MOISTURE AND WOOD

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National Wood Flooring Association

NOTICE

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The information contained in this publication represents widely accepted industry practices. There are, however, no universally approved methods of troubleshooting wood floors. Therefore, manufacturers' recommendations for use of specific products should always supersede the recommendations contained in this publication.

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INTRODUCTION

Wood is one of the oldest building materials known to man and has given us the opportunity to create things by hand that no other building material can claim.

Discoveries from Ancient Egypt have unearthed wooden ships dating as early as 3000 B.C. Pagodas in Japan were built out of wood nearly 1,400 years ago, and still stand strong today in highly seismic, extremely wet environments. A 3,960 foot bridge built in 1850 above Taungthaman Lake is still strong and in use today. The world's tallest structure made entirely of wood (fasteners and all), is a church in Russia built in 1862, standing 123 feet tall.

Wood floors are one of the rare building products that inherently showcase the natural beauty of the material itself, which is indicative of why wood has been used as a flooring material for centuries. One of the keys to ensuring a wood floor's timeless beauty is having a fundamental understanding of the relationship between moisture and wood.

Moisture is the term we use in this publication to denote any or all states of water: gas (water vapor or steam), liquid (water), and bound water (chemically bound within the wood cell walls).

This publication will explore the relationships between moisture and wood as related to the methods and procedures involved when using it as a flooring material.

THE BIOLOGICAL NATURE AND ANATOMY OF WOOD

All woody plants, whether shrubs, woody vines, or trees, share similar biological characteristics that produce wood as their structural tissue. When considering only trees, there are two general categories of wood: softwoods from conifers or gymnosperms (pine, spruce, Douglas fir, etc.), which are cone-bearing plants with needle-like leaves, and hardwoods from angiosperms (maple, oak, hickory, etc.), which are broadleaved plants with enclosed seeds. Despite the names, some hardwoods are soft, and some softwoods are hard; the terms are biological in nature and not necessarily literal.

Softwood

- Needle-bearing
- Remain green year-round
- Come from gymnosperm trees (uncovered seeds, like pinecones)
- Pine, spruce, Douglas fir, cedar, etc.

Hardwood

- Leaf-bearing
- Lose leaves annually
- Come from angiosperm trees (enclosed seeds, like acorns)
- Oak, maple, ash, cherry, etc.

Tree Anatomy

Simply put, knowing that all trees grow with roots below ground and leaves above ground is the basis for understanding wood as the water-conducting tissue of any given plant.

Roots

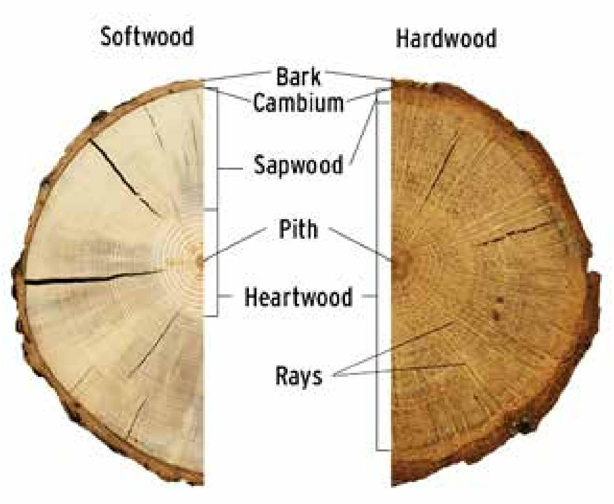
The roots help anchor the tree and collect water and nutrients from the soil. This liquid then travels through the trunk and branches to the leaves.

Leaves

The leaves absorb carbon dioxide from the air and energy from the sun, which enables photosynthesis to happen.

Photosynthesis

The process by which trees use energy from the sun, water, and carbon dioxide to create their own sugars (glucose). Long chains of glucose form cellulose molecules. Bundles of cellulose are called microfibrils, which form one of the major structural components of the tree's cell walls.



Bark
The exterior layer of the tree is outer bark, which provides protection from the environment. The inner bark is living tissue that transports glucose to growing parts of the tree.

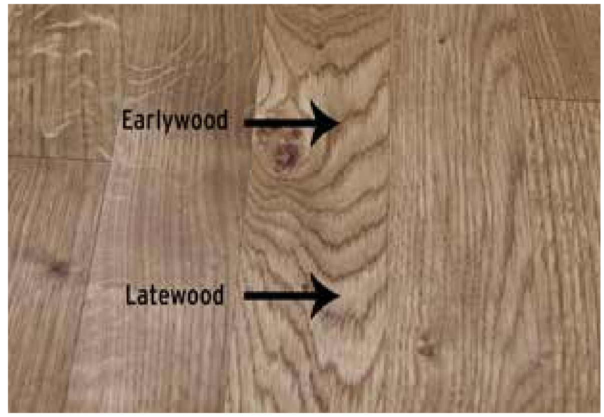
Cambium
The next layer inward, between the bark and wood, is the cambium. The cambium is a thin layer less than 1/16 of an inch thick that is responsible for increases in the tree's diameter by creating new growth rings of wood to the inside and new inner bark to the outside.

Sapwood
The outermost growth rings that are alive and functional (water transport and food storage) are referred to as sapwood, which can vary in appearance and width, by species.

Heartwood
Wood in the center of a large tree, referred to as heartwood, is composed of often darker-colored inactive cells. The chemicals these cells store, called extractives, determine their color.

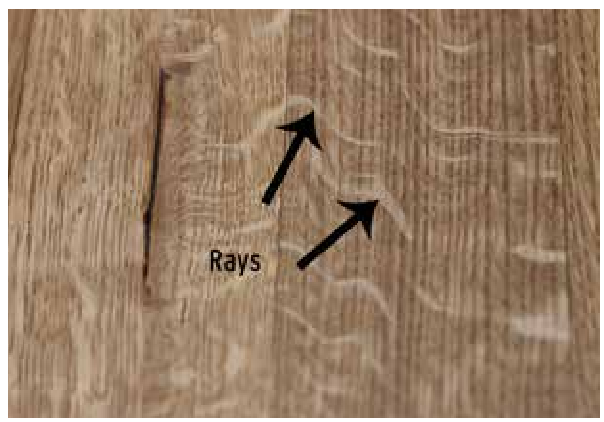
Pith
The small, soft core, occurring near the center of the tree trunk, branch, twig or log.

Growth Rings
As the tree grows, it develops growth rings. The growth rings of hardwoods are composed in part of special cells called vessels or pores that carry water up to the leaves. Each growth ring is essentially a thin cone from the top of the tree to the bottom of the trunk, and through to the roots.



Earlywood
The inner portion of the growth ring is called the earlywood (or springwood), which is formed during the early part of the growing season. In some woods, earlywood is identifiable by larger cell cavities. Earlywood is less dense than latewood and has wider vessels to transport nutrients.

Latewood
The outer portion of the growth ring is called the latewood (or summerwood), which is formed later in the growing season each year. Latewood is more dense than earlywood and has narrow vessels.



Rays
A defining feature in wood is the presence of rays (wood rays), which run from the bark toward the center of the tree, much like spokes on a bicycle wheel. These rays are made of living cells in the tree that help move sugars and other materials from pith to bark, as well as provide other biochemical functions to trees. Because they are a system of cells running perpendicular to the grain, the rays can contribute visual interest to finished flooring depending on how the boards are cut from the log. This is often referred to as ray-fleck.

HARVESTING, SAWING AND SEASONING LUMBER

In the United States, most hardwood comes from privately owned forests, and most privately owned forests are just a few hundred acres in size. Larger forests tend to be commercially owned operations. Hardwood forests are regenerated by natural cycle or by new plantings. As a general rule, it takes at least 40 years for an oak tree to grow to maturity and to a size large enough to cut for useable lumber, but most oak trees are harvested at about 60 years. This means the inventory is available an average of 20 years before it is needed or used.

Harvesting Lumber

When trees are harvested for wood flooring, the milling process usually works this way:

First, the tree is selectively harvested from the forest. Only trees of the necessary height and diameter are selected. It is important to the health of the forest that these trees are removed before they start to decay, as decayed wood is not usable and no longer produces oxygen. In addition, clearing older trees allows younger trees to reach the forest canopy.

Next, the log is rough cut to the desired length. Maximum lengths are maintained whenever possible. All branches are cut (limbed) from the log. The logs are then removed from the forest, loaded onto logging trucks, and delivered to the mill yard.

Milling Process

The handling of the lumber when it gets to the mill is very important and is dependent on its intended end-use.

At the mill, the bark is first removed from the log. All bark, saw dust and other non-usable wood fiber is collected and used for other purposes, like heating the facility or manufacturing wood pellets or mulch.

For sawn or sliced material, the rounded edges are then removed to produce a square log called a cant.

The square logs are next cut into wood slabs at a predetermined thickness, maximizing the usable lumber. The slab edges are then trued and trimmed square, creating what we typically call a lumber board.

Each board is then sorted by quality and classified by grade.

Drying Process

Like most biological entities, trees have a high water content. Water can comprise more than 2/3 the weight of a living tree. In order to use wood as a building material most of this water must be removed. The natural removal of this water begins immediately after the tree is cut down, but is managed during the seasoning process.

After sorting, boards are stacked to facilitate air movement and begin the air-drying process. This is accomplished by placing small, thin boards called "stickers" between each stacked layer of wood. This maximizes air movement, which helps to bring the moisture content of the lumber into equilibrium with its surrounding environment. The temperature, humidity and airflow will influence the time needed to reduce moisture content of the wood. The goal is generally to reach 18-30% moisture content.

Kiln-Drying Lumber

In order to get the lumber dried to a level appropriate for interior use, the lumber typically be dried in a kiln. A kiln is a large oven that provides a controlled environment that removes moisture using a combination of heat and airflow. Temperatures typically range from 100-180 degrees Fahrenheit and help to slowly remove moisture from the wood. Kilns typically dry the lumber down to a moisture content between 6-9%. Kiln drying also results in sterilizing the wood by destroying insects and fungi.

This drying process will cause dramatic dimensional changes. As the cells of the tree dry, they shrink in thickness and/or diameter, but shrink very little lengthwise. Shrinkage and swelling in response to moisture – strain – is characteristic of both hardwoods and softwoods. Drying makes wood shrink and adding moisture makes wood swell. These behaviors are related to wood moisture content and how the wood is cut from the tree.

To properly understand this process and how wood responds to moisture, it is important to first understand the properties of wood moisture content.

MOISTURE CONTENT

The moisture content of wood is measured as the weight of the water in the wood expressed as a percentage of the weight of the wood itself. The weight of the wood itself is obtained by drying the wood to a point where all of the moisture is removed. This is referred to as oven-dried. Weight, shrinkage, strength and other properties depend in part on the moisture content of wood. In trees, moisture content may be as much as 200%. After harvesting and milling, the wood should be dried to the proper moisture content for its expected end-use.

Moisture can exist in wood in two forms: as liquid or water vapor (free water) in the cell cavities (lumina), as well as water held chemically (bound water) within the cell walls.

Free Water

Free water is the moisture held in the cell lumina of the wood. This is the water in wood above fiber saturation point. Free water resembles liquid trapped in a saturated sponge. When you squeeze the sponge, the free water is released, but the sponge does not change shape.

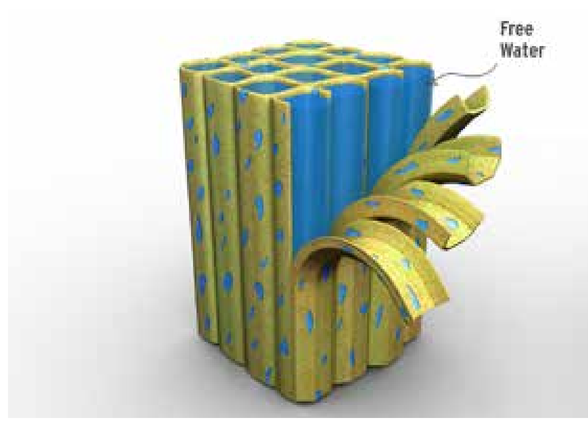
Bound Water

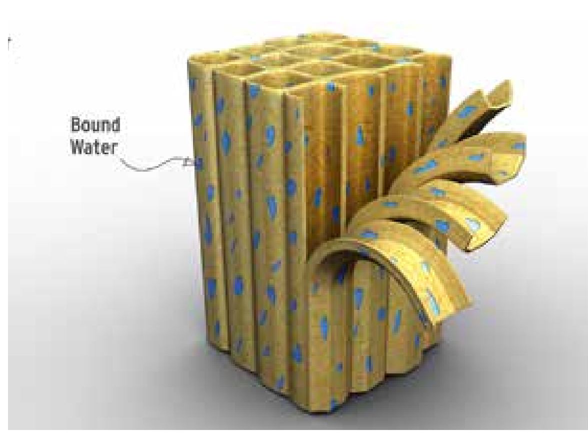
Once all of the free water is gone from the cell lumina, only bound water remains. Bound water is held by chemical or hydrogen bond within the cells of the wood. When only bound water remains, the cells have reached the fiber saturation point.

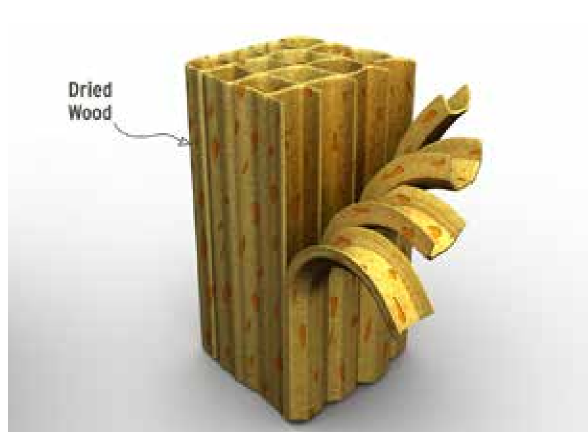
Fiber Saturation Point (FSP)

The fiber saturation point is the moisture content at which the cell walls are completely saturated (all bound water), but no water exists in the cell lumina. FSP is usually between 25-30%, depending on the species. In the sponge analogy, this is when the sponge still feels damp, but you are unable to squeeze any more water from it. Below the FSP, all moisture gained or lost is bound water. As the wood gains or loses bound water, the dimension of the wood begins to change.

How the wood changes dimension is largely influenced by the species characteristics and the way in which the wood is cut from the tree.







GRAIN ANGLE AND DIMENSIONAL STABILITY

Wood is an anisotropic material, meaning it shrinks and swells differently in each direction. Wood shrinks and swells the most circumferentially around the growth rings (tangentially), about half as much across the rings (radially), and only in miniscule amounts along the grain (longitudinally).

Shrinkage and Swelling

Tangential
Tangential movement of wood is a measurement of the amount the wood shrinks or swells across the circumference of the growth rings. Average values for tangential shrinkage from fiber saturation point to oven-dry are between 5-15% for most species of wood.

Radial
Radial movement of wood is a measurement of the amount the wood shrinks or swells perpendicular to the growth rings. Average values for radial shrinkage from fiber saturation point to oven-dry are between 2-8% for most species of wood.

Longitudinal
Longitudinal movement of wood is a measurement of the amount the wood shrinks or swells along the grain/ wood fibers. Average values for longitudinal shrinkage from fiber saturation to oven-dry are between .1–.2% for most species of wood. Wood from near the center of the tree (juvenile wood/pith) of some species can shrink up to 2% or more from fiber saturation point to oven-dry.

Grain Angle

The strain characteristics of wood are affected by how the wood was cut from the tree, or the grain angle, which describes the orientation of the growth rings with respect to the wide face of the board. Traditional sawn material can be cut in any of the ways described on the following page:

Plainsawn

Wood that is cut parallel to the growth rings so that the growth rings are cut from 0° to 45° to the wide face of the board (a tangential cut) is called plainsawn in hardwoods, and flatsawn in softwoods. Plain sawn flooring is more dimensionally stable in thickness (radially) and less stable in width (tangentially).

Quartersawn

Wood that is cut perpendicular to the growth rings so that the growth rings are cut from 45° to 90° to the wide face of the board (a radial cut) is called quartersawn in hardwoods, and vertical-grain in softwoods. Quartersawn lumber is more dimensionally stable in width (radially) and less stable in thickness (tangentially).

Riftsawn

Wood that is cut neither parallel nor perpendicular to the growth rings so that the growth rings make angles of 30° to 60° to the face of the board is known as riftsawn in hardwoods or bastard-sawn in softwoods.

Livesawn

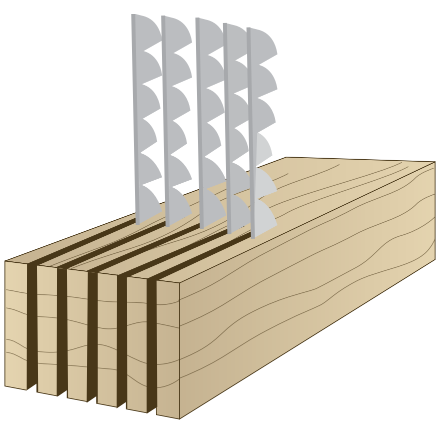
Wood that is cut from the outside diameter through the heartwood incorporating the full range of the above characteristics on the face of the board is known as live-sawn material. This cut of wood is typically wider and incorporates all of the above dimensional stability and aesthetic characteristics.

End-Grain
Wood that is cut so that the face of the board surface exposes the ends of the growth rings is the transverse cut, more often known as end-grain. End-grain flooring will shrink and swell according to the tangential value in the direction across the circumference of the growth rings and according to the radial value in the direction perpendicular to the growth rings, with essentially no movement in thickness.

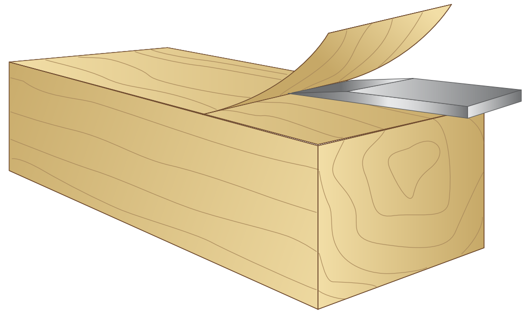
Engineered Wear Layers

Engineered wood flooring is intentionally designed to be more dimensionally stable by adhering the top veneer (or lamina) to a platform that may be made up of a veneer, composite or lumber core material. The construction of these products makes them inherently more stable than their solid counterpart.

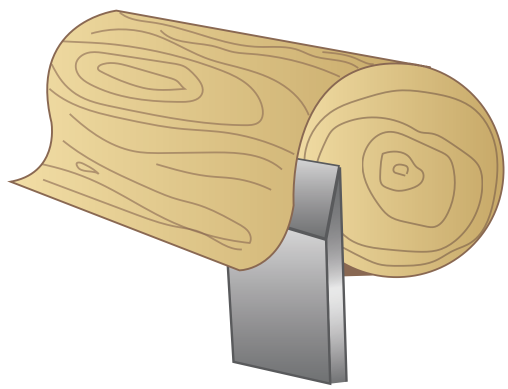
The top veneer (or lamina) of engineered flooring may be cut by 3 different methods, which are referred to as sawn, sliced and rotary peeled. These cuts affect the construction and performance requirements for each product.



Sawn Veneers
With sawn veneers, the wood is sawn in the same fashion as normal solid wood flooring, and are available in all of the cuts previously mentioned. The only difference is the thickness of the cut.



Sliced Veneers
With sliced veneers, the cant is drawn across an angled blade. The process is repeated until the whole cant has been turned into a veneer. The appearance of sliced veneer is similar to sawn veneer and will have the same natural, physical, and strain characteristics. However, slicing has thickness limits and the process can stress the wood fibers.



Rotary-Peeled Veneers
With rotary-peeled veneers, full logs are positioned on a large lathe and spun against a sharp blade. The log continues to spin until the entire log has been turned into a veneer. This technique produces the least amount of waste. Rotary-peeled veneers have a distinct, purely tangential grain pattern. The grain pattern will repeat on wide sheets.

Dimensional Stability

Dimensional stability is the degree to which a piece of solid wood maintains its original (manufactured) dimensions when subjected to changes in moisture content. (For a species comparison of dimensional stability, see NWFA Technical Publication No. A200: Wood Species Used in Wood Flooring.)

How the dimensional stability of a piece of solid wood flooring affects performance depends on how the board was cut from the log – the grain angle. As a general rule, plainsawn flooring will tend to shrink and swell more in width than quartersawn flooring, and solid flooring will not shrink or swell measurably in length.

Dimensional Change Coefficient

Different grain angles result in different properties of movement of solid wood in response to changes in moisture content. The Forest Products Laboratory of the U.S. Department of Agriculture developed the values in the accompanying chart. These values reflect the dimensional change coefficient (DCC) for the various species, measured as tangential shrinkage or swelling within normal moisture content limits of 6-14%.

The DCC can be used as a tool to determine approximately how much shrinkage or swelling to expect in solid wood with change in moisture content. A simple calculation can provide an idea of what to expect when the environmental conditions change. Simply multiply the change in moisture content by the dimensional change coefficient value for the species of flooring. Then multiply the product by the width of the flooring material. The result will indicate an approximate shrink/swell per board value based on moisture gain/loss. Keep in mind, no two trees from the same species are identical, no two boards from the same tree are identical, and properties can vary even within one individual plank of wood.

In actual practice, shrinkage and swelling may be diminished by the boards' proximity to each other, installation methods, fastening systems and moisture interactions from the substrate. These can all influence how an installed floorboard performs when it changes MC.

DIMENSIONAL CHANGE COEFFICIENT

(for common flooring species)

HARDWOODS		SOFTWOODS		IMPORTED WOODS	
SPECIES	C_T	SPECIES	C_T	SPECIES	C_T
Mesquite	0.00129	Cedar, Eastern Red	0.00162	Merbau	0.00158
Chestnut, American	0.00234	Pine, Eastern White	0.00212	Australian Cypress	0.00162
Black Cherry	0.00248	Pine, Ponderosa	0.00216	Padauk	0.00180
Maple, Bigleaf	0.00248	Pine, Lodgepole	0.00234	Teak	0.00186
Locust, Black	0.00252	Spruce, Black	0.00237	Wenge	0.00201
Maple, Silver	0.00252	Hemlock, Eastern	0.00237	Iroko	0.00205
Alder, Red	0.00256	Heart Pine	0.00263	Cumaru*	0.00212
Ash, White	0.00274	Southern Yellow Pine	0.00265	Purpleheart	0.00212
Black Walnut	0.00274	Douglas Fir	0.00267	Spotted Gum*	0.00212
Ash, Oregon	0.00285	Hemlock, Western	0.00274	Mahogany, Santos	0.00238
Sycamore, American	0.00296			Sapele*	0.00259
Hickory, Pecan	0.00315			Brazilian Walnut/Ipe*	0.00282
Elm, American	0.00338			Jatoba	0.00300
Yellow Birch	0.00338			Brazilian Maple*	0.00312
Maple, Sugar/Hard	0.00353			Jarrah	0.00396
Sweetgum	0.00365			Sydney Blue Gum*	0.00466
White Oak	0.00365				
Red Oak	0.00369				
Hickory, True	0.00411				
American Beech	0.00431				

**The estimated DCC was derived using a green to oven-dry tangential shrinkage values from Wood Handbook and other resources, assuming a 30% FSP. It is possible, however, that FSP may be less than 30% with some of these species, affecting the values given.*

EQUILIBRIUM MOISTURE CONTENT (EMC)

The moisture content of wood below the fiber saturation point is a function of both relative humidity and temperature in the surrounding air. When wood is neither gaining nor losing moisture, equilibrium moisture content (EMC) has been reached.

The ideal average moisture content for flooring installation can range from extremes of 4-13% depending on many variables, including geographic location and time of year. Additionally, a wide range of conditions can be experienced between individual jobsites in the same locale, such as an ocean-front or lakeside home versus one that's a few miles inland. Before installation, the flooring product should be identified as being compatible with the area in which it is to be used.

Wood flooring will perform best when the interior environment is controlled to stay within a stable environment and the wood is installed at a moisture content corresponding to those interior conditions. Most wood flooring manufacturers dry their flooring to 6-9% MC, which directly coincides with a relative humidity range of 30-50% and a temperature range 60 to 80 degrees Fahrenheit. This 6-9% range is likely to be the average of all types of wood products used in a normal household environment, assuming common heating and cooling equipment is used to ensure human comfort.

The table below indicates the predicted equilibrium moisture content of wood at any given combination of temperature and relative humidity.

Using this table is a simple way to tie EMC and relative humidity together; for example, at 70°F, a relative humidity of 25% gives an EMC of 5.4%, and a relative humidity of 75% gives an EMC of 14.4%. A 50% swing in relative humidity produces an EMC change of about 9%. How this affects wood flooring depends on its cut, width and species as described and calculated in previous chapters.

Wood flooring is constantly exposed to both long-term (seasonal) and short-term (daily) fluctuations in relative humidity and temperature of the surrounding air. Thus, it is always undergoing at least slight changes in moisture content. These changes are usually gradual, and short-term fluctuations tend to only influence the surface of the wood flooring. The rate at which a wood flooring product reacts to these changes varies by species and construction. Note that moisture content changes can be slowed, but not entirely prevented by protective coatings.

MOISTURE CONTENT OF WOOD AT VARIOUS TEMPERATURE AND RELATIVE HUMIDITY READINGS

Fahrenheit	Celcius																			
30	-1.1	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
40	4.4	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
50	10	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
60	15.6	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
70	21.1	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
80	26.7	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
90	32.2	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
100	37.8	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
120	48.9	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
140	60	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
160	71.1	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95

Relative Humidity (percent)

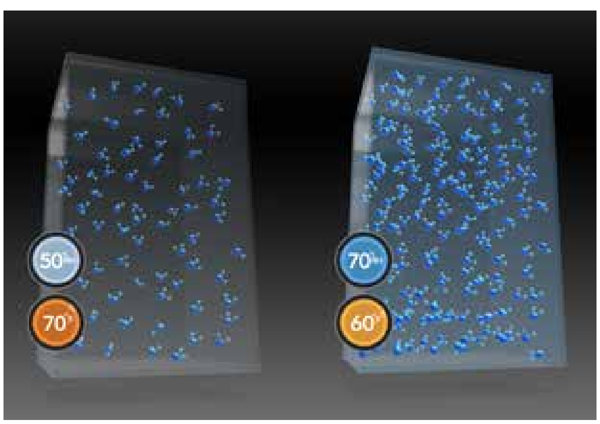
TEMPERATURE/RELATIVE HUMIDITY

In order to understand why temperature and humidity affect wood, it is important to understand the relationship between temperature and humidity.

Temperature is simply a measurement that indicates how hot or cold something is. In the United States we use the Fahrenheit (°F) scale. The majority of the rest of the world uses the Celsius (°C) scale.

Humidity is the amount of water vapor in the air. This air/water vapor mixture, when measured as the actual moisture in a given volume of air (or grains/ft^3) is absolute humidity ($H_{absolute}$). In regular usage, however, we use the term relative humidity (RH), which is the ratio of the amount of moisture in the air to the total amount of moisture the air can hold at that temperature. No matter how the property of humidity is expressed, the values are very much temperature dependent.

- Heating the air will increase its ability to hold moisture; therefore, the relative humidity decreases (absolute humidity remains the same).
- Cooling the air will decrease its ability to hold moisture; therefore, the relative humidity increases (absolute humidity remains the same).



As an example, a sealed box of air has a temperature of 70°F and a relative humidity of 50% (box on the left). With no manipulation to any property other than temperature, the same box of air at 60°F would have a relative humidity of 70% (box on the right). The reason is simple: cooler air is able to hold less water vapor than warmer air, so at 70°F the amount of moisture in the air at 50% is half the amount of moisture that the air can hold. At 60°F, however, that same amount of water in the same amount of air represents 70% of the total amount of water vapor that the air can hold.

Humidity is important because wood products exchange water molecules from the surrounding air based upon the amount of moisture in the air.

Testing Temperature and Relative Humidity

Hygrometers are instruments used for measuring the amount of water vapor in the air. There are a few types of these instruments, but in modern times, we employ digital thermo-hygrometers. These tools can typically read temperature, relative humidity, and less relevant properties like absolute humidity and dew point. Many of today's thermo-hygrometers are wireless, have data logging, and even have remote capabilities.

ACCLIMATION

The Process of Acclimating Wood

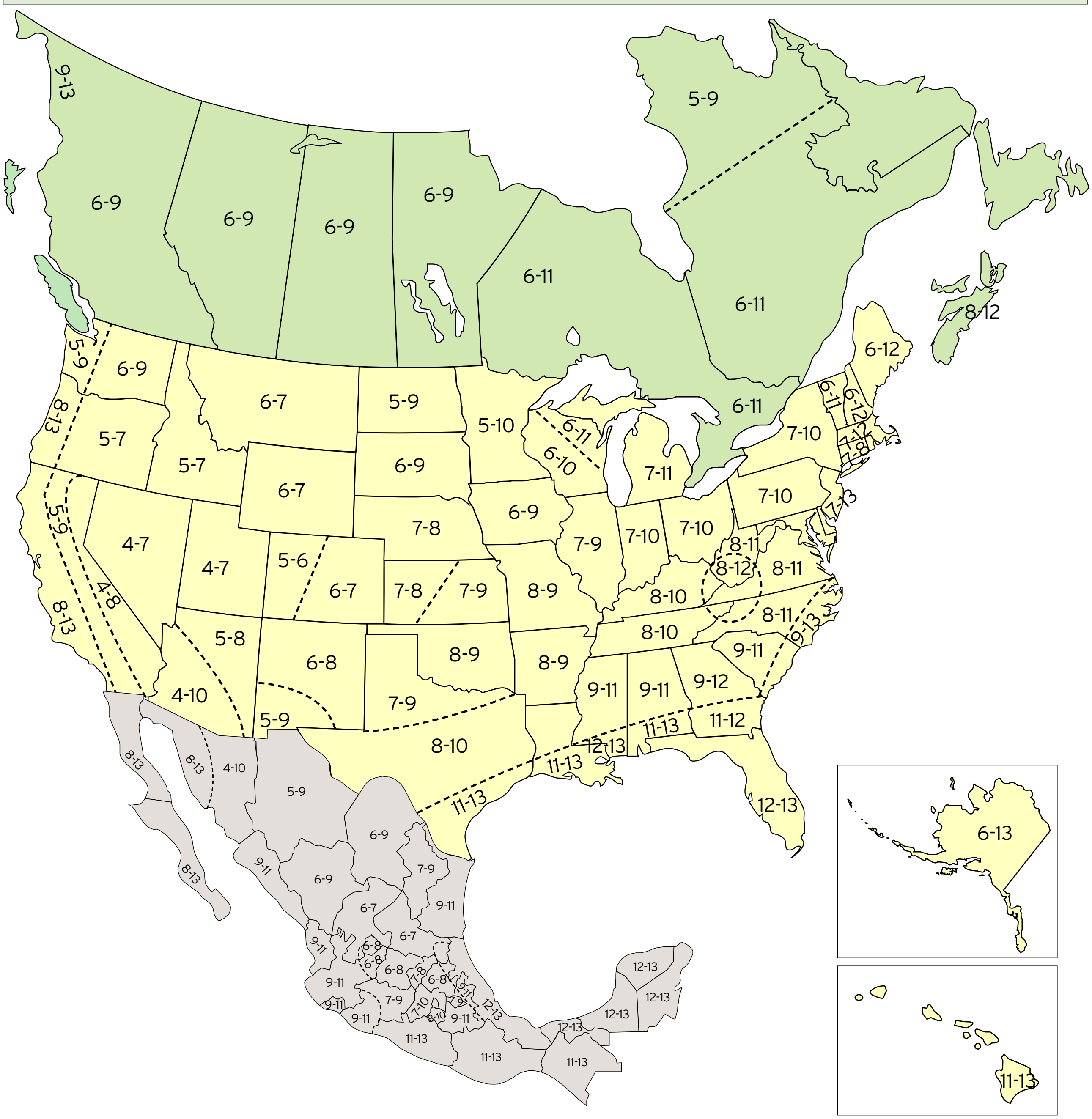
The process of allowing a wood floor's moisture content to equilibrate with the surrounding environment in which it will perform is defined as **acclimation**. Acclimation requirements for factory finished solid and engineered flooring is product- and manufacturer-specific; however, the simple rules of how wood interacts with its environment will not change.

To properly acclimate a wood floor, proceed as follows unless otherwise directed by the flooring manufacturer:

1. Interior environmental conditions vary from region to region and jobsite to jobsite. Determine what the expected in-use (e.g., normal living) conditions are and customize the floor selection around those conditions. This customized floor selection may include identifying species, cut, width, installation method, or whether to use solid or engineered flooring for each unique situation.
2. Ensure that the building is enclosed and all wet work is complete prior to delivery of the materials.
3. Verify gutters, downspouts and soil surrounding the property are placed/graded to drain water away from the building and the crawlspace meets required criteria detailed within this publication and/or local building codes.
4. Verify that the room and building receiving new flooring is maintained at the expected in-use (e.g., normal living) conditions for temperature and humidity for a minimum of five days preceding installation to promote proper conditioning of the space (longer jobsite conditioning may be necessary due to tighter building envelopes). These same conditions should be maintained during and after installation. Check the moisture content of exposed wood products on the jobsite and compare with the values on the EMC chart to ensure they coincide. Permanent or temporary heating, cooling, humidification or dehumidification systems may be necessary to achieve and maintain these conditions.
   Note that the use of temporary propane heating systems will introduce moisture to the environment. Large amounts of water are produced with the combustion of propane. These systems should be avoided during the acclimation process.
5. Do not store wood flooring in uncontrolled environmental conditions.
6. Upon delivery, check wood flooring moisture content and/or the product specifications on the packaging to ensure it is compatible with the conditions. Record, date, and document all results. Check other wood materials on the jobsite for comparison.
7. Engineered wood flooring should not be delivered, nor packages opened, on a jobsite that is outside of the conditions set forth by the manufacturer of the flooring product.
8. For solid wood, check and record the moisture content of multiple boards from a variety of bundles. Take MC readings on a minimum of 40 boards for every 1,000 square feet of flooring and average your results. In general, more readings will result in a more-accurate average number. Any unusually high or low moisture readings should be isolated and addressed individually.
9. If wood flooring is delivered at a moisture content that coincides with the expected in-use (e.g., normal living) conditions of the facility, and these conditions are maintained, no on-site acclimation may be required.
10. If the moisture content of the solid flooring product is outside of the range of these expected in-use (e.g., normal living) conditions, acclimation of the product to these conditions will be required in order to get the flooring and the facility aligned. This may include introducing moisture to the wood or removing moisture from the wood prior to installation. When doing so, you must take into account that the increase/decrease in moisture may distort the wood, which could adversely affect the installation.
11. When solid flooring needs time to acclimate to the environment, this can be facilitated by separating the flooring into small lots and/or completely opening the packaging. Then cross stack the materials with spacers (3/4-inch to 1-inch stickers) between each layer of flooring to allow air circulation on all sides of all boards until EMC has been reached.
12. Prior to installation, ensure the wood flooring is within acceptable range of moisture content relative to the wood subfloor. For solid strip flooring (less than 3 inches wide), there should be no more than 4% moisture content difference between properly acclimated wood flooring and wood subflooring materials. For solid plank flooring (3 inches or wider), there should be no more than 2% difference in moisture content between properly acclimated wood flooring and wood subflooring materials. If the moisture content of the subflooring and wood flooring are outside of these tolerances, the flooring should not be installed until it is within the proper range.

While it takes time to acclimate a product, the ultimate goal is to get the materials to reach a moisture content that is in equilibrium with the expected end-use environment. Bringing wood flooring to equilibrium includes conditioning the materials in a stable environment as long as necessary to ensure the materials have reached the proper moisture content based on the temperature and humidity levels of the facility. However, once the environmental conditions change above, and/or below the floor, so will the moisture content of the flooring.

MOISTURE MAP OF NORTH AMERICA



The numbers on the accompanying map provide examples of how average moisture contents for interior use of wood products vary from one region to another, and from one season to another within a region. Actual moisture content conditions in any location may differ significantly from these numbers.

MOISTURE TESTING CHECKLIST

Test and record temperature, humidity and moisture content of wood flooring and substrate, and compare with material selection requirements.

TEMPERATURE/RELATIVE HUMIDITY

Flooring Manufacturer Acclimation Requirements: __________

____

Temperature: Min________ F/C Max________ F/C

Relative Humidity: Min________% Max________%

Thermo-hygrometer Used: __________________________

WOOD FLOOR MOISTURE TESTING

Moisture Meter Type: __________________________

Name: ________________ Model: __________________

Meter Species Correction: ______________________

Number of Readings: ___________________________

High Reading: ______________ Low Reading: __________

Comparison Readings (trim, door, cabinets, etc.): __________

____

Areas of Concern: ____________________________

Average Reading (sum of readings/40): ______________

>> 40 Readings per 1,000 Square Feet (minimum) <<

1 ________	11 ________	21 ________	31 ________
2 ________	12 ________	22 ________	32 ________
3 ________	13 ________	23 ________	33 ________
4 ________	14 ________	24 ________	34 ________
5 ________	15 ________	25 ________	35 ________
6 ________	16 ________	26 ________	36 ________
7 ________	17 ________	27 ________	37 ________
8 ________	18 ________	28 ________	38 ________
9 ________	19 ________	29 ________	39 ________
10 ________	20 ________	30 ________	40 ________

WOOD SUBFLOOR

Meter Setting: ________________________________

Comparison Readings (trim, door, cabinets, etc.): __________

____

Number of Readings: ___________________________

Average Reading (sum of readings/20): ______________

>> 20 Readings per 1,000 Square Feet (minimum) <<

1 ________	6 ________	11 ________	16 ________
2 ________	7 ________	12 ________	17 ________
3 ________	8 ________	13 ________	18 ________
4 ________	9 ________	14 ________	19 ________
5 ________	10 ________	15 ________	20 ________

CONCRETE SUBSTRATE

Moisture Test(s) Required by Flooring Manufacturer:

- ☐ RH (ASTM F2170)
- ☐ Meter (ASTM F2659)
- ☐ CaCl (ASTM F1869)
- ☐ Other

Results of Required Tests: ________________________

____

Number of Tests: ______ Location of Tests: ______________

____

Moisture Test(s) Required by Adhesive Manufacturer:

- ☐ RH (ASTM F2170)
- ☐ Meter (ASTM F2659)
- ☐ CaCl (ASTM F1869)
- ☐ Other

Results of Required Tests: ________________________

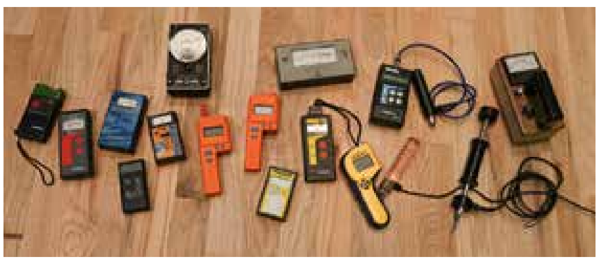
____

Number of Tests: ______ Location of Tests: ______________

____

TESTING MOISTURE IN WOOD

The determination of moisture content is an essential part of quality control within the flooring installation process. Flooring installers must know the moisture content of not only the wood flooring, but of the substrate as well. Hand-held electronic moisture meters should be a critical part of every flooring contractor's toolbox. Moisture content (MC) from 5-30% may be determined using various moisture meters developed for this purpose.



Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials (Oven Dry Method – ASTM D4442)

The most accurate method in all cases, and for any moisture content, is to determine gravimetric moisture content by following ASTM D4442, which requires weighing the piece of wood with moisture, removing the moisture by fully drying it in an oven (102°C-105°C or 215°F-220°F) and then reweighing.

The equation for determining moisture content is:

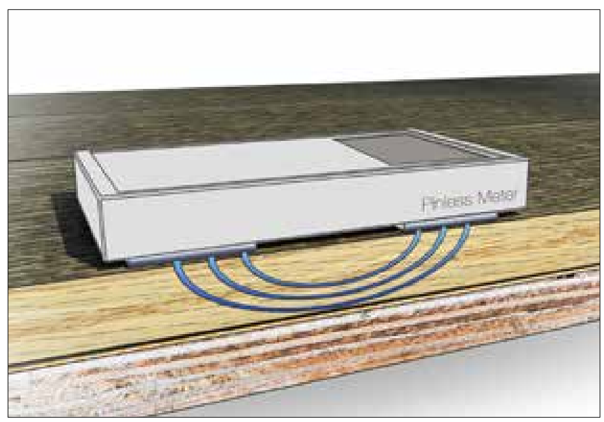
$$\frac{\text{(weight of wood with water - oven-dry weight of wood)}}{\text{oven-dry weight of wood}} \times 100 = \text{MC (\%)}$$

Moisture Meters

Moisture meters can measure the MC and provide information to help the user:

- Determine if floor boards are properly acclimated/conditioned for installation to proceed.
- Determine wood subfloor readiness for floor installation.
- Determine when a second coat of finish can be applied.
- Assess water damage.

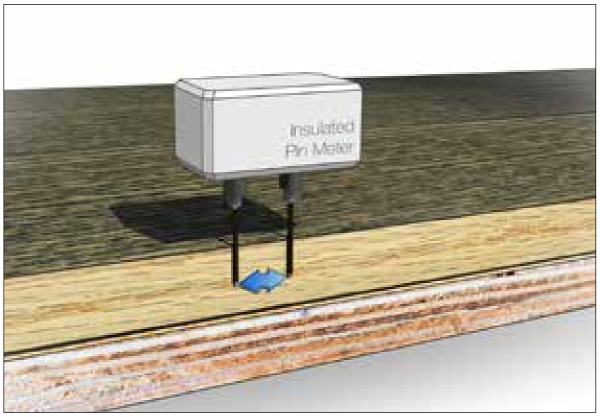
Each moisture meter is unique, and it is important that you know your meter to get the most out of it. There are two main types of meters: pinless meters (dielectric) and pin-type meters (electrical resistance).

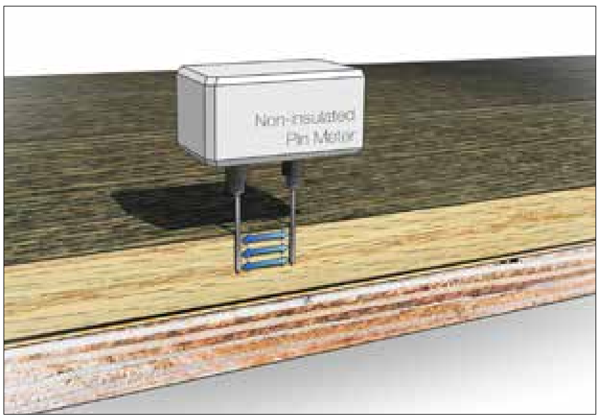


Pinless

The pinless, dielectric types, which are also referred to as non-invasive, non-destructive, scanning, or surface meters, do not leave any small holes in the flooring and are quite different from the pin-type meters. Signal penetration for these types of meters can be up to 1 inch. The meter can be moved across the surface to identify areas of moisture in a wood block or plank. It is relatively unaffected by temperature. Rough surfaces have very little impact on the reading. Measurements can also be taken through coatings, varnishes or paints without damage to the surface.

When using these meters on engineered flooring made of multiple species (wear layer, core and backing), check with the meter manufacturer for testing protocol, accuracy and appropriate species correction values.





Pin-type

The pin-type meters measure the electrical resistance across opposing sets of pins, which are pushed into the wood. Most pin-type meter manufacturers recommend placing the pins of your meter parallel with the direction of the grain of the wood. These types of meters work like this: an electrical current is forced through the wood sample between the probes. Because wood is a poor conductor of electricity and water is a good conductor of electricity, wood with higher MC has a lower resistance. The results are displayed as a number that represents a moisture content percentage.

Pin-type meters are available with either insulated or non-insulated pins. Non-insulated pins will read as deep as they are inserted and will average the resistance through the entire depth of the pins. Insulated pins are typically available in many different lengths, from 1-3 inches, and are used with a slide hammer extension. Insulated pins only measure the resistance at the tips of the pins, allowing one to evaluate the moisture gradients through the sample of flooring or a flooring system.

Both types of meters will give generally reliable readings somewhere between 5-30% MC.

When using these meters on engineered flooring made of multiple species (wear layer, core and backing), check with the meter manufacturer for testing protocol, accuracy, and appropriate species correction values.

Temperature correction

The temperature of the wood will significantly influence the readings of a pin-type meter. Be sure to check with your meter manufacturer for temperature correction values. Temperature correction is the adjustment that is made to the moisture meter reading to compensate for the phenomena that the electric conductance of wood increases as the temperature increases, and vice-versa. This adjustment, whether manual or automatic, allows for accurate measurements of moisture content even at extreme temperatures (i.e., less than 50°F and greater than 90°F). Please refer to the chart on page 19.

Species correction

Most meter manufacturers calibrate their meters to pine/Douglas Fir/hemlock. Verify with the manufacturer the correction to use for the specific meter and species. Some meters have a species correction adjustment built in. Species correction is a meter-manufacturer-specified, user-adjusted setting that is made to the moisture meter to compensate for either varying electrical properties (for pin-type meters) or densities (for pinless meters) of the species under test, as compared to the species of the reference calibration. Making these adjustments allows for a more-accurate assessment of the moisture within the wood being tested.

When testing engineered flooring, the wear layer species may not coincide with the material being tested. Core type must be accounted for. Check with the meter manufacturer for testing protocol, accuracy and appropriate species correction values.

Meter drift

Be sure to record readings from meters within the first 2-3 seconds to ensure accuracy. Meter drift is the decrease (or increase) in true moisture content over a specified elapsed time.

Calibration

Calibration ensures the meter is giving accurate readings. All meters must be calibrated from time to time. ASTM D4444 is the standard test method for laboratory standardization and calibration of hand-held moisture meters. Some meters can be checked for calibration internally or by use of a calibration block supplied by the manufacturer. Check with the meter manufacturer to determine when and how to get your meter properly calibrated. Most meter manufacturers will provide a calibration certificate, which verifies the equipment being tested is operating properly.

TEMPERATURE CORRECTION

SURFACE TEMPERATURE		METER READINGS										
°F	°C	6	7	10	15	20	25	30	35	40	50	60
0	-17.8	9	11	15	22	31	38	45	53			
20	-6.7	8	10	14	20	28	34	40	47	55		
40	4.4	7	8	12	18	24	30	36	42	48		
60	15.6	6	7	11	16	21	27	32	38	43	54	
80	26.7	6	7	9	14	19	23	28	33	38	47	55
100	37.8	5	6	8	12	17	21	25	29	34	42	50
120	48.9	5	5	7	11	15	19	22	26	30	38	44
140	60	4	5	7	10	14	17	20	23	27	34	40
160	71.1	4	4	6	9	12	15	18	21	24	30	36

Moisture content values above the fiber saturation point are only qualitative. The temperature correction values shown in this chart have been rounded for easy reference.

TESTING WOOD SUBFLOORS

At the time of installation, it is important to know the moisture content of not only the wood flooring, but of the substrate as well. It is critical to check with the meter manufacturer for proper settings or correction values when testing wood subfloor materials.

Due to the variability in wood subfloor materials and the non-wood resins often used within them, it can sometimes be difficult to get an accurate moisture reading of this material. When in doubt, use a moisture meter to check the MC of other conditioned wood materials (2x4s, newel posts, wood beams, etc.) within the structure in order to get an idea of where the EMC is in comparison to where it should be, and use this value as a baseline for testing the subfloor.

After calibrating your meter for the subfloor material being tested, check the MC in a minimum of 20 areas per 1,000 square feet and average the results. Record, date, and document all results. Pay special attention to exterior walls and plumbing. In general, more readings will result in a more-accurate average.

The MC of the subfloor should coincide with the expected in-use (e.g., normal living) conditions of the facility, based on the EMC chart provided. Anything outside of this range would be considered unusually high or low. Any unusually high or low MC readings must be identified and documented in order to establish the size and magnitude of the problem area. Installation should not proceed until the origin of the moisture has been identified and remedied.

Another key variable of the moisture content of wood subfloors involves what is going on below the subfloor. When the space below the subfloor is conditioned to the same temperature and RH as above the floor, the moisture content across the subfloor material should be the same. When conditions below the subfloor are different from above the subfloor, the moisture content will vary through the thickness. This difference will affect the installed wood flooring and will require some sort of moisture mitigation.

Moisture Mitigation over Wood Subfloors

Installation of a vapor retarder reduces the potential for moisture- or vapor-related problems, but does not eliminate moisture migration when the conditions below the subfloor differ from conditions above the subflooring material. When the moisture content in the subfloor exceeds what the EMC should be for the expected in-use (e.g., normal living) conditions or when the conditions of the crawlspace or basement differ from conditions above the subfloor material, do not use an impermeable vapor retarder material as it may trap moisture on or in the wood subfloor, potentially leading to subfloor rot, decay, or mold growth. Use of a moisture retarding membrane will slow the vapor transmission, but will not stop it.

TESTING CONCRETE SUBSTRATES

As concrete moves through its initial drying period, regular checking of moisture content can start after 30 days. Excess moisture in the concrete will cause problems such as finished product distortion or failure of the adhesive systems under the flooring.

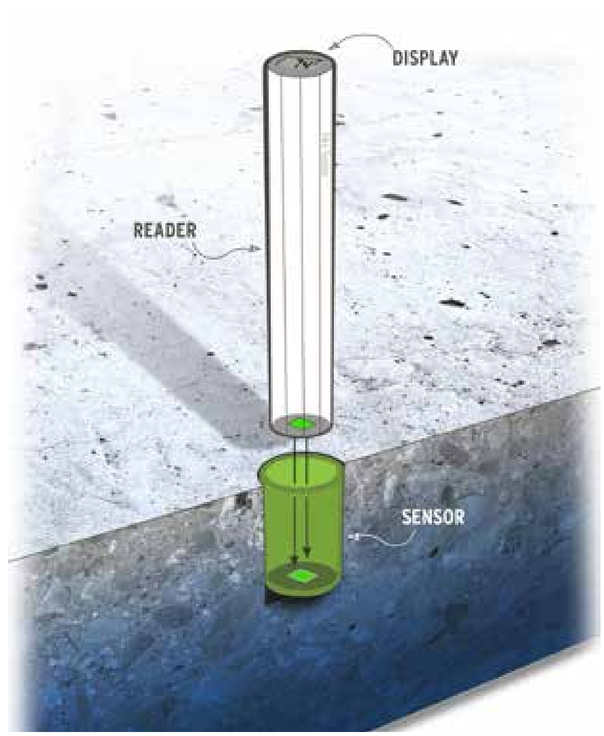
Every concrete slab on-grade should have a vapor retarder installed directly beneath it prohibiting the passage of ground moisture through the slab. If the vapor retarder below the slab has been compromised, moisture will be able to move freely through the slab and into the flooring system. Unfortunately, there is no way of knowing whether there is an intact vapor retarder in place.

Any of the following moisture tests indicate the condition of the concrete floor at the time of the test, under the ambient conditions of the test. They may not predict future conditions of the slab. All concrete slabs, regardless of age, will exhibit changes in moisture over time.

Concrete slabs must meet a moisture specification prior to installing a wood floor. The following are some of the tests that are commonly recommended for checking the moisture condition of the concrete before starting the installation. All tests should be performed as dictated by the ASTM standard. Appropriate moisture testing, specified by the flooring and/or adhesive manufacturer, is the only way to identify if moisture levels in the slab are adequate for the systems being used.

Calcium Chloride Test (ASTM F1869)

This test method allows you to obtain a quantitative value indicating the moisture vapor emissions rate (MVER) from the surface of a concrete subfloor using anhydrous calcium chloride. This test is conducted by use of a pre-weighed dish of calcium chloride placed under a transparent cover that is sealed to the concrete floor. After the test has been in place for 60-72 hours, the calcium chloride is reweighed and calculated to determine how much moisture vapor has been emitted. The moisture vapor emitted is measured in pounds. This measurement is the equivalent weight of water evaporation during a 24-hour period, per 1,000 square feet. Three tests are required for areas up to 1,000 square feet, and one additional for every additional 1,000 square feet. The MVER result only reflects the condition of the concrete floor at the time of the test and may not indicate future conditions. The maximum allowable emission of moisture vapor from the subfloor should not exceed 3 pounds per 1,000 square feet per 24 hours. A moisture control system is required when readings exceed this limit and is strongly recommended regardless of the results.



Relative Humidity Probe Test (ASTM F2170)

This test method allows you to obtain a quantitative value indicating the percentage of relative humidity within a concrete slab. This test is conducted by drilling a hole at a specified depth into the slab and placing a hollow sleeve liner into the hole. After 72 hours, the RH is then tested within the slab with a probe. Three tests are required for the first 1,000 square feet, and at least one additional for each additional 1,000 square feet. The moisture test results indicate the moisture condition of the slab only at the time of the test and may not indicate future conditions. The maximum allowable limit of relative humidity within the slab is 75% RH. A moisture control system is required when readings exceed this limit and is strongly recommended regardless of the results.

Electronic Meters (ASTM F2659)

This standard guide is for preliminary evaluation of comparative moisture conditions of concrete, gypsum cement, and other floor slabs and screeds by use of non-destructive electronic moisture meters. The types of meters include handheld electrical resistance and impedance meters specifically designed to evaluate the top 1/2"-1" of the surface of concrete. The results of these tests are not quantifiable and should only be used to determine acceptability of the substrate when the flooring and/or adhesive manufacturer specifies this test. These tools are intended to assist the user in identifying location for placement of quantifiable tests.

Plastic Sheet Test (ASTM D4263)

This test is used to indicate the presence of capillary moisture in concrete. The test involves taping an 18-inch-square of transparent polyethylene onto the concrete subfloor, leaving it for 16 hours, and visually inspecting the underside of the sheet and the concrete for the presence of moisture. This is not a quantifiable test method and is not recommended to determine acceptability of substrate prior to install.

Moisture Control over Concrete Substrates

Always follow the flooring and/or adhesive manufacturer's instructions for acceptable vapor retarding systems. In on-grade and below-grade applications, be certain to account for potential, unseen moisture infiltration from the surrounding earth. Because each of these tests only indicate the conditions of the slab at the time of the test, and because concrete is a porous material subject to changes in moisture conditions, it is always recommended to use a moisture mitigation system.

SOURCES OF MOISTURE

Whether evaluating the jobsite prior to installing a new floor, renovating an existing floor, helping someone problem-solve potential risks, or evaluating post-installation damage, it is important to know the various sources of moisture that can have an adverse effect on wood flooring and begin to identify alleviation of the problem.

New Construction

During construction of a new home, moisture can enter the house in a number of ways:

- Subflooring material and framing exposed to rain and snow prior to roof sheathing being in place.
- Doors and windows not installed until construction is in the final phases.
- Inoperable HVAC systems throughout the building process, which can allow the interior of the building to be directly influenced by unfavorable exterior conditions.

Because builders usually work on short, demanding schedules, and homes are being built tighter and more energy-efficient, the moisture introduced from the building process is not allowed to evaporate at the same rate it once did. The amount of moisture introduced during the building process can be significant. This moisture can be enough to create extensive flooring failures if not properly addressed.

This highlights the importance of testing and documenting moisture conditions prior to installation of a wood floor. On renovation work, this can also occur if rain occurs during the process of re-roofing, or in cases where windows are being installed or replaced.

Water in Concrete

Concrete is comprised of three main materials: Coarse and fine aggregates, Portland cement, and water. When water is introduced to the dry materials, a chemical reaction occurs that is known as hydration. However, there is a lot more water added to the mix than only the amount that is necessary for hydration. Typically, only about one-third to one-half of the water that is in the standard concrete mix is added for hydration; the balance is there to facilitate placement and finishing. This means that for 1 cubic yard of concrete, approximately 140 – 150 lbs., or 17.5 gallons, of water must evaporate.

Under "ideal" circumstances, including the proper water to cement ratio and the ambient conditions surrounding the slab, it may take 30-45 days after placement for the slab to reach a point where you can begin moisture testing. However, the drying clock does not start until the slab has been protected from re-wetting and the ambient conditions are conducive to drying. Curing compounds inhibit the evaporation of moisture and also will extend the drying time dramatically. It is not unheard of for concrete placed on a metal pan and sealed with a curing compound to have more than 8 pounds of moisture emission one-and-a-half years after installation. If the building is not closed in, or is not acclimated to operating environment, the slab will take even longer to dry.

Groundwater

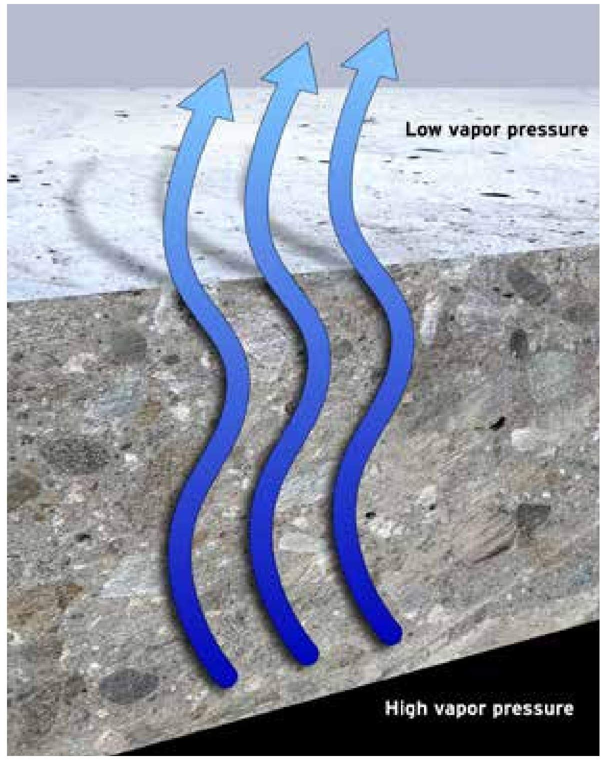
If the concrete slab is poured directly over an intact vapor retarder, moisture from below should not be a concern. Unfortunately, there is no way of knowing whether there is an intact vapor retarder in place.

There are many potential sources of groundwater moisture, which may include landscape irrigation, underground springs that may only appear during wet seasons, and breached or degraded vapor retarders. The three main ways this moisture finds its way through the concrete slab include hydrostatic pressure, capillary action, and vapor diffusion.

Hydrostatic pressure can occur only when exterior water levels are above the bottom of the slab. As such, it only develops in "below-grade" applications. Moisture issues related to hydrostatic pressure are avoided by using adequate drainage systems and/or waterproofing membranes around the foundation of the structure.

Capillary action refers to the ability of water to travel up against the pull of gravity through a porous material. One common example of this action is water "wicking" up through a paper towel, following the direction of the paper fibers (as seen in the photo). Although not as serious as bulk water movement, capillary forces are both powerful and rather secretive, since they often work in the dark of a crawlspace, causing significant damage to a building without the occupant's knowledge.

This water migration is fed by an infinite moisture source within the ground below the slab. Vapor retarders below the slab can minimize the effects of capillary rise.



A fundamental principle in nature is for materials in vapor form to seek equilibrium. This process is called vapor diffusion. Materials that are higher in concentration in one area will disperse to areas of lower concentration. Relative humidity of subgrade soil will typically be 100%. The higher vapor pressure below the slab will naturally find its way to the area above the concrete, which will have a lower vapor pressure. This natural movement of water in vapor form can cause flooring failure. An intact vapor retarder below the slab can minimize or alleviate this issue.

Any of these sources may cause water to penetrate the foundation walls or rise through the ground surface into the foundation or crawl space.

Crawl Spaces

Crawl spaces exist when the floor of the house is built over an open space that is deep enough to allow a person to gain access to the under-floor area by crawling. Evaporation of soil moisture is usually greatest when the temperature of the soil is warm (summer months). Moisture travels upward by capillary action – as much as 14-18 gallons per day have been noted under a 1,000 square foot house – and evaporates within the crawl space. Capillary rise occurs in nearly all areas where the soil is clay or silt. A crawlspace can be classified into three general categories:

1. Open pier-and-beam foundations are considered open crawl spaces. Open crawl spaces may have a continuous wall on just one side and be open on the other sides. If a building is constructed on pier-and-beam construction, floor insulation is common. Skirting these types of crawl spaces to form an enclosed crawl space and then adding venting could result in moisture issues, especially in areas of the country where humidity levels are high.

2. Traditional crawl spaces with continuous perimeter walls that include vents to the outside are considered ventilated crawl spaces.

   The International Residential Code (IRC/ICC) contains a standard requirement for minimum vent openings of 1 square foot per 150 square feet of crawlspace floor area. The basis for the code requirement was the combined idea that:
   A. The primary source of crawl space moisture was evaporation from the crawl space floor, and
   B. Crawl space ventilation would allow for dissipation of this evaporated moisture.

   However, the IRC does allow omitting the vents in a crawl space with perimeter insulation if:
   A. A Class 1 vapor retarder material is installed (sealed and taped) over the ground, with the cover extending 6 inches (150 mm) up the side walls, and
   B. The crawlspace has a continuously operated exhaust fan, or conditioned air is supplied to the crawl space, or the crawl space is used as a plenum or receives air from the ventilation system.

3. Crawl spaces with continuous perimeter walls with no vents and that are conditioned to the same temperature and humidity levels as the interior space are considered enclosed and conditioned crawl spaces. These crawl spaces present the ideal circumstances to create a balanced condition below and above the flooring system.

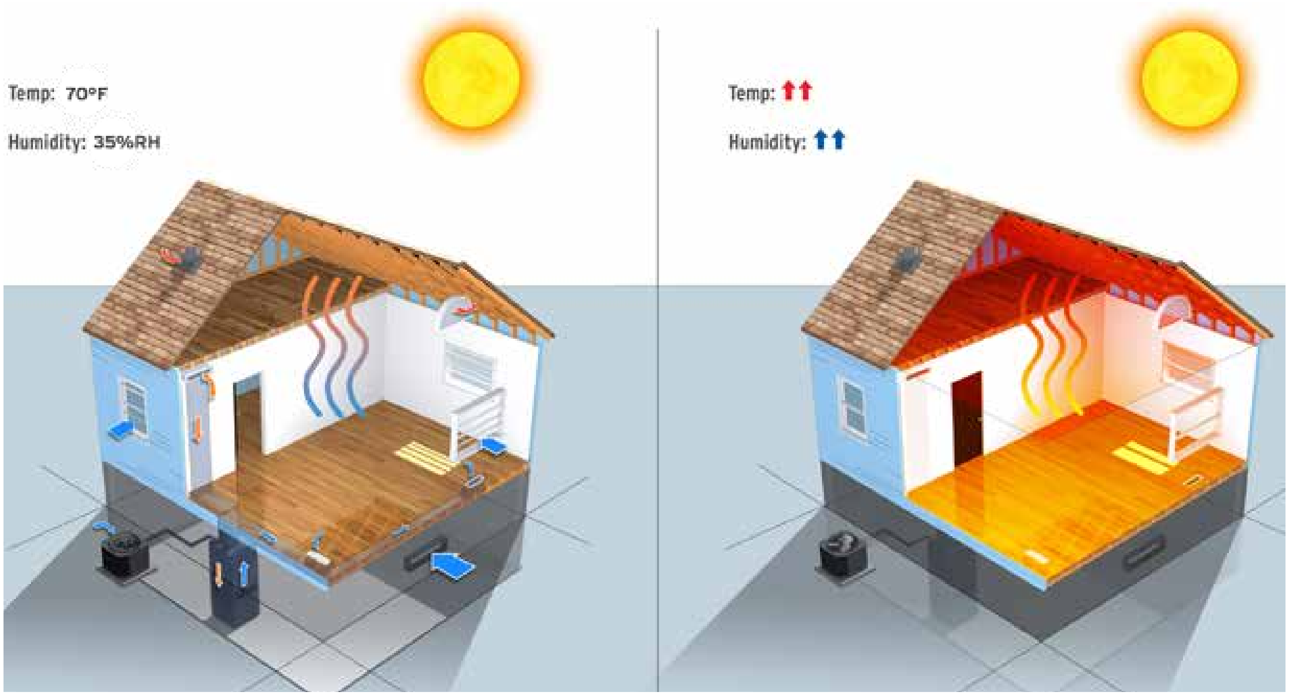
Surface Water

Rain water falling on the ground or from the roof can pass through or under the foundation walls. In some areas, heavy soils may retain surface drainage and cause water pressure against the foundation walls or slab. Sprinkler systems and poor drainage around the home can have the same effect and consequences as rainwater.

Generated within the House

There are many sources of moisture generated within the house. Moisture sources can vary based on the occupants' lifestyles such as cooking, houseplants, pets, and laundry. As moisture is released into the house, it moves to all rooms by natural air movement or by forced air movement from the HVAC system.

- Mopping the floor in a 150-square-foot kitchen can release the equivalent of 4-1/2 pints of water into the air.
- A shower or bath can release about 1/2 pint of water into the air.
- Washing the dishes can release about 1/2 pint of water into the air.
- Cooking or boiling water can add about 1/2 pint of water into the air.
- A family of four gives off about 1/2 pint of water per hour just breathing (this is why bedrooms are unexpected moisture sources).
- Moisture is sometimes introduced into basements and crawl spaces from the mechanical systems within the house. This includes clothes dryer vents, condensed water from cooling systems, or discharge from automatic icemakers being directed somewhere other than away from the building.



HVAC Systems

Improper usage, inoperable systems, or inadequate HVAC systems can inhibit added moisture to the home and create poor conditions for the wood floor.

- During humid seasons and in humid climates (when the average RH remains above 50%), dehumidification systems may be necessary if air conditioning alone does not control the RH levels within the home.
- During dry seasons and in the arid climates (where the average RH remains below 30%), supplemental humidification may be necessary in the home to sustain adequate RH levels.
- Rooms or basements where HVAC vents are closed-off and are not conditioned to the same temperature and humidity levels as the rest of the interior space can result in sub-climates within the home, which can have adverse effects on any adjoining floors within the home.
- When air conditioning and heating systems are not used or are completely shut down for an extended period of time, the air exchange necessary for the performance of the home and the wood floor is sacrificed. Floors will shrink or swell due to this limited air movement and inconsistent humidity levels. Sunlight through windows can generate heat, creating abnormal humidity levels, which may fluctuate from day to night. Controlling the atmosphere during and after the installation is critical to avoid issues. This is often referred to as the greenhouse effect.

ADDRESSING WATER DAMAGE

When a wood floor has been damaged by a leak or a flood, it must be addressed before further damage occurs.

The first step in repairing a water-damaged wood floor is to identify and eliminate the source of moisture. Once the moisture source has been identified and removed, the floor can then be assessed.

It is important to understand that water will migrate to areas below the wood floor system anytime there is a flood. When water damage occurs, the wood flooring and subflooring systems must be evaluated to determine the extent of damage and ensuing repairs.

Subfloor Materials Evaluation

- Plywood – swelling, distortion and delamination can occur when exposed to high levels of moisture. Moisture tests should be conducted using insulated pin, hammer probe type meters on the surface, on the backing, and within the core of the material in several areas of the damaged material to properly assess the extent of moisture intrusion. Replace when the damage is evident. Ensure replacement material is within acceptable MC ranges prior to reinstallation of wood flooring.
- Oriented Strand Board (OSB) – swelling can occur with OSB when exposed to water. Swelling in OSB can create a decrease in density and a reduction in within-board strength due to the release of compaction stress created during the pressing process of manufacturing. This will directly affect how existing fasteners hold the wood flooring to the subflooring material. Replace when damage is evident. Ensure replacement material is within acceptable MC ranges prior to reinstallation of wood flooring.
- Concrete – concrete is a porous material. It typically does not become damaged when exposed to water; however, adhesives, sealers and other compounds will slow the drying of a wetted concrete slab. Moisture levels must be evaluated and properly addressed prior to installation of new flooring. Concrete substrates should be dried by use of airflow, heat, and dehumidifiers until moisture levels are within the flooring and adhesive manufacturer's required ranges.

Wood Flooring Materials Evaluation and Remediation

- Identify the type of flooring and installation methods.
  - Identify type of substrate.
  - Existing materials below the flooring surface may create additional mitigation costs and concerns (i.e., asbestos underlayment, radiant heating systems, etc.).
- Determine the target moisture content for the geographic area and for the facility.
  - Reference the EMC chart on page 12.
  - Consider the time of year repairs are to take place and assess the HVAC systems' ability to sustain an adequate environment.
- Conduct moisture testing.
  - Use insulated pin, hammer probe type meters to achieve readings at multiple depths of flooring and subflooring material.
  - Use pinless, dielectric meters to scan the flooring surface and map the damage.
  - Check existing, unaffected wood for reference.
  - Target should be within 2% of expected "in-use" moisture content.
- Use dehumidification systems to stabilize the ambient conditions and bring them within the target range.
  - Some of the most effective types of dehumidification systems include desiccant systems and low-grain refrigerant systems.
  - Dehumidifiers should be placed on the flooring surface as well as below the flooring surface (when applicable).
  - Unconditioned areas directly below the wood subflooring system or sleepers, such as basements and crawlspaces, should also be opened to introduce heat and airflow. Any insulation on the underside of the floor joists should also be removed.

- Many times damage will dissipate or even completely disappear as the flooring dries out over time.
- Airflow and heat can be used to speed the natural drying process.
- Vacuum extraction systems include placement of large mats/panels that are attached to vacuum/ suction systems designed to pull water from the flooring surface.
- Negative and positive air pressure systems force airflow beneath and within the flooring systems in order to decrease the moisture content by direct use of airflow.
- A buckled wood floor requires replacement wherever the buckling has occurred. Once the flooring has buckled, the fasteners or adhesives are no longer effective, and the system will never return to its original state. Once the moisture source has been identified and eliminated, the buckled portion of the flooring may be replaced. The remainder of the flooring should be treated as noted.

MOISTURE RELATED WOOD FLOOR ISSUES

For more information on moisture-related issues, refer to NWFA Technical Publication No. C200: Problems, Causes and Cures of Hardwood Floors.

Buckling

Buckling occurs when the wood floor pulls away from the subfloor, rising above the plane of the floor level. A buckled floor can lift several inches or feet from the subfloor. Buckling happens most often after a wood floor has been exposed to excessive moisture or flooding for an extensive period of time. When the wood swells, the stresses are theoretically high enough to push out walls; however, the fasteners or adhesives holding the floor in place usually give way so that the flooring can exhaust the pressures and lift from the floor surface.

Checking (solid wood and engineered wood with sliced or sawn face veneers)

Checking is lengthwise separation of the wood cells that normally extend across the rings of annual growth (along the rays), as the result of stresses from the drying process. Checks may be acceptable in all flooring grades; however, the length and extent of the check is determined by the manufacturer for each particular grade product. Checks may also be present, but not visible to the naked eye, during the manufacturing quality control inspections or during installation, and may be present in an installed floor. Such closed checks may become evident in an installed floor if the floor loses moisture and shrinks.

Lathe Checks (engineered wood with rotary-peeled veneers)

In engineered flooring with rotary-peeled face veneers, as the knife separates the veneer from the log, the separated sheet of wood is severely bent and stresses build up in the region near the knife edge. If the strength of the wood is exceeded, this stress is relieved by separations (or checks) of the wood fibers parallel to the grain of the veneer at the knife edge. The knife edge of the veneer is known as the open (or loose) side, and the opposite side of the veneer is known as the closed (or tight) side.

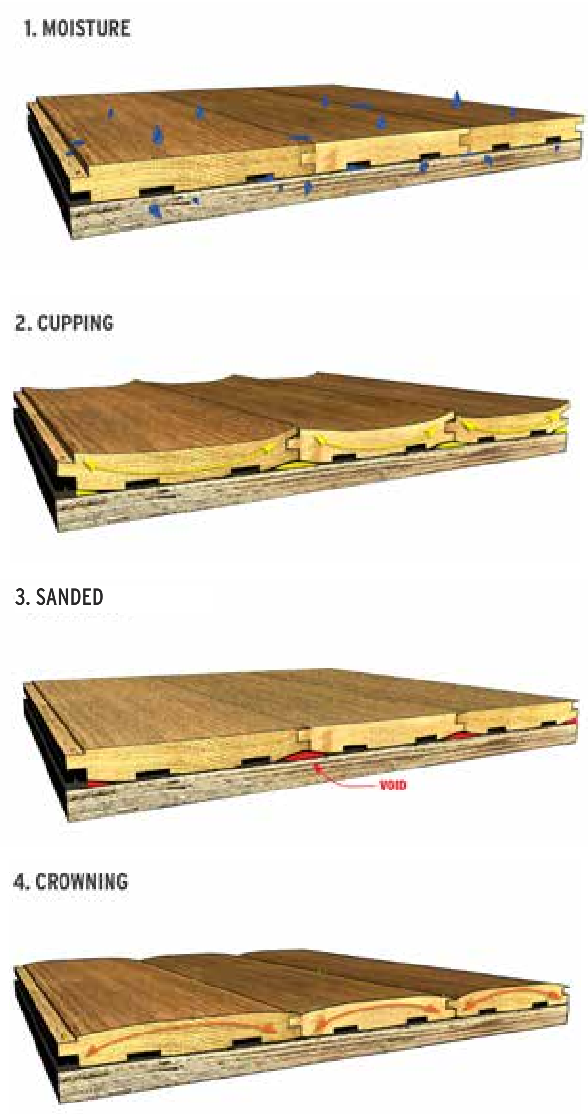
Lathe checks are always on the open side of the veneer, and are not visible on the face of the finished board.

Splits/Cracks

A split or crack is a lengthwise separation of the wood due to the tearing apart of the wood cells. It normally is caused by mechanical damage during handling when the product is dropped, banged, or in other ways damaged during transporting, or installation.

Crowning

Crowning is the opposite of cupping. Crowning is defined as a convex or crowned appearance of individual boards with the center of the board higher than the edges. Crowning is caused by a moisture imbalance through the thickness of the wood; the wood is wetter on the top of the board than on the bottom. This usually occurs with high humidity levels and a dry substrate. Another more-common cause of crowning results when a previously cupped floor was resanded prior to it being completely dry.



Cupping

Cupping is defined as a concave or dished appearance of individual boards with the edges raised above the center. Cupping is caused by a moisture imbalance through the thickness of the wood; the wood is wetter on the bottom of the board than the top. In severe cases, the cell walls along the edges of adjoining boards are crushed against one another, causing compression set. Compression set is a permanent condition that deforms the edges of individual boards.

Compression Set

Compression set occurs when boards are subjected to a substantial increase in moisture while being restricted from swelling by adjacent boards. This results in a permanent narrowing/crushing of the boards along the sides due to permanent cellular damage.

Dry Cupping

Engineered flooring can also exhibit what is known as "dry cupping." When relative humidity levels remain below the manufacturer's recommendations for long enough, engineered flooring can begin to dry cup. When this happens, the wear layer loses moisture and begins to shrink across its outer face, which can exert enough force on the core material to pull the edges of the plank upward. This causes a cupped appearance across the width of the board. In severe cases, the wear layer may delaminate from the core material when stresses exceed the strength of the adhesives used in the manufacturing process (ply separation) or when the stresses exceed the strength of the wood fibers within the material itself (wood shear).

Gaps

Nearly every solid wood floor presents some separation between the individual boards – gaps – throughout the floor. In the winter months, when the air in the building is heated, the surrounding air loses moisture and relative humidity levels drop. When this happens, moisture is lost and gaps appear between individual boards throughout the floor. This is a normal phenomenon and is directly related to the environmental conditions the wood is being exposed to. Once the interior heating systems are turned off and the indoor environment regains moisture, most of these seasonal gaps will disappear. The only way to avoid seasonal change in wood flooring is to maintain consistent relative humidity levels throughout the year.

It is important not to fill seasonal gaps when they appear as this could cause subsequent damage to the wood flooring as it expands again in the humid seasons.

Seasonal gaps between boards are more prominent with solid wood flooring products than with engineered wood flooring products. The structural composition of engineered wood flooring allows it to be more dimensionally stable than solid wood flooring.

Abnormal gaps are those that remain with seasonal change and should not be confused with normal, or seasonal gaps.

End-lifting and End-gapping

Solid wood does not shrink or swell measurable in its length. Most end-lifting and end-gapping occurs with engineered wood flooring.

End-lift occurs when the ends of wood flooring boards appear raised. This is very common with engineered flooring that has experienced an increase in moisture, where the lamina running perpendicular to the face of the board swells at a different rate and in a different direction than the adjoining layers, forcing the ends of the material to lift.

Gaps at end-joints of engineered flooring can be caused by a change in moisture content, where the lamina running perpendicular to the face of the board shrinks and swells at a different rate and in a different direction than the adjoining layers. Due to the construction of engineered flooring, it is common for it to shrink and swell in its width and length when exposed to drastic changes in moisture content.

CONCLUSION

Having a clear understanding of the relationship between moisture and wood allows us to better understand what to expect as we work with the flooring products we deal with on a daily basis. It is an undisputed fact that moisture, whether in the form of liquid, vapor, or bound water, will affect the performance of wood flooring, regardless of style, species, width, installation method, or construction. As professionals in this industry, it is our responsibility to mitigate the adverse effects of moisture on wood floors and to communicate to our customers the benefits and limitations of wood floors.

GLOSSARY

Absolute Humidity
The amount of water vapor present in a unit volume of air, usually expressed as grains/cu.ft.

Acclimation
The act of allowing wood moisture content to become at equilibrium with the environment in which the wood will perform.

Air-Dry
The process of drying lumber by exposure to air in a yard or shed without artificial heat.

ASTM D4263 (Plastic Sheet Test)
Standard test method for indicating moisture in concrete by the plastic sheet method. This test method is used to indicate the presence of capillary moisture in concrete.

ASTM D4442 (Oven Dry Method)
Standard test methods for direct moisture content measurement of wood and wood-based materials.

ASTM F1869 (Calcium Chloride Test)
Standard test method for measuring the moisture vapor emissions rate of concrete subfloor using anhydrous calcium chloride. This test method covers the quantitative determination of the rate of moisture vapor emitted from below-grade, on-grade, and above-grade (suspended) bare concrete floors.

ASTM F2170 (Relative Humidity Probe Test)
Standard test method for determining relative humidity in concrete floor slabs using in situ probes. This test method covers the quantitative determination of percent relative humidity in concrete slabs for field or laboratory tests.

ASTM F2659 (Electronic Meters)
Standard guide for preliminary evaluation of comparative moisture condition of concrete, gypsum cement, and other floor slabs and screeds using a non-destructive electronic moisture meter.

Bark
The layer of tissue on the outside of the cambium, including the inner bark (living tissue) and the outer bark (dead tissue).

Bound Water
Water held chemically within the cell walls of wood that cannot be removed without changing the structure or composition of the wood material itself. Water in wood below the fiber saturation point.

Calibration
The act of checking and adjusting the accuracy of a measuring instrument.

Cambium
The thin layer (less than 1/16" thick) of living cells between the bark and wood that is responsible for increases in the tree's diameter by creating new growth rings of wood to the inside and new inner bark to the outside.

Capillary Action
The movement of water within the spaces of a porous material (such as concrete) due to the forces of adhesion, cohesion and surface tension. It is the ability of a liquid to flow in narrow spaces without the assistance of, and sometimes in opposition to, external forces like gravity.

Cell Lumina (Cell Cavity)
The void space of a cell enclosed by the cell wall.

Conditioning
Exposure under controlled temperature and relative humidity to bring wood to a desired moisture content.

Dew Point
The temperature at which the atmospheric water vapor condenses out as a liquid.

Dimensional Change Coefficient
A number that reflects how much a certain species of wood will change in size in relation to change in moisture content.

Dimensional Stability
The degree in which a piece of wood maintains its original (manufactured) dimensions when subjected to changes in temperature and humidity.

Earlywood (Springwood)
The portion of the growth ring that is formed during the early portion of the growing season, often characterized by being less dense with larger cells.

End-Grain
A slice of wood cut so that the growth rings are facing up, as the transverse cut.

End-Lift
The ends of wood flooring boards appear raised.

Equilibrium Moisture Content
The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given temperature and relative humidity.

Fiber Saturation Point
The stage in drying or wetting wood at which the cell walls are saturated with water and the cell cavities (lumina) are empty of free water. It is usually taken as approximately 30% moisture content, based on oven-dry weight.

Free Water
Moisture held in the cell cavities (lumina) of the wood, not bound in the cell walls. Water in wood above fiber saturation point.

Grain Angle
A description of how the wood was cut from the tree, related to the orientation of the growth rings with respect to the wide face of the board.

Growth Rings
A layer of wood growth added to the tree during a single growth season.

Hardwood (Angiosperms)
Wood produced by broad-leafed trees in the botanical group referred to as angiosperms. These trees have vessels, and in most cases, are broad-leaved trees with enclosed seeds (acorns, walnuts, etc.) that lose their leaves in the fall. Some examples of hardwoods include maple, oak and hickory.
The term hardwood does not necessarily refer to the actual hardness of the wood.

Heartwood
The wood extending from the pith to the sapwood, the cells of which no longer participate in the life process of the tree. It is usually darker than sapwood.

Humidity
The amount of water vapor in the air.

Hydration
The chemical reaction that begins once water is combined with Portland cement.

Hygrometer
An instrument used for measuring the degree of humidity or relative humidity of the atmosphere.

Hygroscopic
A substance that can absorb and retain moisture, or lose or throw off moisture. Wood and wood products are hygroscopic. They expand with absorption of moisture and their dimensions become smaller when moisture is lost or thrown off.

Kiln
A chamber having controlled airflow, temperature and relative humidity for drying lumber, veneer and other wood products.

Kiln-Dried
Wood that is dried in a kiln with use of artificial heat and airflow.

Latewood
The portion of the growth ring that is formed after the earlywood formation has ceased. It is usually denser and stronger mechanically than earlywood.

Livesawn
A method of sawing a log straight through its diameter, leaving in the heart of the log, and all of the grain and character variations seen throughout all grades of lumber.

Longitudinal
Parallel to the direction of the grain direction of the wood.

Meter Drift
The decrease (or increase) in true moisture content over a specified elapsed time after electrode pins insertion as estimated by the moisture meter.

Moisture Content
The weight of the water in the wood expressed as a percentage of the weight of the wood itself.

Moisture Meter
A tool used for the rapid determination of moisture content in wood by electrical means. There are two main types of meters: pinless meters (dielectric) and pin-type meters (electrical resistance).

Photosynthesis
The process by which trees use energy from the sun, water, and carbon dioxide to create their own sugars (glucose).

Pith
The small, soft core occurring near the center of the tree trunk, branch, twig or log.

Plainsawn (Flatsawn)
Cut parallel to the growth rings. Wood flooring cut so that the growth rings are mostly parallel (0° to 45°) to the wide face of the board (a tangential cut). This cut is called plainsawn in hardwoods, and flatsawn in softwoods.

Quartersawn (Vertical Grain)
Cut perpendicular to the growth rings. Wood flooring cut so that the growth rings are mostly perpendicular (45° to 90°) to the wide face of the board (a radial cut). This cut is called quartersawn in hardwoods, and vertical-grain in softwoods.

Radial
The horizontal direction in the tree between the pith and the bark. A radial section is a lengthwise section in a plane that passes through the centerline of the tree trunk.

Rays (Medullary or Wood Rays)
Strips of cells that run from the bark toward the center of the tree. The rays serve primarily to store food and help move sugars and other materials from pith to bark. Because they are actually a second system of live cells running perpendicular to the grain, they can contribute visual interest to finished flooring depending on how the boards are cut from the log.

Relative Humidity
The ratio of the amount of water present in the air to that which the air would hold at saturation at the same temperature, usually expressed as a percentage.

Riftsawn (Bastard Sawn)
Cut neither parallel nor perpendicular to the growth rings. Wood flooring cut so that the growth rings make angles of 30° to 60° to the face of the board. This cut is known as riftsawn or bastard sawn.

Roots
The part of the tree that attaches it to the ground, conveying water and nutrients.

Sapwood
The active wood near the outside of the tree. It is usually lighter in color than the heartwood.

Shrinkage
Change in dimension due to a loss in moisture below the fiber saturation point.

Softwood (Gymnosperm)
Wood produced by coniferous trees in the botanical group referred to as gymnosperms. These trees generally have no vessels, and in most cases, are cone-bearing plants (pinecones) with needle-like leaves. Some examples of softwoods include pine, spruce and douglas fir. The term softwood does not necessarily refer to the actual hardness of the wood.

Species Correction
The adjustment that is made to a moisture meter to compensate for either varying electrical properties (for pin-type meters) or densities (for pinless meters) of the species under test, as compared to the species of the reference calibration.

Swelling
Change in dimension due to a gain in moisture below the fiber saturation point.

Tangential
The surface or section of wood perpendicular to the wood rays and parallel to the growth rings.

Temperature
A measurement that indicates how hot or cold something is. In the United States we use the Fahrenheit (°F) scale. The majority of the rest of the world uses the Celsius (°C) scale.

Temperature Correction
The adjustment, or correction, that is made to a pin-type moisture meter reading to compensate for the phenomena that the electric conductance of wood increases as the temperature increases, and vice-versa.

Transverse Cut (Cross Section)
A section of wood cut perpendicular to the grain, or the surface exposed by such a cut.

Vapor Diffusion
The flow of water vapor through a material.

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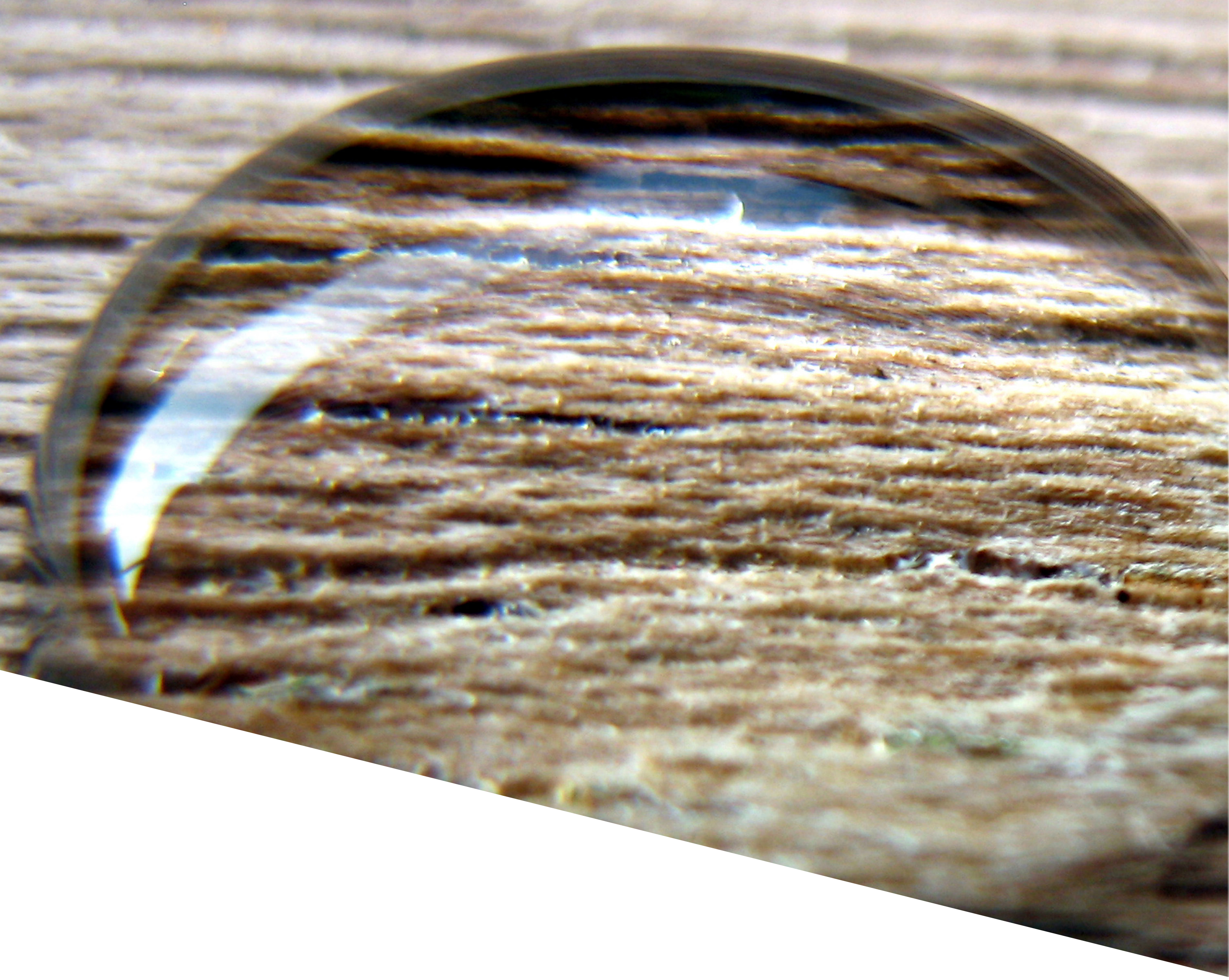

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