC-resistance based meters:

▪ DC-resistance based moisture meters can provide good estimates of the actual moisture content of wood when both the temperature and the species are known.
▪ Moisture gradients can also be readily assessed using resistance-based moisture meters equipped with insulated pins.
▪ DC-resistance meters are the most practical and versatile for detailed testing of construction lumber that is in place.
▪ DC-resistance meter readings must be corrected for the effect of wood temperature and species, in order to get the most accurate predictions of MC.
▪ Typically they only provide reliable results up to fibre saturation, say 30%.
• Proper pinning depth or readings taken at various depths is important to ensure a good estimate of the average MC for the cross-section.
• Care must be taken to ensure that reading are obtained from sound, clear wood and special precautions taken when dealing with species prone to wet pockets.
• For solid wood treated with some preservatives or fire-retardants there is an effect on the meter readings however there is limited information available on how to compensate those readings.

With respect to the use of dielectric based moisture meters:

• Dielectric meters are useful for scanning or pre-screening areas where more moisture exists and are a useful survey tool in conjunction with DC-resistance meters.
• Specific gravity of the material being scanned is the prime factor influencing the meter readings.
• The effect of temperature of the wood is less than half of that effect for DC-resistance based meters.
• Moisture gradients cannot be assessed accurately using dielectric meters.
• Both types of meters can be used on composite products such as Plywood and OSB.
• Little is known on how much effect preservatives or fire retardants have on dielectric moisture meter readings.

Finally, with respect to the interpretation of the severity of moisture readings found:

• The 19-20% code limit is only a guide for lumber producers for drying wood so that it can be used in construction with low risk of mould growth. Further drying is expected in place. This was based on experience and construction practices that extend back to the 1800’s.
• The grading rules specify a 19-20% MC limit for drying but allow up to 5% of a load of lumber to be over that value. This tolerance for “off spec” pieces acknowledges that there is variability in MC from piece to piece in the kiln charge due to drying conditions and natural variability in the material. Additionally, there are high moisture gradients in the lumber right after kiln drying that may partly equalize in storage.
• Construction that uses wood framing having high moisture content needs to involve practices that maximize drying of the structure and should involve monitoring of moisture content at critical locations in the structure.
• Monitoring the moisture content of building materials is an emerging need in construction. Accuracy is perhaps less important than identifying when a problem exists.
• Having both DC-resistance and dielectric meters available to inspectors is an effective way of screening for moisture problems. Probably also needed is a temperature meter and RH meter. Flexibility in the capability of tools very desirable.
7 References


