In Situ Moisture Testing of Building Products as a Predictor of Actual Conditions

Garth D. Hall and Sarah K. Flock
Raths, Raths, and Johnson
Table 1. Recommended moisture content values for various wood items at time of installation.

<table>
<thead>
<tr>
<th>Use of Wood</th>
<th>Moisture Content for:</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Most Areas of the</td>
<td>Dry Southwestern Areas</td>
<td>Damp, Warm Coastal Areas</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>United States</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Individual Pieces</td>
<td>Average</td>
<td>Individual Pieces</td>
<td>Average</td>
</tr>
<tr>
<td>Interior:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodwork, flooring</td>
<td>8</td>
<td>6-10</td>
<td>6</td>
<td>4-9</td>
<td>11</td>
</tr>
<tr>
<td>Furniture, wood trim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminated timbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior:</td>
<td>12</td>
<td>9-14</td>
<td>9</td>
<td>7-12</td>
<td>12</td>
</tr>
<tr>
<td>Siding, wood trim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Framing, sheathing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminated timbers</td>
<td></td>
<td></td>
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</tbody>
</table>

Air-Dried Lumber and Dimension

In most parts of the country, the minimum moisture content that can be generally obtained in air drying is about 12 to 15 percent. Most air-dried material is usually closer to 20 percent moisture content when used. Air-dried lumber is suitable for items that are not ordinarily subjected to the artificial heat and dehumidification of buildings or where appreciable shrinkage can be tolerated. All types of out-buildings, such as sheds and barns, can usually be safely constructed of air-dried lumber. Air-dried lumber is also satisfactory for products used outdoors, such as boxes and crates, parts of agricultural implements, and truck and trailer bodies.
Softwood lumber intended for framing in construction is usually targeted for drying to an average moisture content of 15%, not to exceed 19%. Softwood lumber for many other uses is dried to a low moisture content, 10% to 12% for many appearance grades to as low as 7% to 9% for furniture, cabinets, and millwork. Hardwood lumber for framing in construction, although not in common use, should also be dried to an average moisture content of 15%, not to exceed 19%. Hardwood lumber for furniture, cabinets, and millwork is usually dried to 6% to 8% moisture content.
Of Building Materials Are Affected by:

- Climate
- Temperature
- Humidity of surrounding air
- Direct Wetting
- Direct exposure to precipitation or water infiltration
TEMPERATURE OF WOOD

From Electric Moisture Meters for Wood
## EQUILIBRIUM MOISTURE CONTENT

Table 12-1. Equilibrium moisture content of wood, exposed to outdoor atmosphere, in several U.S. locations in 1997

<table>
<thead>
<tr>
<th></th>
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<td>15.1</td>
<td>13.9</td>
<td>13.8</td>
<td>13.9</td>
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<td>18.0</td>
<td>17.7</td>
<td>18.1</td>
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<td>13.3</td>
<td>13.3</td>
<td>13.3</td>
<td>13.4</td>
<td>13.3</td>
<td>14.2</td>
<td>14.4</td>
<td>13.9</td>
<td>13.0</td>
<td>13.7</td>
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<td>ID</td>
<td>Boise</td>
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<td>10.0</td>
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<td>9.0</td>
<td>7.3</td>
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<td>8.4</td>
<td>10.0</td>
<td>13.3</td>
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<td>Las Vegas</td>
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<td>7.7</td>
<td>7.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.0</td>
<td>4.5</td>
<td>5.2</td>
<td>5.3</td>
<td>5.9</td>
<td>7.2</td>
<td>8.4</td>
</tr>
</tbody>
</table>

*EMC values were determined from the average of 30 or more years of relative humidity and temperature data available from the National Climatic Data Center of the National Oceanic and Atmospheric Administration.
Failure Criteria
by Harri Viitanen and Mikael Salonvaara

Failure often has a fatal effect on the service life and durability of materials. Durability of materials to different agents varies: weather, water, heat, humidity, radiation (mold and decay fungi, bacteria). Performance requirements of materials and structures should be different for inside surfaces, inside structures (interior layer), and outside surface and structures, and the effect of different organisms on the service life should be verified carefully.

Organisms can have permanent or temporary effects (esthetic or technical) and the requirements for repair of problems are varied. Performance requirements and quality of items vary for different targets. For example, mold growth on the inside surface of buildings can be more serious for the use of buildings than mold on the outside surface of buildings due to the potential health risk of microbe. Mold growth also has different effects on the substrate itself: in some cases, mold destroys materials (e.g., wall papers and paints) or mold is only a superficial layer on the materials (e.g., tiled walls or fences). Mold or mildew is a general classification of organisms growing on the surface of materials (discouraging organisms or fungi). Blue-stain fungi are a special part of discouraging fungi. They can penetrate into the sapwood of several wood species and cause color change in the wood material.

Damage classes are varied and have different effects on the durability and service life of materials. For example, mildew (or mold fungi) on the surface of different materials often cause indirect effects (color changes, health problems) and do not always change the properties of materials. Decay fungi are a general classification of fungi-decaying wood and other wood-based materials. Bioncrocorrosion causes direct damage to materials, e.g., decay fungi and bacteria deteriorate different materials (wood-based materials, plastics, paper, metals, concrete, masonry). Bioncrocorrosion is often connected with corrosion of metals.

DEFINITIONS FOR “FAILURE”
In order to predict failures we first have to define the term. Failure involves direct changes in the properties of materials or structures. The changes or deformations can be of various degrees; excess moisture can cause reversible or irreversible deformations or degradation in performance resulting from physical changes, chemical or biological processes. One type of failure is increased heat loss caused by high moisture content in materials and air flow through building envelopes systems. Other types are mold growth, rot damage, freeze-thaw cycles resulting in structural failures, dimensional changes, corrosion, condensation of volatile organic compounds (VOC), etc. Some of these failures affect only the appearance of the systems under consideration, but some may have severe consequences such as risk to the health of occupants (sick building syndrome caused by VOC and mold) or structural collapse of the whole building.

Some definitions for failure and related phenomena are presented mainly in the ISO Performance Standards for Building—Classification of Terms (5707-1:1989) and in the references [1]. Here are some definitions compiled:

Failure: Termination of the ability of an item to perform a specified function.

Decay: Damage of material and structures.

Service life: Period of time after installation during which all essential requirements of an item are met or exceed the performance requirements.

Durability: Capability of a building or its parts to perform its required function over a specified period of time under the influence of the agents anticipated to service.

Degradation mechanism: Chemical, mechanical, or physical changes that lead to changes in critical properties of a building component when exposed to degradation agents.

Degradation agents: e.g., water, heat, organisms, chemicals, wrong use of building, construction defects, etc. They often have a synergistic effect (many agents are often needed for the development of damage).

Degradation or disintegration: Reduction in performance over time of a component or material.

Biocorrosion: Any undesirable change in the properties of a material caused by the vital activities of organisms.

Bioncrocorrosion: Layer on the surface of material consisting of inorganic and organic dust and organisms.

Biocorrosion: Reduction in the basic properties of material over time caused by the decaying activity of organisms (e.g., decay fungi and bacteria).

EXISTING STANDARDS AND BUILDING CODE REQUIREMENTS
There are different standards and recommendations defining the service life or durability of materials, e.g., ISO Performance Standards in Building—Checklist for Briefing—Contents of Brief for Building Design Standards (9699)
DECAY FUNGI

BROWN, SOFT, AND WHITE ROT
DECAY FUNGI

BROWN, SOFT, AND WHITE ROT
FAILURE?
FAILURE?
FAILURE?
PUBLISHED THRESHOLDS

- International Energy Agency (IEA)
- CSA S478 – 95 Guideline on Durability in Buildings
- BSI - Guide to Durability of Buildings and Building Elements, Products and Components
HUNT AND GARRATT RECOMMEND A GUIDELINE OF 20% MOISTURE CONTENT

GRIFFIN DOCUMENTED THAT MC MUST BE ABOVE FIBER SATURATION POINT, AROUND 28% TO 30% FOR DECAY FUNGI TO GROW EFFECTIVELY IN WOOD

INTERNATIONAL ENERGY AGENCY PUBLISHED CRITERIA REGARDING MOISTURE TOLERANCES FOR WOOD PRODUCTS AT SURFACE RELATIVE HUMIDITY OF 80% ON A MONTHLY BASIS CAN PERMIT MOLD GROWTH

LIMITING MOISTURE CONTENT IS THE PRIMARY METHOD OF PREVENTING DECAY FUNGI
Designation: D 4442 – 92 (Reapproved 2003)

Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

This standard is issued under the fixed designation D 4442; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope
1.1 These test methods cover the determination of the moisture content (MC) of solid wood, veneer, and other wood-base materials, including those that contain adhesives and chemical additives. The test methods below describe primary (A) and secondary (B through D) procedures to measure moisture content:

   Method A—Primary Oven-Drying Method
   Method B—Secondary Oven-Drying Method
   Method C—Distillation (Secondary) Method
   Method D—Other Secondary Methods

1.2 The primary oven-drying method (Method A) is intended as the sole primary method. It is structured for research purposes where the highest accuracy or degree of precision is needed.

1.3 The secondary methods (B through D) are intended for special purposes or under circumstances where the primary procedure is not desired or justified. In these procedures, moisture content values cannot be reported with an accuracy greater than integer percentage values. However, a greater level of accuracy may be reported if the appropriate primary procedures are used.

1.4 Distillation (secondary) method is intended for use with materials that have been chemically treated or impregnated such that the oven-drying procedures introduce greater error than desired in the results.

1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:
   D 9 Terminology Relating to Wood
   D-933 Guide for Moisture Conditioning of Wood and Wood-Base Materials

3. Terminology

3.1 Definitions:

   3.1.1 moisture content—amount of water contained in the wood, usually expressed as a percentage of the mass of the oven-dry wood (in accordance with Terminology D 9).

   3.1.2 Discussion—The moisture content of wood or other wood-based materials can be expressed either as a percentage of the mass of the oven-dry sample (oven-dry basis) or as a percentage of initial mass (wet basis). The methods described in this standard refer to the oven-dry basis. Because oven-dry mass is used, moisture content values may exceed 100 %. The term moisture content when used with wood-based materials can be misleading since untreated wood frequently absorbs varying amounts of volatile components (extractives which are evaporated when determining moisture content). Definition of the moisture content of wood is further complicated when determined by a thermal method because of thermal degradation, which causes the final moisture-free mass to decrease from small but continuous losses.

4. Significance and Use

4.1 Moisture content is one of the most important variables affecting the properties of wood and wood-base materials. The procedures in these test methods are structured to permit the full range of use from fundamental research to industrial processing. Method A is designed for obtaining the most precise values of moisture content consistent with the needs of the user. It also provides means of assessing variability contributed by the oven or specimen hygroscopicity, or both. In addition, criteria are described for defining the endpoint in oven-drying. Method A is the reference (primary) standard for

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Test Methods D 4442 – 92 (Reapproved 2003)

D 9 Terminology Relating to Wood

D-933 Guide for Moisture Conditioning of Wood and Wood-Base Materials

Copyright ASTM International, 100 Barr Harbor Drive, PO Box C70, West Conshohocken, PA 19428-2959, United States.
1. Scope

1.1 These test methods apply to the measurement of moisture content of solid wood, including veneer, and wood products containing additives, that is, chemicals or adhesives (subject to conditions in 6.4 and 9.4). They also provide guidelines for meter use and calibration by manufacturers and users as alternatives to oven-dry measurements.

1.2 Conductance and dielectric meters are not necessarily equivalent in their readings under the same conditions. When these test methods are referenced, it is assumed that either type of meter is acceptable unless otherwise specified. Both types of meters are to be calibrated with respect to moisture content on an oven-dry mass basis as determined by Test Methods D 4442.

1.3 The method title indicates the procedures and uses for each type of meter:

<table>
<thead>
<tr>
<th>Method</th>
<th>Conductance Meters</th>
<th>Dielectric Meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Section 8 to 10</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Section 8 to 10</td>
<td></td>
</tr>
</tbody>
</table>

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

- D 4442 "Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials"\(^1\)
- D 4933 Guide for Moisture Conditioning of Wood and Wood-Based Materials\(^2\)

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 Conductance meters—Conductance meters are those devices that measure predominantly ionic conductance between pairs of applied voltage, usually dc. Direct-current conductance meters are commonly referred to as "resistance" meters. Most commercial conductance meters have high input impedance (about 10^10 Ω), wide-range (10^5 to 10^7 Ω) ohmmeters. Their scales are calibrated to read directly in moisture content (oven-dry basis) for a particular calibration species and at a specific reference temperature. Readings of conductance meters are practically independent of the relative density (specific gravity) of the specimen material.

3.1.2 Dielectric meters—There are two general types of dielectric meters that may be arbitrarily categorized by their predominant mode of response—power loss and admittance (or permittivity). Both have surface contact electrodes and readout scales that are usually marked in arbitrary units. Most dielectric meters operate in the r-f frequency range, generally between 1 and 10 MHz. Admittance meters respond primarily to capacitance (dielectric constant) of the material being measured. Power loss meters react primarily to resistance of the material. Readings of dielectric meters are significantly affected by the relative density (specific gravity) of the specimen material.

4. Significance and Use

4.1 Hand-held meters provide a rapid mean of sampling moisture content of wood-based materials during and after processing to maintain quality assurance and compliance with standards. However, these measurements are inferential, that is, electrical parameters are measured and compared against a calibration curve to obtain an indirect measure of moisture content. The electrical measurements are influenced by actual moisture content, a number of other wood variables, environmental conditions, geometry of the measuring probe, and design of the meter. The maximum accuracy can only be obtained by an awareness of the effect of each parameter on the meter output and verification of readings as specified by these test methods.
## LABORATORY DATA

<table>
<thead>
<tr>
<th>Meter</th>
<th>Pine</th>
<th>OSB</th>
<th>Plywd</th>
<th>Int Gyp</th>
<th>Ext Gyp</th>
<th>FG Faced</th>
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<tr>
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<td>0.1</td>
<td>0.1</td>
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<tr>
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<td>6.5</td>
<td>&lt;6</td>
<td>6.5</td>
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**EMC, April 2006, 70 degrees F, 35% RH**

<table>
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<th>Plywd</th>
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**EMC, October 2006, 70 degrees F, 75% RH**
CASE STUDY #1

- EIFS
- Plywood
- Vapor Retarder
CASE STUDY #1

- 44.3% March 2005
- 37.2% November 2006
IV. Moisture Readings
CASE STUDY #2

- EIFS
- WRB
- Plywood
- Vapor Retarder
IV. Moisture Readings

November 2002
Case Study #3

Stone
WRB
Plywood
Vapor Retarder
IV. Moisture Readings

19, 21 Benedict
26, 27

April 2003
### Moisture Inspection Report

<table>
<thead>
<tr>
<th>Section</th>
<th>Action</th>
<th>Description</th>
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<td>E3</td>
<td>Crack</td>
<td>Crack in EIFS on accent band at window needs to be properly sealed.</td>
</tr>
<tr>
<td></td>
<td>Windows</td>
<td>Firm</td>
</tr>
<tr>
<td>C7</td>
<td>Crack</td>
<td>Crack in stone/rock at EIFS needs to be properly sealed.</td>
</tr>
</tbody>
</table>

**Annex: views**

Building #34 - Type Edgewood
19821 Benedict Crescent
Basking Ridge, NJ 07920

June 2007
REMEDIAL ACTIONS

If decay of wood products is suspected, an inspection should be made by a trained professional, especially if the decay involves structural elements. If decay has occurred, it is imperative to identify and correct the source of moisture. If the source of moisture is eliminated and the wood products are dried down below the threshold moisture content for decay, then the decay will cease its progression. Although it is usually advisable to remove the decayed areas, it is not always necessary if the moisture source is eliminated and the structural integrity is not compromised. Reduction of the moisture content will not kill the decay, as spores will still be present. The decayed area will re-establish its growth if the moisture contents exceed 20 to 25%.

APA – Controlling Decay in Wood Construction
CONCLUDING REMARKS

- Moisture Meters Can Be Useful Tool
  - Quality Control for Construction
  - Identifying Extent of Moisture Effects on Framing and Sheathing
    - Localized Point Sources of Water Intrusion
    - Uniform Moisture Levels From Environmental Influences
- Monitoring Changes in Moisture Content
- Diagnosing Causes and Sources of Water Intrusion
- Understand and Consider Limitations
CONCLUDING REMARKS

- Careful Interpretation of Data
  - Seasonal Variations
    - Humidity
    - Temperature
    - Precipitation
  - Substrate type

- Can Materials Serve Their Intended Function
  - Load Bearing
  - Lateral Resistance
  - Support For Cladding

- Understanding the Difference between Design Guidelines and Failure Criteria