Chapter 1
Properties of Wood Related to Drying

Chapter 1 was revised by William T. Simpson, Supervisory Research Forest Products Technologist.

Lumber drying is one of the most time- and energy-consuming steps in processing wood products. The anatomical structure of wood limits how rapidly water can move through and out of wood. In addition, the sensitivity of the structure to stresses set up in drying limits the drying rate; rapid drying causes defects such as surface and internal checks, collapse, splits, and warp. Drying time and susceptibility to many drying defects increase at a rate that is more than proportional to wood thickness. The variability of wood properties further complicates drying. Each species has different properties, and even within species, variability in drying rate and sensitivity to drying defects impose limitations on the development of standard drying procedures. The interactions of wood, water, heat, and stress during drying are complex. The purpose of this chapter is to describe some of the fundamental properties of wood that are relevant to lumber drying. We will discuss commercial wood species, wood structure, lumber grades, water movement in wood, how wood dries, specific gravity and weight of wood, wood shrinkage, stress development during drying, and electrical and thermal properties of wood.

Commercial Wood Species

More than 100 commercially important species of trees grow in the United States. A similar number of species are imported into the United States, and the potential for additional imported species grows. The lumber produced from all of these species varies greatly in drying characteristics. The most commonly used commercial names for lumber and the corresponding species names accepted by the Forest Service for the trees from which the lumber is cut are given in table 1-1 for domestic species and table 1-2 for tropical species. Table 1-1 was adapted from the standard nomenclature of domestic hardwoods and softwoods developed by the American Society for Testing and Materials (1981). Tropical species follow the nomenclature used by Chudnoff (1984). While the commonly used lumber names are generally satisfactory for the buying and selling of lumber, they sometimes refer to lumber from a number of species that differ in green moisture content, shrinkage, or drying characteristics. In the tables and indexes of physical properties and drying schedules given in this and other chapters, the woods are arranged alphabetically by the common species names accepted by the Forest Service.

Hardwoods and Softwoods

Trees can be divided into two classes, hardwoods and softwoods. The hardwoods, such as birch, maple, and oak, have broad leaves. Some softwoods or conifers, such as the cedars, have scalelike leaves, while others, such as pine, Douglas-fir, and spruce, have needlelike leaves.

The terms hardwood and softwood are not directly associated with the hardness or softness of the wood. In fact, such hardwood trees as cottonwood, basswood, and yellow-poplar have softer wood than such softwoods as longleaf pine and Douglas-fir.

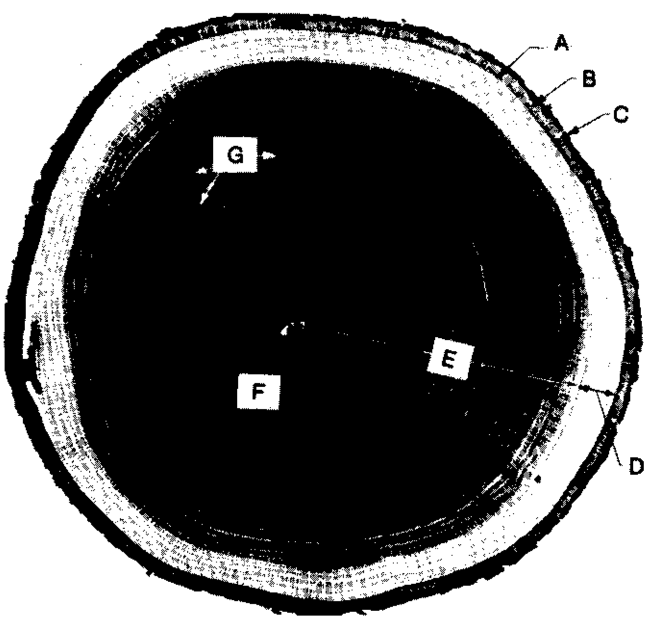

Figure 1-1—Cross section of a white oak tree trunk. A, Cambium layer (microscopic) is inside inner bark and forms wood and bark cells. B, Inner bark is moist and soft, and contains living tissue; the inner bark carries prepared food from leaves to all growing parts of tree. C, Outer bark containing corky layers is composed of dry dead tissue; it gives general protection against external injuries. Inner and outer bark are separated by a bark cambium. D, Sapwood, which contains both living and dead tissues, is the light-colored wood beneath the bark; it carries sap from roots to leaves. E, Heartwood (inactive) is formed by a gradual change in the sapwood. F, Pith is the soft tissue about which the first wood growth takes place in the newly formed twigs. G, Wood rays connect the various layers from pith to bark for storage and transfer of food. (MC88 9016)

Structural Features of Wood

The structure of wood and the location and amount of water in wood influence its drying characteristics. Wood is composed of bark, sapwood, heartwood, and pith (fig. 1-1). Each wood cell has a cavity (lumen) and walls composed of several layers arranged in different ways (fig. 1-2). The cell wall constituents are cellulose, hemicelluloses, and lignin. Most of the tubelike cells are oriented parallel to the long axis of the tree and are termed fibers, tracheids, or vessels, depending on their particular anatomical characteristics and function. Another type of cell, the wood ray, lies on radial lines from the center of the tree outward and perpendicular to the length of the tree. Figures 1-3 and 1-4 illustrate the arrangement of cells in softwoods and hardwoods, which have a similar but not identical anatomy.

One particular type of anatomical element, the pit, is important in water flow. A pit is a small, valve-like opening that connects adjacent wood cells and thus is an important pathway for the flow of water. Pits often become encrusted with substances or otherwise clogged so that water flow through them is very slow. Several types of pits are shown in figure 1-5.

Pits in softwoods often become aspirated as drying progresses. In aspiration, the torus is displaced so that it covers the pit aperture. In effect, the valves close during drying so that water flow through them is inhibited. The result is a decrease in drying rate.

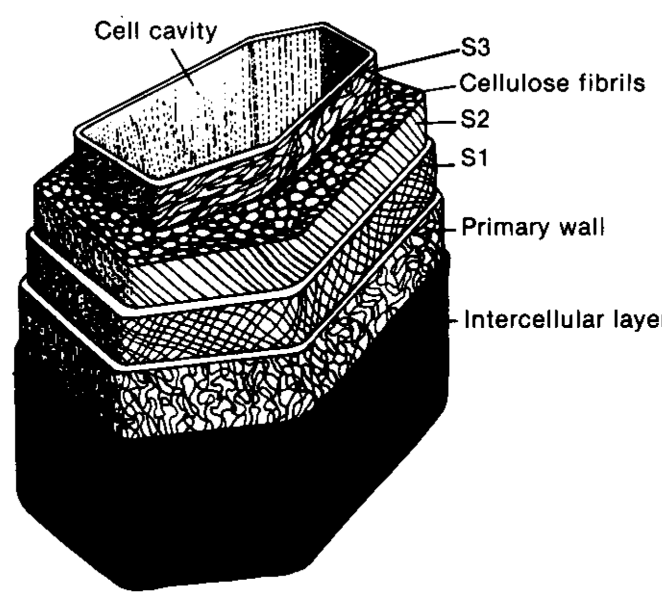

Figure 1-2—Cross section of a wood cell showing the several layers in the cell wall.
(ML88 5567)

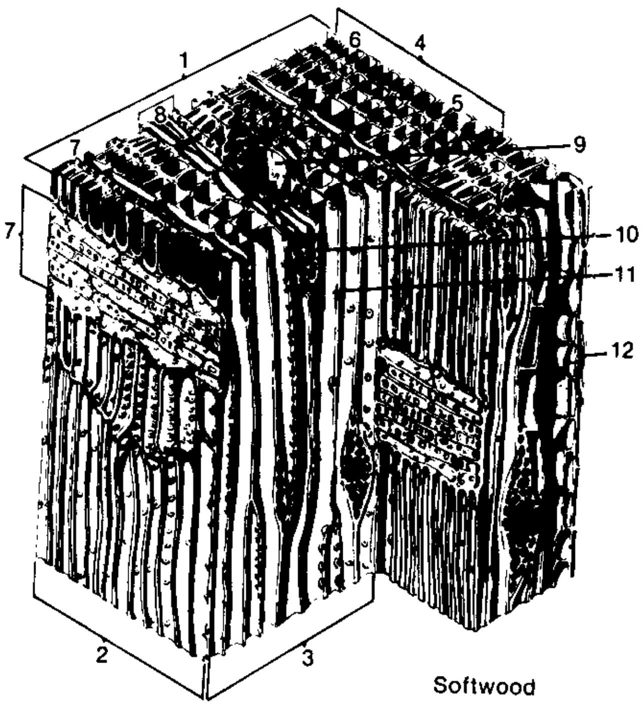

Figure 1-3—Wood structure of a softwood with resin ducts. (ML88 5568)

1. Cross-sectional face
2. Radial face
3. Tangential face
4. Growth ring
5. Earlywood
6. Latewood
7. Wood ray
8. Fusiform ray
9. Vertical resin duct
10. Horizontal resin duct
11. Bordered pit
12. Simple pit

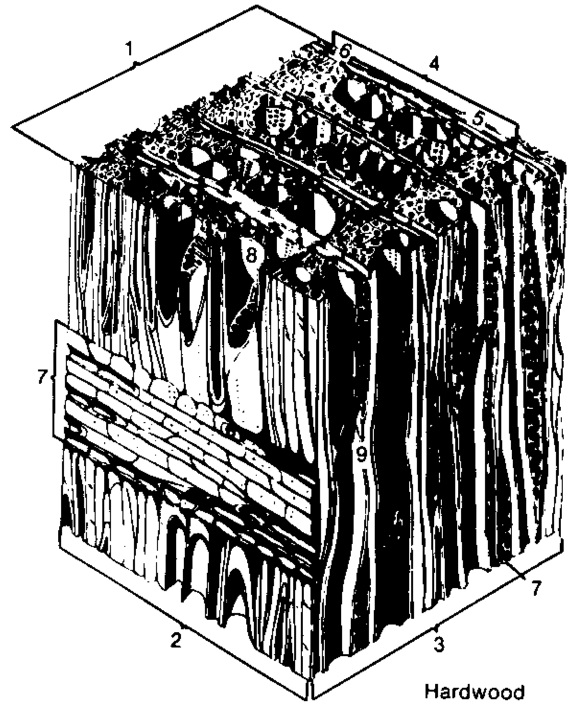

Figure 1-4—Wood structure of a hardwood. (ML88 5570)

1. Cross-sectional face
2. Radial face
3. Tangential face
4. Growth ring
5. Earlywood
6. Latewood
7. Wood ray
8. Vessel
9. Sieve plate

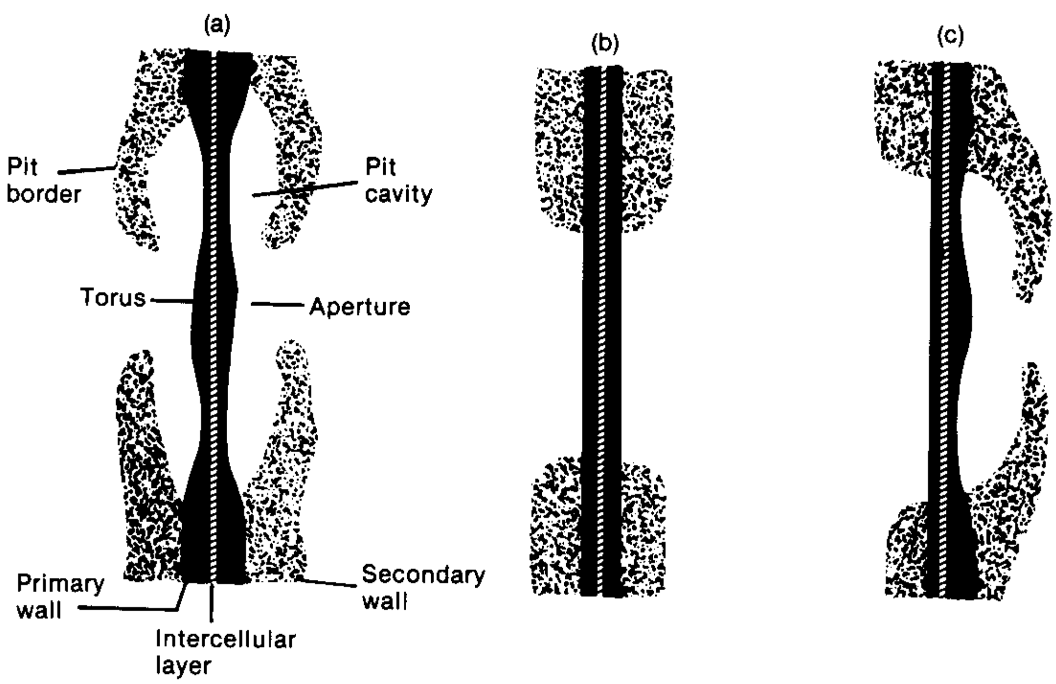

Figure 1-5—Pit cross sections. (a) Bordered pit (with torus in softwoods); (b) simple pit; and (c) half-bordered pit. (ML88 5569)

Sapwood and Heartwood

Sapwood and heartwood (fig. 1-1) affect the drying of wood. The sapwood layer next to the bark contains living cells that actively transport fluids necessary to the life of the tree. As the tree grows and increases in diameter by adding new layers of sapwood, the inner layers die. This inner wood, called heartwood, becomes infiltrated with gums, resins, and other material. Sapwood of softwood species is usually higher in moisture content than heartwood; sapwood moisture content in hardwood species is usually somewhat higher than or about equal to that of heartwood. The infiltration of gums and other material in heartwood make it more resistant to moisture flow (less permeable) than sapwood, and thus heartwood usually requires longer drying time. The lower permeability of heartwood also makes it more susceptible to certain drying defects (ch. 8), and so it requires milder drying conditions. Heartwood is usually darker than sapwood. However, because the change in color may occur slowly over a period of several years, a band of heartwood may be indistinguishable from adjacent sapwood; nevertheless, the heartwood will not dry easily because it is less permeable. Heartwood is also usually more resistant to decay and .some stains than sapwood.

Pith

The pith of a tree (fig. 1-1F) is usually near the center of the tree and is laid down by the growing tip. It is usually very small. Pith sometimes cracks during drying.

Annual Growth Rings

Diameter growth of a tree in temperate climates is represented by rings that usually can be easily seen on the end of a log as concentric circles around the pith. The closer the rings are to the pith, the smaller their radii of curvature. Each annual growth ring is composed of an inner part called earlywood (springwood), which is formed early in the growing season, and an outer part, called latewood (summerwood), which is formed later. When lumber is cut from a log, the annual rings are cut across in one direction or another and form a characteristic pattern on the broad face of the boards (fig. 1-6). In tropical woods, where there may be more than one active growing period annually, growth rings cannot be considered annual rings. In the majority of tropical species, however, there is no noticeable beginning or end of successive growth periods, so the typical pattern of rings shown in figure 1-6 does not occur.

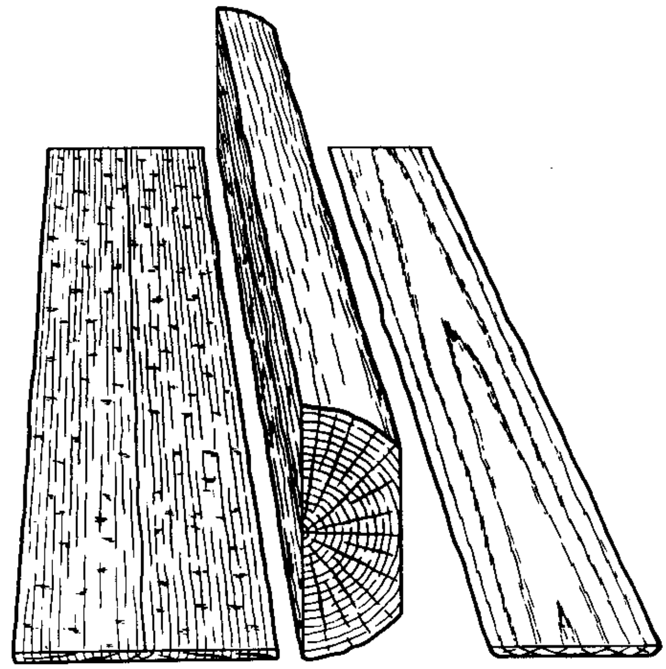

Figure 1-6—Annual growth rings. Quartersawn board (left) shows edge of annual rings on its broad face; flatsawn board (right) shows side of rings. (M 554)

The orientation of growth rings to the faces and edges of boards depends on how lumber is cut from a log. Lumber can be cut from a log in the two ways shown in figure 1-6. Sawing tangent to the annual rings produces flatsawn lumber, also called plainsawn, flat-grained, or slash-grained lumber. Sawing perpendicular to the annual rings produces quartersawn lumber, also called edge-grained or vertical-grained lumber. The angle of cut to the annual rings often lies somewhere in between. In commercial practice, lumber with rings at angles of 45° to 90° to the wide surface is called quartersawn, and lumber with rings at angles of 0° to 45° is called flatsawn. Hardwood lumber in which annual rings make angles of 30° to 60° to the wide face is sometimes called bastard sawn.

Either flatsawn or quartersawn lumber is generally suitable for most purposes. However, each type of sawn lumber responds differently in drying. Flatsawn lumber is less susceptible to collapse, shrinks and swells less in thickness, and dries faster than quartersawn. Quartersawn lumber shrinks and swells less in width, and has less twist, cup, and surface checks than flatsawn. These drying defects are discussed in chapter 8.

Wood Rays

Wood rays appear as ribbonlike strands on the face of quartersawn boards (fig. 1-6) and as short lines on the face of flatsawn boards in species with large rays. Because rays are weak and dry faster than the surrounding wood cells, surface, end, and honeycomb checks usually occur in or next to them. Species such as oak and beech, which have large rays, require special care during the early stages of drying to avoid checks.

Grain and Texture

The physical characteristics of various species that have some bearing on drying are loosely termed grain and texture. The terms fine grained and coarse grained refer to ring pattern, either the prominence of the latewood band or the width of the rings. When used in connection with wood cells, grain refers only to the direction of the cells or fibers. In straight-grained wood, the fibers run generally parallel to the length of the board, and in cross-grained or spiral-grained, they run at an angle. The terms end grain and side grain are commonly used in discussing moisture loss and drying defects. A cross section of a log or board has an end-grain surface. Any other section (radial, tangential, or intermediate) has a side-grain surface.

Texture usually refers to the diameter of individual cells. Fine-textured wood has small cells and coarse-textured, large cells. If all the cells of a wood are approximately the same size, the wood is usually called uniform textured. Uniform-textured woods in general are less likely to develop drying defects than nonuniform-textured woods. The word texture should not be used in describing hardness of wood.

Color

As a tree grows, the white or straw-colored sapwood gradually changes to heartwood, and the formation of extractives changes the color of most species. Holly, basswood, cottonwood, and magnolia, however, are examples of hardwoods in which the wood undergoes little or no change in color. Spruces and true firs are examples of softwoods that do not change color greatly.

The temperatures used in kiln drying sometimes darken wood, especially in high-temperature drying. Changes in the color of heartwood during drying are usually of little concern, but those that occur in sapwood are often significant. Chemical stains can occur when green sapwood of some species is kiln dried. The sapwood of hickory tends to turn pinkish when kiln dried (low initial temperatures must be used to preserve its whiteness) and paper birch sapwood may turn brownish. Hard maple sapwood is prone to darkening if dried at temperatures that are too high. Whiteness of the sapwood is often a very desirable feature of these species, and darkening reduces their value.

Beneficial color changes can be brought about by steaming wood before drying. Walnut, for example, is steamed in vats to darken the sapwood before drying so that it more nearly matches the color of the heartwood. Sapwood of sweetgum can be steamed to produce a salmon color that at one time was desirable for some products. Red alder is also steamed to produce a uniform honey-brown color of sapwood and heartwood.

Several other types of stain are considered drying defects, and they are discussed in chapter 8.

Variations in Structure

Lumber commonly contains variations in wood structure, such as spiral grain, knots, compression wood, tension wood, and juvenile wood.

Cross grain in lumber may result either from the way in which the log is sawed (diagonal grain) or from spiral grain that occurred in the growing tree. When spiral grain alternately runs in one direction and another in successive groups of growth rings, interlocked grain results. Lumber containing diagonal, spiral, or interlocked grain shrinks more in length than straight-grained lumber. Such lumber may bow, crook, and twist during drying.

Knots are sections of tree branches appearing in boards. Because of shrinkage, some kinds of knots may drop out during drying; more often, however, they are loosened or checked during drying and drop out of the board during handling or machining. These are called incased knots, and they result from the growth of trunk wood around dead branches. Intergrown knots, caused by the intergrowth of trunk wood and living branches, are much less likely to drop out of dried lumber.

Compression wood occurs in softwoods mainly on the lower side of leaning trees but sometimes in other parts of the tree trunk. Because this wood shrinks more along the length of boards than normal wood, boards that contain both compression and normal wood may bow, crook, and twist during drying. If this warping is restrained, the compression wood may fracture and form crossbreaks in the lumber.

Tension wood occurs in hardwoods, mainly on the upper side of leaning trees but sometimes in other parts of the trunk. Lumber containing this wood will shrink more longitudinally than normal wood, causing warp during drying.

Juvenile wood occurs in a cylinder around the pith. Once juvenile wood is formed, it does not mature-it is in the tree and lumber forever. However, as growth progresses, the new wood, as it is formed, gradually acquires more mature wood characteristics. Juvenile wood varies with species and occurs in the first 5 to 20 years of growth. The structural and physical properties of juvenile wood are considered inferior. From the standpoint of drying, the main problem is that juvenile wood shrinks more along the grain than mature wood, and warp is likely to occur during drying. Juvenile wood is more prevalent in fast-grown plantation trees than in slower grown stands. Species that are grown in volume in plantations, such as southern pine, present warp problems in drying.

Commercial Lumber Grades

When a log is sawed into lumber, the quality of the boards varies. The objective of grading is to categorize each board by quality so that it meets the requirements of the intended end uses. The grade of a board is usually based on the number, character, and location of features that may lower its strength, utility, appearance, or durability. Common visible features that affect grade are knots, checks, pitch pockets, shake, warp, and stain. Some of these features are a natural part of the tree and some can be caused by poor drying and storage practices.

Hardwood Lumber Grades

Most hardwood lumber is graded according to rules adopted by the National Hardwood Lumber Association. The grade of a board is determined by the proportion that can be cut into a certain number and size of smaller pieces clear of defects on at least one side. The grade is based on the amount of usable cuttings in the board rather than on the number or size of grade-determining features that characterize most softwood grades.

The highest cutting grade is termed Firsts and the next grade Seconds. Firsts and Seconds are usually combined into one grade, FAS. The third grade is termed Selects, followed by No. 1 Common, No. 2 Common, Sound Wormy, No. 3A Common, and No. 3B Common. Standard grades are described in table 1-3, which illustrates the grade-determining criteria of board length and width, surface measure of clear cuttings, percentage of board that must yield clear cuttings, and maximum number and size of cuttings allowed.

Hardwood lumber is usually manufactured to standard sizes. Standard lengths are in 1-ft increments from 4 to 16 ft. Hardwood lumber is usually manufactured to random width, but there are minimum widths for each grade as follows:

Firsts	6 in
Seconds	6 in
Selects	4 in
Nos. 1, 2, 3A, 3B Common	3 in

Standard thicknesses for rough and surfaced-two-sides (S2S) lumber are given in table 1-4.

This brief summary of grades is not complete and is only intended to offer a general view of how hardwood lumber is graded. The official grading rules of the National Hardwood Lumber Association should be consulted for complete details. There are also grading rules for dimension stock and special finished products such as flooring.

Softwood Lumber Grades

Softwood lumber grades can be divided into two categories based on use: for construction and for remanufacture. Construction lumber is expected to function as graded and sized after the primary processing steps of sawing, drying, and planing. Lumber for remanufacture is further modified in size and/or shape before use. There are many individual grading rules for different softwood species. The U.S. Department of Commerce has published the American Softwood Lumber Standard PS-20-70, which is an optional standard, in an attempt to reduce the differences in grading rules.

Construction lumber can be divided into three general categories: stress-graded, non-stress-graded, and appearance lumber. Stress-graded and non-stress-graded lumber are used where structural integrity is the prime concern; structural integrity is of secondary importance in appearance lumber. Almost all softwood lumber nominally 2 to 4 in thick is stress graded. This is the lumber that is typically used as 2 by 4 studs, joists, rafters, and truss members. Grading is based on the premise that lumber has lower strength than clear wood; characteristics used for grading are density (usually judged by ring count), decay, slope of grain, knots, shake, checks and splits, wane, and pitch pockets. These characteristics can be visually assessed.

Lumber intended for general building and utility purposes with little or no remanufacture is typically non-stress graded. Boards are one of the most common non-stress-graded products. The common grades are separated into several different categories that vary with species and grading associations. First-grade boards are usually graded primarily for serviceability, although appearance is also a consideration. Typical uses are siding, cornice, shelving, and paneling. Second- and lower-grade boards are permitted more and larger knots and are suitable for such products as subfloors, sheathing, and concrete forms.

Appearance lumber is often nonstress graded but forms a separate category because of the importance of appearance. Secondary manufacture is usually restricted to onsite fitting and cutting. Typical products are trim, siding, flooring, casing, and steps. Most appearance grades are described by combinations of letters such as B&BTR and C&BTR, although such terms as select and clear are used for some species. The upper grades allow a few minor imperfections such as small planer skips, checks, stain, and pin knots. The number and size of imperfections increase as the grade drops.

Lumber intended for further manufacture in plants as opposed to onsite modifications is usually graded as factory or shop lumber. It forms the basic raw material for many secondary operations such as furniture and mill work. Factory Select and Select Shop are typically the highest grades, followed by No. 1, No. 2, and No. 3. Grade characteristics are influenced by the width, length, and thickness of the piece and are based on the amount of high-quality material that can be cut from it.

There are several other grading systems for specialty products such as ladders, pencils, tanks, laminating stock, and industrial clears.

Moisture content is often specified in softwood lumber grades. For many products, the moisture content must be within certain limits and the grade stamp must include the moisture content at the time of surfacing. Lumber surfaced green is usually required to be stamped S-GRN. Most softwood lumber is dried to below 19 percent moisture content, and when surfaced at this moisture content it is stamped S-DRY. Sometimes the maximum allowable moisture content is 15 percent, and this is stamped as MC-15 or KD.

Wood-Moisture Relations

All wood in growing trees contains a considerable quantity of water, commonly called sap. Although sap contains some materials in solution, from the drying standpoint sap can be considered plain water. Most of this water should be removed to obtain satisfactory service for most uses of wood. All wood loses or gains moisture in an attempt to reach a state of balance or equilibrium with the conditions of the surrounding air. This state of balance depends on the relative humidity and temperature of the surrounding air. Therefore, some knowledge of wood-moisture relations is helpful in understanding what happens to wood during drying, storage, fabrication, and use.

The amount of moisture in wood is termed the moisture content. It can be expressed as a percentage of either dry or wet weight. For most purposes, the moisture content of lumber is based on dry weight, but the moisture content of wood fuel is usually based on wet weight. Moisture content on dry and wet basis is defined as follows:

On dry basis,

$$\text{Moisture content (percent)} = \frac{\text{Weight of water in wood}}{\text{Weight of totally dry wood}} \times 100$$

On wet basis,

$$\text{Moisture content (percent)} = \frac{\text{Weight of water in wood}}{\text{Weight of dry wood and water}} \times 100$$

These two ways of expressing moisture content can be related by

$$\text{Moisture content (dry)} = \frac{\text{Moisture content (wet)}}{100 - \text{Moisture content (wet)}} \times 100$$

In this manual we will deal only with the dry basis. For most species, the common and accurate method of determining moisture content is the ovendrying method, or oven test. This method is inaccurate for species with a high extractives content. In ovendrying (described in ch. 6), all the water is evaporated from a wood section by heating. Knowing the wood weight before and after ovendrying allows calculation of moisture content.

The amount of water in green or wet wood varies greatly, depending mainly on species. The moisture content of some species may be as low as 30 percent, whereas that of others may be as high as 200 percent. Large variations may occur not only between species but also within the same species and even in the same tree. In softwood species, sapwood usually contains more water than heartwood. In species such as redwood, the butt logs of trees may contain more water than the top logs. Some species contain an abnormal type of heartwood, called wetwood or sometimes sinker stock, that is sometimes higher in green moisture content than normal wood of the species. In addition to the higher moisture content, wetwood is slower to dry than normal wood and often more susceptible to such drying defects as honeycomb and collapse.

Contrary to popular belief, the amount of water in green wood does not vary greatly with the season of the year in which the trees are cut. Moisture content values for green wood of various species is given in table 1-5.

Free and Bound Water

Water is held in wood as free water or bound water. Free water is contained in the cell cavities (fig. 1-2); bound water is held within the cell walls. Free water is held within the cell cavities less tightly than the bound water is held within the cell walls. Consequently, slightly more energy is required to remove bound water than free water. Free water does not affect as many wood properties as bound water, but does affect thermal conductivity and permeability. Bound water affects many physical and mechanical properties, and its removal causes changes that affect the use of the wood.

Fiber Saturation Point

The fiber saturation point is defined as the moisture content at which the cell walls are saturated but no free water remains in the cell cavities. Moisture content of the individual cell walls at the fiber saturation point is usually about 30 percent, but may be lower for some species. Care must be used in judging whether a piece of wood is at the fiber saturation point. The term really refers to individual cells rather than boards or other pieces of wood. The mechanisms of how wood dries will be discussed later, but basically wood dries from the outside to the inside. Thus, during drying, the outside part of a board might be at 15 percent moisture content while the inside might still be at 45 percent. The average moisture content of the entire board might be 30 percent, but it is erroneous to consider the board to be at the fiber saturation point. There will be a continuous variation or gradient of moisture content from the outside to the inside of the board from 15 to 45 percent, and only some cells will be exactly at the fiber saturation point of 30 percent.

The fiber saturation point is important in the drying of wood for the following reasons: (1) more energy is required to evaporate water from a cell wall than from the cell cavity (approximately 5 percent more at 15 percent moisture content and 15 percent more at 6 percent moisture content); (2) a wood cell will not shrink until it reaches the fiber saturation point; and (3) large changes in many physical and mechanical properties of wood begin to take place at the fiber saturation point.

Equilibrium Moisture Content

Wood loses or gains moisture until the amount it contains is in balance with that in the surrounding atmosphere. The amount of moisture at this point of balance is called the equilibrium moisture content (EMC). The EMC depends mainly on the relative humidity and temperature of the surrounding air, although species

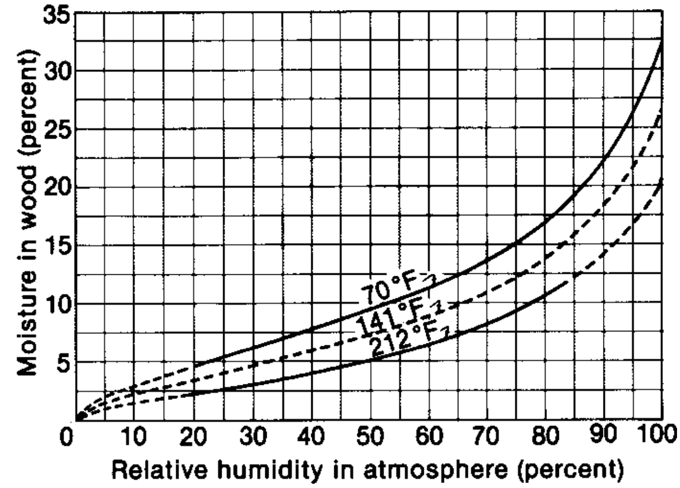

Figure 1-7—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere at three temperatures. (ML88 5572)

and previous moisture history have a slight effect on EMC. The relationship of EMC to relative humidity and temperature is shown in figure 1-7. If, for example, wood is kept in air at 141 °F and 65 percent relative humidity, it will eventually either gain or lose moisture until it reaches approximately 10 percent moisture content.

Kiln drying usually requires control of EMC conditions, that is, temperature and relative humidity, in the kiln. Thus both temperature and relative humidity have to be measured. Two thermometers-dry bulb and wet bulb--are used to obtain temperature and relative humidity. The dry-bulb thermometer measures temperature in the usual way, and the result is called the dry-bulb temperature. The sensor of the wet-bulb thermometer is kept wet with a wick cover, from which water evaporates at a rate determined by the relative humidity and temperature of the air. The drier the air, the faster the rate of evaporation. This evaporation has a cooling effect that increases as the rate of evaporation increases. Thus, the drier the air, the greater the cooling effect and the lower the temperature indicated by the wet-bulb thermometer. The difference between dry- and wet-bulb temperatures, called the wet-bulb depression, is thus a measure of the relative humidity of the air.

The relationship between relative humidity, temperature, and EMC is shown in table 1-6 for temperatures below 212 °F, and in table 1-7 for temperatures above 212 °F. For example, assume that the dry-bulb temperature in a kiln is 150 °F and the wet-bulb temperature 130 °F. The wet-bulb depression then is 20 °F. Wet-bulb depression temperatures are shown across the top of tables 1-6 and 1-7 and dry-bulb temperatures on the extreme left of the table. To find the EMC at the assumed conditions, (1) locate 20 °F wet-bulb depression column and (2) follow this column downward until it intersects the 150 °F dry-bulb temperature line. The EMC value, 8 percent, is the underscored value. Note that the relative humidity value (not underscored), 57 percent, is given directly above the EMC value. Wet- and dry-bulb temperatures, EMC, and psychrometric relations are further discussed in the appendix to this chapter.

How Wood Dries

Water in wood normally moves from higher to lower zones of moisture content. This fact supports the common statement that "wood dries from the outside in," which means that the surface of the wood must be drier than the interior if moisture is to be removed. Drying can be broken down into two phases: movement of water from the interior to the surface of wood, and removal of water from the surface. Moisture moves to the surface more slowly in heartwood than in sapwood, primarily because extractives plug the pits of heartwood. In drying, the surface fibers of heartwood of most species reach moisture equilibrium with the surrounding air soon after drying begins. This is the beginning of the development of a typical moisture gradient (fig. 1-8), that is, the difference in moisture content between the inner and outer portions of a board. The surface fibers of sapwood also tend to reach moisture equilibrium with the surrounding air if the air circulation is fast enough to evaporate water from the surface as fast as it comes to the surface. If the air circulation is too slow, a longer time is required for the surfaces of sapwood to reach moisture equilibrium. This is one reason why air circulation is so important in kiln drying. If it is too slow, drying is also slower than necessary and mold might even develop on the surface of lumber. If it is too fast, electrical energy in running the fans is wasted, and in certain species surface checking may develop if wet-bulb depression and air velocity are not coordinated.

Water moves through wood as liquid or vapor through several kinds of passageways. These are the cavities of fibers and vessels, ray cells, pit chambers and their pit membrane openings, resin ducts of certain softwoods, other intercellular spaces, and transitory cell wall passageways (Panshin and de Zeeuw 1980). Most water lost by wood during drying moves through cell cavities and pits. It moves in these passageways in all directions, both along and with the grain. Lighter species in general dry faster than heavier species because their structure contains more openings per unit volume.

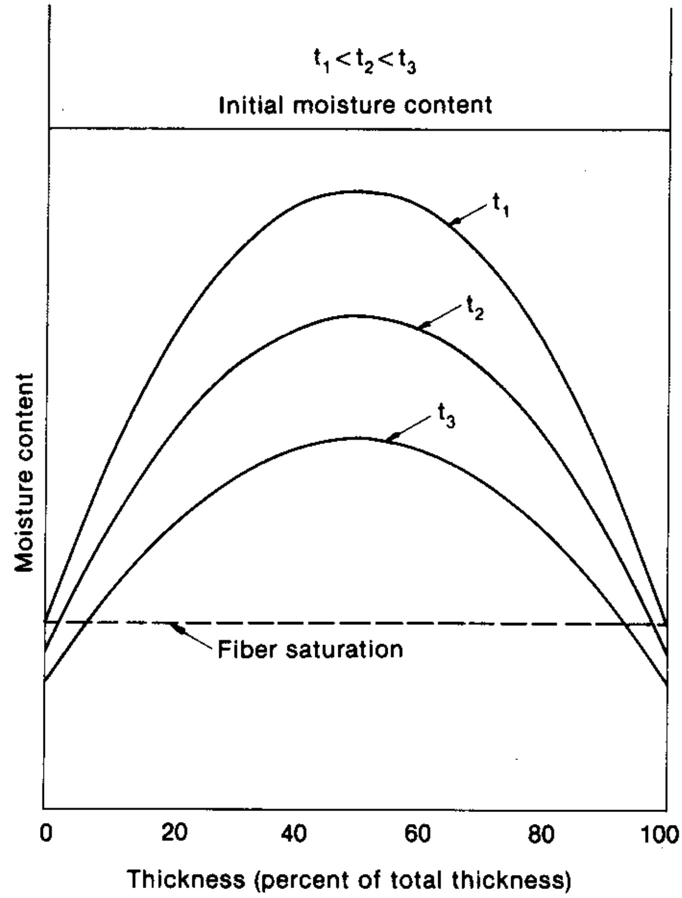

Figure 1-8—Typical moisture gradient in lumber during drying at times increasing from t_1 to t_3. (ML88 5571)

Forces That Move Water

When wood is drying, several forces may be acting simultaneously to move water (Siau 1984):

1. Capillary action causes free water to flow through the cell cavities and pits.
2. Differences in relative humidity cause water vapor to move through the cell cavities by diffusion, which moves water from areas of high to areas of low relative humidity. Cell walls are the source of water vapor; that is, water evaporates from the cell walls into the cell cavities.
3. Differences in moisture content cause bound water to move through the cell walls by diffusion, which moves water from area of high to areas of low moisture content. Generally, any water molecule that moves through wood by diffusion moves through both cell walls and cell cavities. Water may evaporate from a cell wall into a cell cavity, move across the cell cavity, be readsorbed on the opposite cell wall, move through the cell wall by diffusion, and so on until it reaches the surface of the board.

When green wood starts to dry, evaporation of water from the surface cells sets up capillary forces that exert a pull on the free water in the zones of wood beneath the surface, and a flow results. This is similar to the movement of water in a wick. Much free water in sapwood moves in this way. In comparison to diffusion, capillary movement is fast.

Longitudinal diffusion is about 10 to 15 times faster than lateral (radial or tangential) diffusion. Radial diffusion, perpendicular to the growth rings, is somewhat faster than tangential diffusion, parallel to the rings. This explains why flatsawn lumber dries faster than quartersawn lumber. Although longitudinal diffusion is 10 to 15 times faster than lateral diffusion, it is of practical importance only in short items. Common lumber is so much longer than it is thick that most of the water removed during drying does so through the thickness direction, leaving from the wide face of a board. In lumber where width and thickness are not greatly different, such as in squares, significant drying occurs in both the thickness and width directions.

The rate ‘of diffusion depends to a large extent upon the permeability of the cell walls and their thickness. Thus permeable species dry faster than impermeable ones, and the rate of diffusion decreases as the specific gravity increases.

Because moisture moves more freely in sapwood than heartwood, both by diffusion and by capillary flow, sapwood generally dries faster than heartwood under the same drying conditions. The heartwood of many species, however, is lower in moisture content than sapwood, and may reach final moisture content faster.

Factors That Influence Drying Rate

The rate at which moisture moves in wood depends on the relative humidity of the surrounding air, the steepness of the moisture gradient, and the temperature of the wood. The lower the relative humidity, the greater the capillary flow. Low relative humidity also stimulates diffusion by lowering the moisture content at the surface, thereby steepening the moisture gradient and increasing diffusion rate. The higher the temperature of the wood, the faster moisture will move from the wetter interior to the drier surface. If relative humidity is too low in the early stages of drying, excessive surface and end checking may result. And if the temperature is too high, collapse, honeycomb, or strength reduction may occur (see ch. 8).

Lumber Thickness

Drying rate is also affected by thickness. Drying time increases with thickness and at a rate that is more than proportional to thickness. For example, if thickness is doubled, drying time is more than doubled. Theoretically, if drying were controlled completely by diffusion, drying time would increase by a factor of four if thickness were doubled. But because of the other mechanisms involved in drying, drying time increases between three and four times. Thickness variation in lumber caused by poor sawing can lead to excessive moisture content variation after drying or excessive kiln time to equalize the variation. For example, the kiln-drying time for l-in-thick red oak will vary by about 4 percent for each 1/32-in variation in thickness.

Specific Gravity and Weight of Wood

Specific gravity is a physical property of wood that is a guide to ease of drying as well as an index of weight (table 1-8). In general, the heavier the wood, the slower the drying rate and the greater the likelihood of developing defects during drying. Specific gravity is defined as the ratio of the weight of a body to the weight of an equal volume of water. The specific gravity of wood is usually based on the volume of the wood at some specified moisture content and its weight when ovendry:

$$\text{Specific gravity} = \frac{\text{Ovendry weight of wood}}{\text{Weight of equal volume of water}}$$

Thus, if the specific gravity of a piece of green wood is 0.5, the ovendry weight of the wood substance in a cubic foot of the green wood is one-half the weight of a cubic foot of water. The higher the specific gravity of wood, the greater the amount of ovendry wood per unit volume of green wood. Thus, at the same moisture content, high specific gravity species contain more water than low specific gravity species. The green weight of 1 ft^3 of wood can be calculated from the following formula:

$$\text{Green weight} = \text{Specific gravity} \times (\text{Moisture content} + 100) \times 62.4/100 \text{ lb}$$

For example, the green weight of 1 ft^3 of a species of specific gravity 0.4 at 75 percent moisture content is 43.7 lb. The ovendry weight (by substituting 0 for moisture content in the formula) is 25 lb, and thus 18.7 lb of water are present. At a specific gravity of 0.6 at 75 percent moisture content, the green weight is

65.5 lb, the ovendry weight 37.4 lb, and the weight of water 28.1 lb. Thus, there are 9.4 lb more water at a specific gravity of 0.6 than at 0.4.

As the above formula indicates, weight of wood depends on its specific gravity and moisture content. Calculated weights for lumber are given in table 1-9. The values for weights per thousand board feet apply to a thousand feet, surface measure, of boards exactly 1 in thick (actual board feet) and not to a thousand board feet lumber scale. These weights were determined in the way described by Panshin and de Zeeuw (1980) and the resulting weight per cubic foot at the given moisture content multiplied by 83.3, the number of cubic feet in a thousand board feet. Note that two correction factors are given for calculating weights at moisture contents not shown in table 1-9. These factors are simply added to table values to calculate weights between table values. The correction factor for below 30 percent moisture content takes into account the volumetric shrinkage that occurs below 30 percent moisture content. The correction factor above 30 percent moisture content does not require a shrinkage correction component.

Since the weights in table 1-9 are based on actual board feet-a thousand lineal feet of lumber exactly 1 in thick and 12 in wide-they must be adjusted upward for rough lumber greater than 1 in thick and downward for surfaced lumber less than 1 in thick.

Example: What is the weight of 1,000 fbm of nominal 1 by 8 ponderosa pine lumber at 6 percent moisture content dressed to 25/32 in thick by 7-1/2 in wide?

The downward adjustment factor is calculated as follows:

$$\frac{25/32 \times 7\frac{1}{2}}{1 \times 8} = 0.732$$

From table 1-9, the weight of 1,000 fbm, actual, of this size ponderosa pine is 2,271 lb. With the downward adjustment the weight is

$$2{,}271 \times 0.732 = 1{,}662 \text{ lb}$$

Example: What is the weight of 1,000 fbm of nominal 4/4 rough, random width, northern red oak lumber at 75 percent moisture content? Assume the target sawing thickness is 37/32 in.

The upward adjustment factor is calculated as follows:

$$\frac{37/32}{1} = 1.156$$

Table 1-9 does not have a column for 75 percent moisture content, so the correction factor in column 2 must be used. The weight at 60 percent moisture content in table 1-9 is 4,666 lb. Using the correction factor of 29.1 lb per 1 percent moisture content, the weight of 1,000 fbm, actual, is

$$(75 - 60) \times 29.1 + 4{,}666 = 5{,}103 \text{ lb}$$

And with the upward adjustment factor, the weight of the nominal 4/4 lumber is

$$5{,}103 \times 1.156 = 5{,}899 \text{ lb}$$

Shrinkage of wood

Shrinkage of wood is the basic cause of many problems that occur in wood during drying and also in service. When water begins to leave the cell walls at 25 to 30 percent moisture content, the walls begin to shrink. Even after drying, wood will shrink and swell in service as relative humidity varies (table 1-6). Drying stresses develop because wood shrinks by different amounts in the radial, tangential, and longitudinal directions and because during drying, shrinkage starts in the outer fibers before it starts in the inner fibers. These stresses can cause cracks and warp to develop.

When wood is dried to 15 percent moisture content, about one-half of the total possible shrinkage has occurred; when dried to 8 percent, nearly three-fourths of the possible shrinkage has occurred. Figure 1-9 illustrates how Douglas-fir shrinks with loss of moisture. While these curves are not straight, the relationship between moisture content and shrinkage is generally approximated a a straight-line relationship.

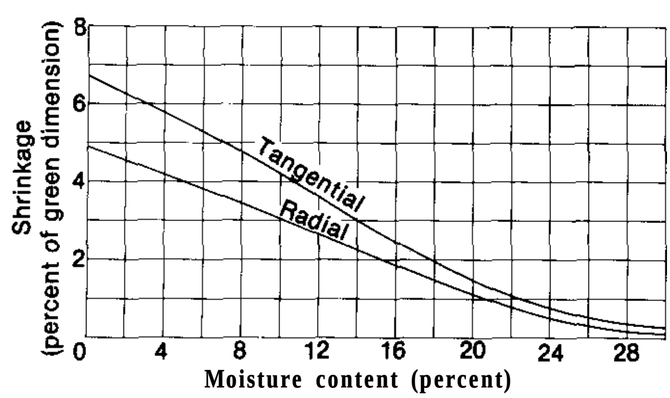

Figure 1-9—Typical relation of moisture content to shrinkage of Douglas-fir. Although the curves are not straight lines, they may be considered as such for practical shrinkage calculations. (ML88 5573)

Average Shrinkage Values

Table 1-10 gives average shrinkage values for various species of wood. These values are given in percentages of the green dimension.

$$\text{Shrinkage (percent)} = \frac{\text{Green dimension} - \text{Dry dimension}}{\text{Green dimension}} \times 100$$

Wood shrinks about 1.5 to 2 times as much parallel to the growth rings (tangential) as it does at a right angle to the growth rings (radial). The shrinkage along the grain (longitudinal) is small (0.2 percent or less for norma1 wood). Characteristic shrinkage patterns of boards are shown in figure 1-10.

Table 1-10 gives shrinkage values at only 20, 6, and 0 percent moisture content. Knowing the total shrinkage of a species at 0 percent moisture content, the percent shrinkage at any moisture content below 30 percent can be calculated. Since shrinkage curves are reasonably close to straight lines from 30 percent (approximate fiber saturation point) to 0 percent moisture content, each 1 percent change in moisture contact below 30 percent is equal to 1/30 of the total shrinkage from 30 to 0 percent.

$$S_M = \frac{S_0(30 - M)}{30}$$

where S_M is percent shrinkage from green to moistwe content M and S_0 is total shrinkage to 0 percent moisture content from table 1-10.

Example: What is the tangential shrinkage of western hemlock from green to 12 percent moisture content?

From table 1-10, the shrinkage of western hemlock to 0 percent moisture content is 7.8 percent. From the above equation

$$S_M = \frac{7.8(30 - 12)}{30} = 4.7 \text{ percent}$$

Shrinkage Variability

Shrinkage differs not only with respect to the length, width, and thickness of a board, but even in material cut from the same species and from the same tree. The values listed in table 1-10 are only representative values for the species, and individual observations of shrinkage may differ from them.

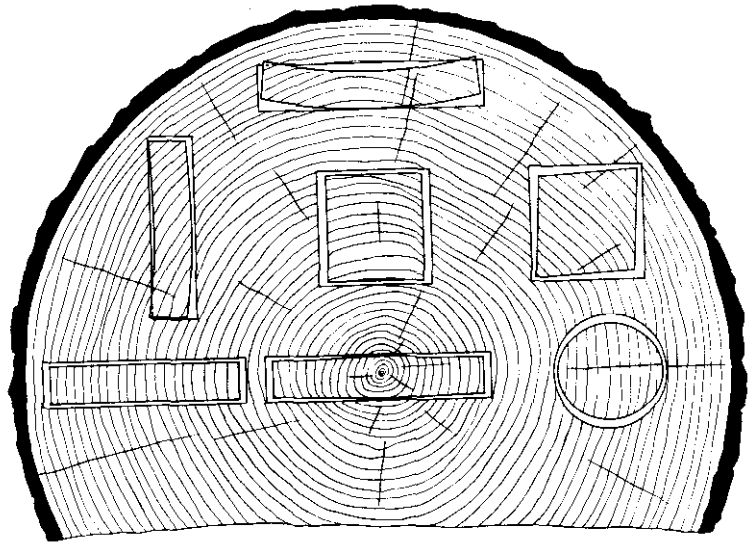

Figure 1-10—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of annual growth rings. The dimensional changes shown are somewhat exaggerated. (M 12494)

On the average, hardwoods shrink more than softwoods. In general, species of high specific gravity shrink more than ones of low specific gravity, but there are exceptions. Basswood, a light species, has high shrinkage, while the heavier black locust has more moderate shrinkage. The amount of shrinkage and the difference between radial and tangential shrinkage have a direct influence on the development of drying defects. Species that are high in extractive content–like tropical species such as true mahogany-have relatively low shrinkage.

Longitudinal shrinkage is variable. While it is usually less than 0.2 percent from green to ovendry, reaction wood and juvenile wood can shrink as much as 1 to 1.5 percent. As an increasing amount of young-growth plantation trees with juvenile wood is harvested, the variability of longitudinal shrinkage and its influence on warp become more of a problem.

Drying Stresses

The effect of drying stresses on the development of drying defects is discussed in chapter 8. Drying stresses are the main cause of nonstain-related drying defects. Understanding these stresses provides a means for preventing them. There are two causes of drying stresses: hydrostatic tension and differential shrinkage. Hydrostatic tension forces develop during the flow of capillary water. As water evaporates from cell cavities near the surface, it exerts a pull on water deeper in the wood. This tension pull is inward on the walls of cells whose cavities are full of water, and the result can be an in-

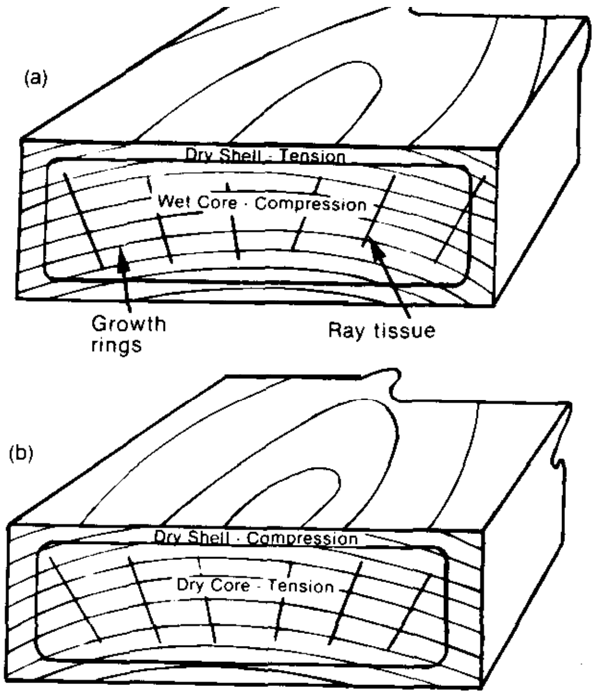

Figure 1-11—End view of board showing development of drying stresses early (a) and later (b) in drying. (ML88 5574)

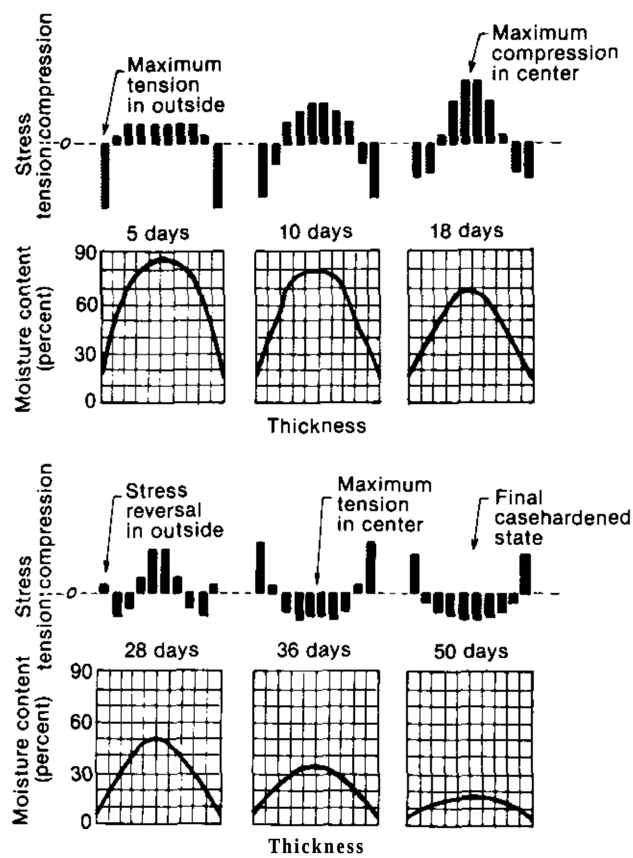

Figure 1-12—Moisture–stress relationship during six stages of kiln drying 2-in red oak. (ML88 5575)

ward collapse of the cell wall. The danger of collapse is greatest early in drying when many cell cavities are full of water, and if the temperature is high, collapse is more likely to occur.

Differential shrinkage between the shell and core of lumber also causes drying defects. Early in the drying process, the fibers in the shell (the outer portion of the board) dry first and begin to shrink. However, the core has not yet begun to dry and shrink, and consequently the core prevents the shell from shrinking. Thus, the shell goes into tension and the core into compression, as illustrated in figure 1-11. If the shell dries too rapidly, it is stressed beyond the elastic limit and dries in a permanently stretched (set) condition without attaining full shrinkage. Sometimes surface checks occur during this early stage of drying, and they can be a serious defect for many uses. As drying progresses, the core begins to dry and attempts to shrink. However, the shell is set in a permanently expanded condition and prevents normal shrinkage of the core. This causes the stresses to reverse-the core goes into tension and the shell into compression. The change in the shell and core stresses and moisture content during drying is shown in figure 1-12. These internal tension stresses may be severe enough to cause internal cracks (honeycomb) to occur.

Differential shrinkage caused by differences in radial, tangential, and longitudinal shrinkage is a major cause of warp. The distortions shown in figure 1-10 are due to differential shrinkage. When juvenile or reaction wood is present on one side or face of a board and normal wood is present on the opposite face, the difference in their longitudinal shrinkage will also cause warp.

Electrical Properties

Electrical properties of wood vary enough with moisture content that they can be used to measure moisture content reasonably accurately and very quickly. Those electrical properties of wood that indicate level of moisture content are resistance to the flow of electrical current and dielectric properties. These properties are utilized in electric moisture meters to estimate the moisture content of wood (James 1988).

The direct current electrical resistance of wood varies greatly with moisture content, especially below the fiber saturation point. It decreases greatly as moisture content increases (table 1-11). Resistance also varies with species, is greater across the grain than

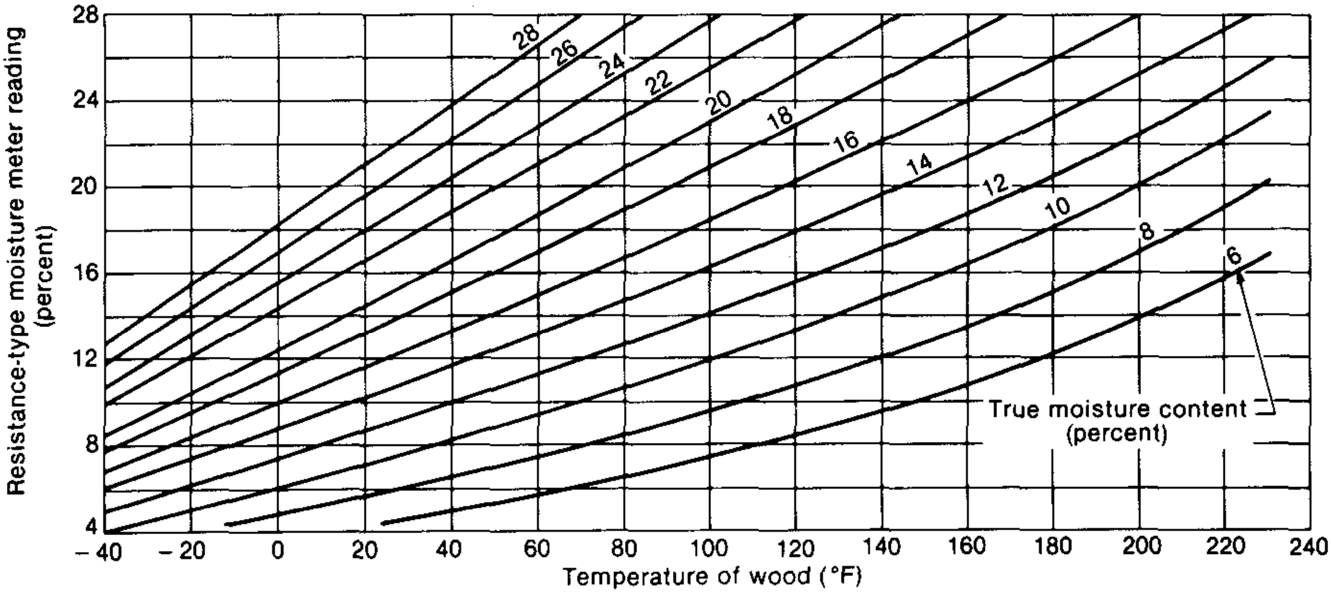

Figure 1-13—Temperature corrections for reading of resistance-type moisture meters, based on combined data from several investigators. Find meter reading on vertical axis, follow horizontally to vertical line correspending to the temperature of the wood, and interpolate corrected reading from family of curves. Example: If meter indicated 18 percent on wood at 120 °F, corrected reading would be 14 percent. This chart is based on a calibration temperature of 70 °F. For other calibration temperatures near 70 °F, adequate corrections can be obtained simply by shifting the temperature scale so that the true calibration temperature coincides with 70 °F on the percent scale. For example, for meters calibrated at 80 °F, add 10 °F to each point on the temperature scale (shift the scale 10 °F toward the left), and use the chart as before. After temperature correction, apply the appropriate species correction. (ML88 5576)

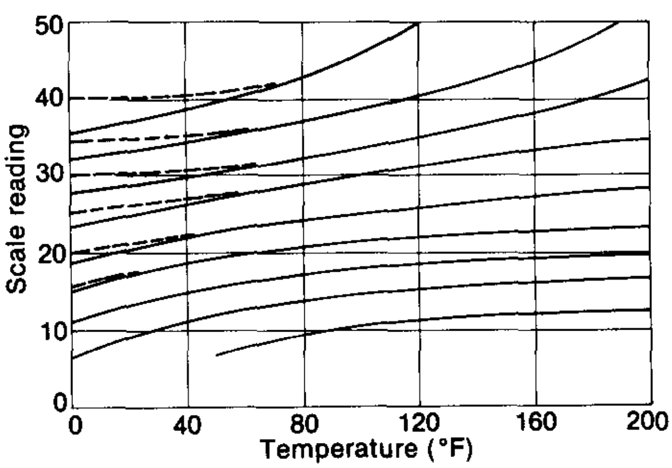

Figure 1-14—Approximate temperature corrections for capacitive admittance meter; data taken using a "Sentry" hand meter with calibration setting of 20 or greater. Solid lines are for the meter itself at room temperature; broken lines are for the meter at the same temperature as the lumber. (ML88 5578)

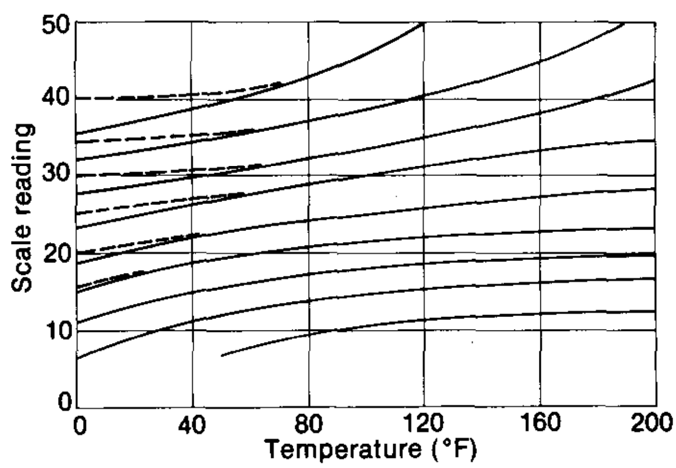

Figure 1-15—Approximate temperature corrections for readings of power-loss type moisture meters; data taken using a Moisture Register model L. Locate the point whose coordinates are the observed scale reading and the specimen temperature, and trace back parallel to the curves to the calibration temperature of the meter (usually 80°F). The vertical coordinate here is the corrected scale reading, which is then converted to moisture content using the usual species conversion tables. Solid lines are for the meter itself at room temperature; broken lines are for the meter at the same temperature as the lumber. (ML88 5579)

along it, and is affected by temperature. Resistance is not greatly affected by specific gravity. Commercial resistance moisture meters are often calibrated for one species, but are supplied with a species correction table. The meters are usually calibrated for 70 °F and also require a temperature correction chart (fig. 1-13). Resistance meters use probes that must be driven into the wood for measurement.

Meters that use the dielectric properties of wood are classified as one of two types-capacitance and power-loss (James 1988). With these instruments, electrodes are pressed against the wood, and high-frequency electric energy is applied. The electrodes do not penetrate the wood. The amount of power absorbed depends on the moisture content of the wood. Species correction tables and temperature correction charts (figs. 1-14 and l-15) are also necessary.

Thermal Properties

Thermal properties are relevant to wood drying because they are related to energy requirements and the time required to heat wood to drying temperature. Specific heat of a material is the ratio of the heat capacity of the material to that of water. It is a measure of the energy required to raise the temperature of the material. Thermal conductivity is a measure of the rate of heat flow through a material. The coefficient of thermal expansion is a measure of the change of dimension caused by temperature change.

Specific Heat

The specific heat of wood depends on the temperature and moisture content of the wood, but is practically independent of density or species. Specific heat of dry wood can be approximately related to temperature T, in degrees Fahrenheit, by the following formula:

$$\text{Specific heat} = 0.25 + 0.0006T$$

When wood contains water, the specific heat increases because the specific heat of water is larger than that of dry wood. If the specific heat of water is taken as one, the specific heat of wood at moisture content m, where m is percent moisture content divided by 100, is

$$\text{Specific heat} = \frac{0.25 + 0.0006T + m}{1 + m}$$

Example: Estimate the energy in British thermal units (Btu) required to raise the temperature of 50,000 fbm of nominal 4/4 northern red oak at 75 percent moisture content from 60 to 110 °F.

This is a continuation of the earlier example on weight of wood, where the weight of 1,000 fbm of 4/4 northern red oak at 75 percent was 5,103 lb. Thus 50,000 fbm weigh 255,150 lb. The specific heat over the interval between 60 and 110 °F can be approximated by using the average temperature as follows:

$$T = \frac{60 + 110}{2} = 85\,°\mathrm{F}$$

Thus, the specific heat is

$$\frac{0.25 + 0.0006 \times 85 + 0.75}{1 + 0.75} = 0.601 \frac{\text{Btu}}{\text{lb} \times °\text{F}}$$

The energy required is the product of the weight, the specific heat, and the temperature rise as follows:

$$\begin{aligned}\text{Energy} &= 255{,}150 \text{ lb} \times 0.601 \frac{\text{Btu}}{\text{lb} \times °\text{F}} \\ &\times (110 - 60)°\text{F} \\ &= 7{,}667 \text{ million Btu}\end{aligned}$$

Thermal Conductivity

The thermal conductivity of wood is affected by density, moisture content, extractive content, grain direction, temperature, and structural irregularities such as knots. It is nearly the same in the radial and tangential directions but two to three times greater parallel to the grain. It increases as the density, moisture content, temperature, and extractive content increase. Thermal conductivity below 40 percent moisture content can be approximated by

$$k = G \times (1.39 + 0.028 \times M) + 0.165$$

and above 40 percent moisture content by

$$k = G \times (1.39 + 0.038 \times M) + 0.165$$

where k is thermal conductivity in Btu·in/h·ft^2. °F and G is specific gravity based on volume at M percent moisture content and ovendry weight.

Thermal Expansion

The thermal expansion of wood is so small that it is overshadowed by shrinkage and swelling. It is far less than dimensional changes associated with changes in moisture content, and conditions that would cause thermal expansion would also cause moisture-related shrinkage. The coefficient of thermal expansion is defined as the unit increase in dimension per degree increase in temperature. The coefficient of ovendry wood in the longitudinal direction is apparently independent of specific gravity and species. In both hardwoods and softwoods, it ranges from 0.0000017 to 0.0000025 inch per inch per degree Fahrenheit.

The coefficients of thermal expansion in the radial and tangential directions are 5 to 10 times greater than in the longitudinal direction and are thus of more practical interest. They depend on specific gravity, and for ovendry wood can be approximated by the following equations over the specific gravity range of 0.1 to 0.8:

$$\text{Radial coefficient} = (18G + 5.5) \times 10^{-6} \text{ per } ^\circ\text{F}$$

$$\text{Tangential coefficient} = (18G + 10.2) \times 10^{-6} \text{ per } ^\circ\text{F}$$

where G is specific gravity. Thermal expansion coefficients can be considered independent of temperature over the range of –60° to 130°F.

The thermal expansion properties of wood containing water are difficult to define. When wood with moisture is heated, it tends to expand because of normal thermal expansion and at the same time to shrink because of drying that occurs with the rise in temperature. Unless wood is below about 3 to 4 percent moisture content, the shrinkage will be greater than the thermal expansion. The question is sometimes asked if thermal expansion can cause checking in lumber. Because thermal expansion is so small, it is doubtful that it can cause checking.

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Table 1-1—Commercial species grown in the United States

Commercial name for lumber	Common tree name	Botanical name
	HARDWOODS	
Alder		
Red alder	red alder	*Alnus rubra*
Apple	apple	*Malus* spp.
Ash		
Black ash[1]	black ash	*Fraxinus nigra*
Oregon ash	Oregon ash	*F. latifolia*
White ash	blue ash	*F. quadrangulata*
	green ash	*F. pennsylvanica*
	white ash	*F. americana*
Aspen[2]	bigtooth aspen	*Populus grandidentata*
	quaking aspen	*P. tremuloides*
Basswood[3]	American basswood	*Tilia americana*
	white basswood	*T. heterophylle*
Beech	beech, American	*Fagus grandifolia*
Birch[4]	gray birch	*Betula populifolia*
	paper birch	*B. papyrifera*
	river birch	*B. nigra*
	sweet birch	*B. lenta*
	yellow birch	*B. alleghaniensis*
Box elder	boxelder	*Acer negundo*
Buckeye	Ohio buckeye	*Aesculus glabra*
	yellow buckeye	*A. octandra*
Butternut	butternut	*Juglans cinerea*
Cherry	black cherry	*Prunus serotina*
Chestnut	American chestnut	*Castanea dentata*
	balsam poplar	*Populus balsamifera*
Cottonwood	black cottonwood	*P. trichocarpa*
	eastern cottonwood	*P. deltoides*
	plains cottonwood	*P. sargentii*
	swamp cottonwood	*P. heterophylla*
Dogwood	flowering dogwood	*Cornus florida*
	Pacific dogwood	*C. nuttallii*
Elder, see Box elder		
Elm		
Rock elm	cedar elm	*Ulmus crassifolia*
	rock elm	*U. thomasii*
	September elm	*U. serotina*
	winged elm	*U. alata*
Soft elm[5]	American elm	*U. americana*
	slippery elm	*U. rubra*
Gum[6]	sweetgum	*Liquidambar styraciflua*
Hackberry	hackberry	*Celtis occidentalis*
	sugarberry	*C. laevigata*
Hickory[7]	mockernut hickory	*Carya tomentosa*
	pignut hickory	*C. glabra*
	sand hickory	*C. pallida*
	shagbark hickory	*C. ovata*
	shellbark hickory	*C. laciniosa*
Holly	American holly	*Ilex opaca*
lronwood	eastern hophornbeam	*Ostyra virginiana*
Locust	black locust	*Robinia pseudoacacia*
	honeylocust	*Gleditsia triacanthos*
Madrone	Pacific madrone	*Arbutus menziesii*
Magnolia	southern magnolia	*Magnolia grandiflora*
	sweetbay	*M. virginiana*
	cucumber tree	*M. acuminata*
Maple		
Hard maple[8]	black maple	*Acer nigrum*
	sugar maple	*A. saccharum*
Oregon maple	bigleaf maple	*A. macrophyllum*
Soft maple[8]	red maple	*A. rubrum*
	silver maple	*A. saccharinum*

Table 1-1—Commercial species grown in the United States—continued

Commercial name for lumber	Common tree name	Botanical name
	HARDWOODS—continued	
Myrtle, *see* Oregon myrtle		
Oak		
Red oak	black oak	*Quercus velutina*
	blackjack oak	*Q. marilandica*
	California black oak	*Q. kellogii*
	cherrybark oak	*Q. falcata var. pagodaefolia*
	laurel oak	*Q. laurifolia*
	northern pin oak	*Q. ellipsoidalis*
	northern red oak	*Q. rubra*
	Nuttall oak	*Q. nuttalli*
	pin oak	*Q. palustris*
	scarlet oak	*Q. coccinea*
	shingle oak	*Q. imbricaria*
	Shumard oak	*Q. shumardii*
	southern red oak	*Q. falcata*
	turkey oak	*Q. laevis*
	willow oak	*Q. phellos*
White oak	Arizona white oak	*Q. arizonica*
	blue oak	*Q. douglasii*
	bur oak	*Q. macrocarpa*
	California white oak	*Q. lobata*
	chestnut oak	*Q. prinus*
	chinkapin oak	*Q. muehlenbergii*
	Emory oak	*Q. emoryi*
	Gambel oak	*Q. gambelii*
	Mexican blue oak	*Q. oblongifolia*
	live oak	*Q. virginiana*
	Oregon white oak	*Q. garryana*
	overcup oak	*Q. lyrata*
	post oak	*Q. stellata*
	swamp chestnut oak	*Q. michauxii*
	swamp white oak	*Q. bicolor*
	white oak	*Q. alba*
Oregon myrtle	California-laurel	*Umbellularia californica*
Osage orange	Osage-orange	*Maclura pomifera*
Pecan[7]	bitternut hickory	*Carya cordiformis*
	nutmeg hickory	*C. myristicaeformis*
	water hickory	*C. aquatica*
	pecan	*C. illinoensis*
Persimmon	common persimmon	*Diospyros virginiana*
Sassafras	sassafras	*Sassafras albidum*
Sycamore	American sycamore	*Platanus occidentalis*
Tanoak	tanoak	*Lithocarpus densiflorus*
Tupelo[9]	black tupelo	*Nyssa sylvatica*
	Ogeechee tupelo	*N. ogeche*
	swamp tupelo	*N. silvatica var. biflora*
	water tupelo	*N. aquatica*
Walnut	black walnut	*Juglans nigra*
Willow	black willow	*Salix nigra*
	peachleaf willow	*S. amygdaloides*
Yellow poplar	yellow-poplar	*Liriodendron tulipifera*
	SOFTWOODS	
Cedar		
Alaska cedar	Alaska-cedar	*Chamaecyparis nootkatensis*
Incense cedar	incense-cedar	*Libocedrus decurrens*
Port Orford cedar	Port-Orford-cedar	*Chamaecyparis lawsoniana*
Eastern red cedar	eastern redcedar	*Juniperus virginiana*
	southern redcedar	*J. silicicola*
Western red cedar	western redcedar	*Thuja plicata*
Northern white cedar	northern white-cedar	*T. occidentalis*
Southern white cedar	Atlantic white-cedar	*Chamaecyparis thyoides*
Cypress[10]	baldcypress	*Taxodium distichum*
	pondcypress	*T. distichum var. nutans*
Fir		
Balsam fir[11]	balsam fir	*Abies balsamea*
	Fraser fir	*A. fraseri*
Douglas fir[12]	Douglas-fir	*Pseudotsuga menziesii*
	Inland Douglas-fir	*P. menziesii var. glauca*
Noble fir	noble fir	*Abies procera*

Table 1-1—Commercial species grown In the United States—concluded

Commercial name for lumber	Common tree name	Botanical name
	SOFTWOODS—continued	
Fir (continued)		
White fir	California red fir	*A. magnifica*
	grand fir	*A. grandis*
	noble fir	*A. procera*
	Pacific silver fir	*A. amabilis*
	subalpine fir	*A. lasiocarpa*
	white fir	*A. concolor*
Hemlock		
Eastern hemlock	Carolina hemlock	*Tsuga caroliniana*
	eastern hemlock	*T. canadensis*
Mountain hemlock	mountain hemlock	*T. medensiana*
West coast hemlock	western hemlock	*T. heterophylla*
Juniper		
Western juniper	alligator juniper	*Juniperus deppeana*
	Rocky Mountain juniper	*J. scopulorum*
	Utah juniper	*J. osteosperma*
	western juniper	*J. occidentalis*
Larch		
Western larch	western larch	*Larix occidentalis*
Pine		
Jack pine	jack pine	*Pinus banksiana*
Lodgepole pine	lodgepole pine	*P. contorta*
Norway pine	red pine	*P. resinosa*
Ponderosa pine	ponderosa pine	*P. ponderosa*
Sugar pine	sugar pine	*P. lambertiana*
Idaho white pine	western white pine	*P. monticola*
Northern white pine	eastern white pine	*P. strobus*
Longleaf pine[13]	longleaf pine	*P. palustris*
	slash pine	*P. elliottii*
Southern pine	loblobbly pine	*Pinus taeda*
	longleaf pine	*P. palustris*
	pitch pine	*P. rigida*
	pond pine	*P. serotina*
	shortleaf pine	*P. echinata*
	slash pine	*P. elliottii*
	Virginia pine	*P. virginiana*
Redwood	redwood	*Sequoia sempervirens*
Spruce		
Eastern spruce	black spruce	Picea mariana
	red spruce	P. rubens
	white spruce	P. glauca
Engelmann spruce	blue spruce	P. pungens
	Engelmann spruce	P. engelmannii
Sitka spruce	Sitka spruce	P. sitchensis
Tamarack	tamarack	Larix laricina
Yew		
Pacific yew	Pacific yew	Taxus brevifolia

[1]Black ash is known commercially in some consuming centers as brown ash, and is also sometimes designated as such in specifications.

[2]Aspen lumber is sometimes designated as popple.

[3]For some commercial uses where a white appearance is required, the sapwood of American basswood (*Tilia americana*) is specified under the designation "white basswood." This commercial-use designation should not be confused with the species (*T. heterophylla*) having the common name white basswood.

[4]The principal lumber species is yellow birch. It may be designated either sap birch (all sapwood) or red birch (all hardwood) or it may be unselected. Sweet birch is sold without distinction from yellow birch. Paper birch is a softer wood used principally for turnings and novelties and is widely know as white birch. The remaining birches are of minor commercial importance.

[5]Soft elm lumber is sometimes designated as white elm. A special type of slowly grown material is sometimes designated commercially as gray elm. Slippery elm is called red elm in some localities, although that term is also used for two other elms.

[6]Usually designated either as red gum or as sap gum, as the case may be, or as gum or sweetgum when not selected for color. (For black gum, *see* tupelo, footnote 9.)

[7]The impossibility of distinguishing between hickory ad pecan lumber for accurate species identification is recognized. Three of the four major *Carya* species in the pecan group have the word "hickory" in their name.

[8]When hard maple or soft maple is specified to be white, the specification generally is interpreted as being a requirement for sapwood, although it sometimes may take on the special meaning of being all sapwood with a minimum of natural color.

[9]The impossibility of distinguishing between black tupelo (blackgum), swamp tupelo, and water tupelo lumber for accurate species identification is recognized.

[10]Cypress includes types designated as red cypress, white cypress, and yellow cypress. Red cypress is frequently classified and sold separately from the other types.

[11]Balsam fir lumber is sometimes designated either as eastern fir or as balsam.

[12]Douglas fir may be specified either as Coast Region Douglas for or as Inland Region Douglas for, but if the particular type is not so specified or is not otherwise indicated through the grade specifications, either or both types will be allowed.

[13]The commercial requirements for longleaf pine lumber are that not only must it be produced from trees of the botanical species of *Pinus elliottii* and *P. palustris,* but each piece in addition must average either on one end or the other not less than six annual rings per inch and not less than one-third summerwood. Longleaf pine lumber is sometimes designated as pitch pine in the export trade.

Table 1-2—Tropical wood species

Common name (other common names)[1]	Botanical name[2]
Afrormosia (kokrodua, assamela)	*Pericopsis elata* (Af)
Albarco (jequitiba, abarco, bacu, cerú, tauary)	*Cariniana* spp. (LA)
Andiroba (crabwood, cedro macho, carapa)	*Carapa guianensis* (LA]
Angelique (basralocus)	*Dicorynia guianensis* (LA)
Apitong (keruing, eng, in, yang, heng, keroeing)	*Dipterocarpus* spp. (As)
Avodire (blimah-pu, apapaye, lusamba, apaya)	*Turraeanthus africanus* (Af)
Balata (bulletwood, chicozapote, ausubo)	*Manilkara bidentata* (LA)
Balsa (corcho, gatillo, enea, pung, lana)	*Ochroma pyramidale (LA)*
Banak (baboen, sangre, palo de sangre)	*Virola* spp. (LA)
Benge (mutenye, mbenge)	*Guibourtia arnoldiana* (Af)
Bubinga (essingang, ovang, kevazingo, waka)	*Guibourtia* spp. (Af)
Caribbean pine (pino, ocote)	*Pinus caribaea* (LA)
Cativo (amansamujer, camibar, muramo, curucai)	*Prioria copaifera* (LA)
Ceiba (silk-cotton-tree, kapok-tree)	*Ceiba pentandra* (LA)
Cocobolo (granadillo, funera, palo negro)	*Dalbergia retusa* (LA)
Courbaril (cuapinol, guapinol, locust)	*Hymenaea courbaril* (LA)
Cuangare (virola, fruta dorado, miguelario)	*Dialyanthera* spp. (LA)
Cypress, Mexican (cipres)	*Cupressus lusitanica* (LA)
Degame (lemonwood, camarón, palo camarón, surr,a)	*Calycophyllum candidissium* (LA)
Determa (red louro, wana, wane, grignon rouge)	*Ocotea rubra* (LA)
Ebony, East Indian (kaya malam, kaya arang)	*Diospyros ebenum* (As)
Ebony, African (mgiriti, msindi, omenowa)	*Diospyros* spp. (Af)
Gmelina (gumhar, yemane)	*Gmelina arborea* (As)
Goncalo alves (palo de cera, palo de culebra)	*Astronium graveolens* (LA)
Greenheart (demerara greenheart, bibiru)	*Ocotea rodiaei* (LA)
Hura (possumwood, arbol del diablo, haba)	*Hura crepitans* (LA)
llomba (gboyei, qualele, walele, otie, akomu)	*Pycanthus angolensis* (Af)
Imbuia (Brazilian walnut, canella imbuia)	*Phoebe porosa* (LA)
Ipe (bethabara, lapacho, amapa, cortez)	*Tabebuia* spp. (lapacho group) (LA)
lroko (semli, odoum, rokko, oroko, abang)	*Chlorophora excelsa* and *regia* (Af)
Jarrah	*Eucalyptus marginata (As)*
Jelutong (jelutong bukit)	*Dyera costulate* (As)
Kapur (keladan, kapoer, Borneo camphorwood)	*Drybalanops* spp. (As)
Karri	*Eucalyptus diversicolor* (As)
Kempas (impas, mengris)	*Koompassia malaccensis* (As)
Keruing (apitong, eng, in, yang, heng, keroeing)	*Dipterocarpus* spp. (As)
Lauan, red, light red, and white (maranti)	*Shorea* spp. (As)
Lignumvitae (guayacán, palo santo)	*Guaiacum* spp. (LA)
Limba (afara, ofram, fraké, akom, korina)	*Terminalia superba* (Af)
Mahogany, African	*Khaya* spp. (Af)
Mahogany, true (Honduras mahogany. caoba)	*Swietenia macrophylla* (LA)
Manni (chewstick, barillo, cerillo, machare)	*Symphonia globulifera* (LA)
Merbau (ipil, tat-talun, lumpha, lumpho, kwila)	*lntsia bijuga* and *palembanica* (As)
Mersawa (palosapis, pengiran)	*Anisoptera* spp. (As)
Mora (nato, nato rojo, mora de Guayana)	*Mora* spp. (LA)
Obeche (arere, samba, ayous, wawa, abachi)	*Triplochiton scleroxylon* (Af)
Ocote pine (pino, ocote)	*Pinus oocarpa* (LA)
Okoume (gaboon, angouma, moukoumi, N'Koumi)	*Aucoumea klaineana* (Af)
Opepe (kusia, badi, bilinga, akondoc, kilingi)	*Nauclea* spp. (Af)
Parana pine (pinheiro do paraná)	*Araucaria angustifolia* (LA)
Pau Marfim (marfim, pau liso, guatambú)	*Balfourodendron riedelianum* (LA)
Peroba de campos (white peroba, ipe peroba)	*Paratecoma peroba* (LA)
Peroba rosa (amarello, amargoso, ibira-romí)	*Aspidosperma* spp. (LA)
Primavera (duranga, San Juan, palo blanca)	*Cybistax donnell-smithii* (LA)
Purpleheart (amaranth, palo morado, morado)	*Peltogyne* spp. (LA)
Ramin (melawis, garu buaja, lanutan-bagio)	*Gonystylus* spp. (As)
Roble (encino, oak, ahuati, cucharillo)	*Quercus* spp. (LA)
Roble (mayflower, amapa, roble blanco)	*Tabebuia* spp. Roble group (LA)
Rosewood, Indian (shisham)	*Dalbergia latifolia* (As)
Rosewood, Brazilian (jacarandá)	*Dalbergia nigra* (LA)
Rubberwood (árbol de caucho, sibi-sibi)	*Hevea brasilliensis* (LA, As)
Sande (cow-tree, mastate, avichuri)	*Brosimum* spp. Utile group (LA)
Santa Maria (jacareuba, barí)	*Calophyllum brasiliense* (LA)
Sapele (aboudikro, penkwa, muyovu)	*Entandrophragma cylindricum* (Af)
Sepetir (sindur, supa, kayu galu, makata)	*Pseudosindora and Sindora* spp. (As)
Spanish cedar (cedro, acajou rouge)	*Cedrela* spp. (LA)
Sucupira (alcornoque, sapupira)	*Bowdichia* spp. (LA)
Sucupira (botonallare, peonía, tatabu)	*Diplotropis purpurea* (LA)
Teak (kyun, teck, teca)	*Tectona grandis* (As]
Wallaba (palo machete, bijlhout, wapa, apá)	*Eperua* spp. (LA)

[1]Additional common names are listed in Chudnoff (1984).
[2]Af is Africa; As, Asia and Oceania; and LA, Latin America.

Table 1-3—Standard hardwood cutting grades[1]

Grade and length (ft) allowed	Width allowed (in)	Surface measure of pieces (ft²)	Amount of each piece that must work into clear-face cuttings (percent)	Maximum cutting allowed (number)	Minimum size of cuttings required
Firsts[2] 8 to 16 (will admit 30 per cent of 8- to 11-foot, 1/2 of which may be 8- and 9-foot)	6+	4 to 9	91-2/3	1	4 inches by 5 feet, or 3 inches by 7 feet
		10 to 14	91-2/3	2	
		15+	91-2/3	3	
Seconds[2] 8 to 16 (will admit 30 per-cent of 8- to 11-foot, 1/2 of which may be 8- and 9-foot)	6+	4 and 5	83-1/3	1	4 inches by 5 feet, or 3 inches by 7 feet
		6 and 7	83-1/3	1	
		6 and 7	91-2/3	2	
		8 to 11	83-1/3	2	
		8 to 11	91-2/3	3	
		12 to 15	83-1/2	3	
		12 to 15	91-2/3	4	
		16+	83-1/3	4	
Selects 6 to 16 (will admit 30 per-cent of 6- to 11-foot, 1/6 of which may be 6- and 7-foot)	4+	2 and 3	91-2/3	1	4 inches by 5 feet, or 3 inches by 7 feet
		4+	([3])		
No. 1 Common 4 to 16 (will admit 10 per-cent of 4- to 7-foot, 1/2 of which may be 4- and 5-foot)	3+	1	100	0	4 inches by 2 feet, or 3 inches by 3 feet
		2	75	1	
		3 and 4	66-2/3	1	
		3 and 4	75	2	
		5 to 7	66-2/3	2	
		5 to 7	75	3	
		8 to 10	66-2/3	3	
		11 to 13	66-2/3	4	
		14+	66-2/3	5	
No. 2 Common 4 to 16 (will admit 30 per-cent of 4- to 7-foot, 1/3 of which may be 4- and 5-foot) 4 to 16 (will admit 30 per-cent of 4- to 7-foot, 1/3 of which may be 4- and 5-foot)	3+	1	66-2/3	1	3 inches by 2 feet
		2 and 3	50	1	
		2 and 3	66-2/3	2	
		4 and 5	50	2	
		4 and 5	66-2/3	3	
		6 and 7	50	3	
		6 and 7	66-2/3	4	
		8 and 9	50	4	
		10 and 11	50	5	
		12 and 13	50	6	
		14+	50	7	
No. 3A Common 4 to 16 (will admit 50 per-cent of 4- to 7-foot, 1/2 of which may be 4- and 5-foot)	3+	1+	[4]33-1/3	([5])	3 inches by 2 feet
No. 3B Common 4 to 16 (will admit 50 per-cent of 4- to 7-foot, 1/2 of which may be 4- and 5-foot)	3+	1+	[6]25	([5])	1-1/2 inches by 2 feet

[1]Inspection to be made on the poorer side of the piece, except in Selects.
[2]Firsts and Seconds are combined as 1 grade (FAS). The percentage of Firsts required in the combined grade varies from 20 to 40 percent, depending on the species.
[3]Same as Seconds with reverse side of board not below No. 1 Common or reverse side of cuttings sound.
[4]This grade also admits pieces that grade not below No. 2 Common on the good face and are sound on the reverse face.
[5]Unlimited.
[6]The cuttings must be sound; clear face not required.

Table 1-4—Standard thickness for rough and surfaced (S2S) hardwood lumber

Nominal rough thickness (in)	S2S thickness (in)	Nominal rough thickness (in)	S2S thickness (in)
3/8	3/16	1-3/4 (7/4)	1-1/2
1/2	5/16	2 (8/4)	1-3/4
5/8	7/16	2-1/2 (10/4)	2-1/4
3/4	9/16	3 (12/4)	2-3/4
1 (4/4)	3/4	3-1/2 (14/4)	3-1/4
1-1/4 (5/4)	1-1/16	4 (16/4)	3-3/4
1-1/2 (6/4)	1-5/16		

S2S refers to lumber that is surfaced on two sides.

Table 1-5—Average moisture content of green wood

Species	Moisture content[1] (percent) Heartwood	Sapwood	Mixed heartwood and sapwood
SOFTWOODS			
Baldcypress	121	171	—
Cedar			
Alaska	32	166	—
Atlantic white	—	—	35
Eastern redcedar	33	—	—
Incense	40	213	—
Northern white	32	240	93
Port-Orford	50	98	—
Western redcedar	58	249	62
Douglas-fir			
Coast type	37	115	45
Intermediate type	34	154	—
Rocky Mountain type	30	112	43
Fir			
Balsam	88	173	117
California red	—	—	108
Grand	91	136	—
Noble	34	115	—
Pacific silver	55	164	—
Subalpine	—	—	47
White	98	160	—
Hemlock			
Eastern	97	119	—
Western	85	170	—
Larch, western	54	119	—
Pine			
Eastern white	50	175	90
Lodgepole	41	120	—
Ponderosa	40	148	—
Red	32	134	—
Southern			
Loblolly	33	110	—
Longleaf	31	106	—
Shortleaf	32	122	—
Sugar	98	219	—
Western white	62	148	—
Redwood			
Old-growth	86	210	—
Second-growth	—	—	127
Spruce			
Black	52	113	77
Engelmann	51	173	—
Sitka	41	142	43
Tamarack	49	—	—
HARDWOODS			
Alder, red	—	97	—
Apple	81	74	—
Ash			
Black	95	—	—
Green	—	58	—
White	46	44	—
Aspen	95	113	—
HARDWOODS—continued			
Basswood, American	81	133	—
Beech, American	55	72	—
Birch			
Paper	89	72	—
Sweet	75	70	—
Yellow	74	72	—
Buckeye, yellow	—	—	141
Butternut	—	—	104
Cherry, black	58	—	—
Chestnut, American	120	—	—
Cottonwood, black	162	146	—
Dogwood, flowering	—	—	62
Elm			
American	95	92	—
Cedar	66	61	—
Rock	44	57	—
Hackberry	61	65	—
Hickory			
Bitternut	80	54	—
Mockernut	70	52	—
Pignut	71	49	—
Red	69	52	
Sand	68	50	—
Water	97	62	—
Holly, American	—	—	82
Hophornbeam, eastern	—	—	52
Laurel, California	—	—	65
Locust, black	—	—	40
Madrone, Pacific	—	—	81
Magnolia	80	104	—
Maple			
Silver (soft)	58	97	—
Sugar (hard)	65	72	—
Oak			
California black	76	75	—
Live	—	—	50
Northern red	80	69	—
Southern red	83	75	—
Southern swamp	79	66	—
Water	81	81	—
White	64	78	—
Willow	82	74	—
Osage-orange	—	—	31
Persimmon, common	—	—	58
Sweetgum	79	137	—
Sycamore, American	114	130	—
Tanoak	—	—	89
Tupelo			
Black	87	115	—
Swamp	101	108	—
Water	150	116	—
Walnut, black	90	73	—
Willow, black	—	—	139
Yellow-poplar	83	106	—

[1]Based on ovendry weight.

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F.

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	89	78	67	57	46	36	27	17	6	—	—	—	—	—	—	—	—	—
	—	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	—	—	—	—	—	—	—	—	—
35	90	81	72	63	54	45	37	28	19	11	3	—	—	—	—	—	—	—
	—	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	—	—	—	—	—	—	—
40	92	83	75	68	60	52	45	37	29	22	15	8	—	—	—	—	—	—
	—	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	—	—	—	—	—	—
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	—	—	—	—
	—	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	—	—	—	—
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	—	—
	—	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	—	—
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5
	—	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13
	—	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20
	—	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25
	—	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31
	—	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35
	—	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38
	—	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41
	—	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*
95	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44
	—	*21.3*	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F—continued

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)																		
	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
55	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60	9	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2.3	*1.3*	*0.2*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
65	16	13	8	6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	3.8	*3.0*	*2.3*	*1.4*	*0.4*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	22	19	15	12	9	6	3	—	—	—	—	—	—	—	—	—	—	—	—
	4.9	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*	—	—	—	—	—	—	—	—	—	—	—	—
75	28	24	21	18	15	12	10	7	4	1	—	—	—	—	—	—	—	—	—
	5.6	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*	—	—	—	—	—	—	—	—	—
80	32	29	26	23	20	18	15	12	10	7	5	3	—	—	—	—	—	—	—
	6.3	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*	—	—	—	—	—	—	—
85	36	33	30	28	25	23	20	18	15	13	11	9	4	—	—	—	—	—	—
	6.7	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*	—	—	—	—	—	—
90	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	—	—	—	—
	7.2	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.3*	*2.8*	*2.1*	*1.3*	*0.4*	—	—	—	—
95	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	—	—	—
	7.5	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5.1*	*4.8*	*4.4*	*4.0*	*3.6*	*3.0*	*2.3*	*1.5*	*0.6*	—	—	—

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F—continued

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperature (°F)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46
	—	21.3	19.0	17.5	16.1	15.0	13.9	13.1	12.4	11.8	11.2	10.6	10.1	9.6	9.2	8.9	8.5	8.1
105	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48
	—	21.4	19.0	17.5	16.2	15.1	14.0	13.3	12.6	11.9	11.3	10.8	10.3	9.8	9.4	9.0	8.7	8.3
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50
	—	21.4	19.0	17.5	16.2	15.1	14.1	13.3	12.6	12.0	11.4	10.8	10.4	9.9	9.5	9.2	8.8	8.4
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52
	—	21.4	19.0	17.5	16.2	15.1	14.1	13.4	12.7	12.1	11.5	10.9	10.4	10.0	9.6	9.3	8.9	8.6
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53
	—	21.3	19.0	17.4	16.2	15.1	14.1	13.4	12.7	12.1	11.5	11.0	10.5	10.0	9.7	9.4	9.0	8.7
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55
	—	21.2	18.9	17.3	16.1	15.0	14.0	13.4	12.7	12.1	11.5	11.0	10.5	10.0	9.7	9.4	9.0	8.7
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56
	—	21.0	18.8	17.2	16.0	14.9	14.0	13.4	12.7	12.1	11.5	11.0	10.5	10.0	9.7	9.4	9.0	8.7
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58
	—	20.7	18.6	16.9	15.8	14.8	13.8	13.2	12.5	11.9	11.4	10.9	10.4	10.0	9.6	9.4	9.0	8.7
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60
	—	20.2	18.4	16.6	15.4	14.8	13.7	13.0	12.4	11.8	10.2	10.8	10.3	9.9	9.5	9.2	8.9	8.6
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62
	—	19.8	18.1	16.2	15.2	14.2	13.4	12.7	12.1	11.5	11.0	10.6	10.1	9.7	9.4	9.1	8.8	8.5
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63
	—	19.4	17.7	15.8	14.8	13.9	13.2	12.4	11.8	11.3	10.8	10.4	9.9	9.6	9.2	9.0	8.6	8.4
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65
	—	18.9	17.3	15.5	14.5	13.7	12.9	12.2	11.6	11.1	10.6	10.1	9.7	9.4	9.0	8.8	8.4	8.1
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66
	—	18.5	16.9	15.2	14.2	13.4	12.7	12.0	11.4	10.9	10.5	10.0	9.6	9.2	8.9	8.6	8.2	7.9
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67
	—	18.1	16.4	14.9	14.0	13.2	12.4	11.8	11.2	10.8	10.3	9.8	9.4	9.1	8.8	8.4	8.1	7.7
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68
	—	17.7	16.0	14.6	13.8	13.0	12.2	11.7	11.1	10.6	10.0	9.7	9.2	9.0	8.7	8.3	8.0	7.6

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F—concluded

Dry-bulb temper-ature (°F)	Relative humidity[1] and equilibrium moisture content [2] (%) at various wet-bulb depression temperatures (°F)																		
	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
100	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	—	—
	7.8	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.9*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.6*	*0.7*	—	—
105	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	—	—
	7.9	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	—	—
110	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	—
	8.1	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	—
115	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	8.2	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	8.3	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	8.3	*8.0*	*7.7*	*7.5*	*7.2*	*7.0*	*6.7*	*6.5*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.6*	*2.7*	*1.6*
130	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	8.3	*8.0*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.4*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.0*	*2.0*
140	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	8.4	*8.0*	*7.8*	*7.6*	*7.3*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*	*3.4*	*2.6*
150	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	8
	8.3	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*	*3.6*	*2.9*
160	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	8.2	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*	*3.7*	*3.2*
170	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33	28	24
	8.0	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*	*3.7*	*3.2*
180	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	7.8	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.4*	*3.8*	*3.3*
190	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37	32	28
	7.7	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*	*3.8*	*3.3*
200	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	51	39	34	30
	7.5	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*	*3.8*	*3.3*
210	67	65	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41	36	32
	7.4	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*	*3.7*	*3.8*

[1]Relative humidity values not italic.
[2]Equilibrium moisture content values italic.

Table 1-7—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions above 212°F.

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)														
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
215	92	90	89	87	85	83	82	80	78	77	75	74	72	71	69
	14.4	*13.5*	*12.7*	*12.0*	*11.4*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.8*	*7.5*
220	—	—	—	—	—	84	82	81	79	77	76	74	73	71	70
	—	—	—	—	—	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.6*	*8.3*	*8.0*	*7.7*	*7.4*
225	—	—	—	—	—	—	—	—	—	—	76	75	73	72	70
	—	—	—	—	—	—	—	—	—	—	*8.5*	*8.2*	*7.9*	*7.6*	*7.3*
230	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
235	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
240	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
245	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
250	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
255	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
260	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 1-7—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions above 212°F—concluded

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)														
	19	**20**	**22**	**24**	**26**	**28**	**30**	**35**	40	**45**	**50**	**55**	**60**	**70**	**80**
215	68 *7.3*	66 *7.0*	63 *6.6*	61 *6.2*	58 *5.9*	56 *5.6*	53 *5.3*	47 *4.7*	42 *4.2*	37 *3.8*	33 *3.4*	29 *3.0*	25 *2.7*	19 *2.2*	14 *1.7*
220	68 *7.2*	67 *7.0*	64 *6.6*	62 *6.2*	59 *5.8*	56 *5.5*	54 *5.3*	48 *4.6*	43 *4.2*	38 *3.7*	34 *3.4*	30 *3.0*	26 *2.7*	20 *2.2*	15 *1.7*
225	69 *7.1*	68 *6.9*	65 *6.4*	62 *6.1*	60 *5.7*	57 *5.4*	55 *5.2*	49 *4.6*	44 *4.1*	39 *3.7*	35 *3.3*	31 *3.0*	27 *2.7*	21 *2.2*	16 *1.7*
230	69 *7.0*	68 *6.7*	65 *6.3*	63 *6.0*	60 *5.7*	58 *5.4*	55 *5.1*	50 *4.5*	45 *4.0*	40 *3.6*	35 *3.3*	31 *2.9*	28 *2.6*	22 *2.1*	16 *1.7*
235	— —	— —	— —	63 *5.9*	61 *5.6*	58 *5.3*	56 *5.0*	50 *4.4*	45 *4.0*	41 *3.5*	36 *3.2*	32 *2.9*	29 *2.6*	22 *2.1*	17 *1.7*
240	— —	— —	— —	— —	— —	— —	57 *4.9*	51 *4.4*	46 *3.9*	41 *3.5*	37 *3.1*	33 *2.8*	29 *2.6*	23 *2.1*	18 *1.7*
245	— —	— —	— —	— —	— —	— —	— —	52 *4.3*	47 *3.8*	42 *3.4*	38 *3.1*	34 *2.8*	30 *2.6*	24 *2.1*	18 *1.7*
250	— —	— —	— —	— —	— —	— —	— —	— —	47 *3.7*	43 *3.3*	38 *3.0*	35 *2.7*	31 *2.5*	25 *2.0*	19 *1.6*
255	— —	— —	— —	— —	— —	— —	— —	— —	— —	43 *3.3*	39 *2.9*	35 *2.7*	32 *2.4*	25 *2.0*	20 *1.6*
260	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	40 *2.9*	36 *2.6*	32 *2.3*	26 *1.9*	21 *1.6*

[1]Relative humidity values not italic.
[2]Equilibrium moisture content values italic.

Table 1-8—Specific gravity of wood

Species	Average specific gravity
SOFTWOODS	
Baldcypress	0.42
Cedar	
Alaska	0.42
Atlantic white-	0.31
Eastern redcedar	0.44
Incense	0.35
Northern white	0.29
Port-Orford	0.39
Western redcedar	0.31
Douglas-fir	
Coast type	0.45
Interior west	0.46
Interior north	0.45
Interior south	0.43
Fir	
Balsam	0.33
California red	0.36
Grand	0.35
Noble	0.37
Pacific silver	0.40
Subalpine	0.31
White	0.37
Hemlock	
Eastern	0.38
Western	0.42
Larch, western	0.48
Pine	
Eastern white	0.34
Lodgepole	0.38
Ponderosa	0.38
Red	0.41
Southern pine	
Loblolly	0.47
Longleaf	0.54
Shortleaf	0.47
Sugar	0.34
Western white	0.35
Redwood	
Old-growth	0.38
Second-growth	0.34
Spruce	
Black	0.38
Engelmann	0.33
Red	0.37
Sitka	0.37
Tamarack	0.49
HARDWOODS	
Alder, red	0.37
Apple	0.61
Ash	
Black	0.45
Green	0.53
White	0.55
Aspen	
Bigtooth	0.36
Quaking	0.35
Basswood, American	0.32
Beech, American	0.56

Species	Average specific gravity'
HARDWOODS—continued	
Birch	
Paper	0.48
Sweet	0.60
Yellow	0.55
Buckeye, yellow	0.33
Butternut	0.36
Cherry, black	0.47
Chestnut, American	0.40
Cottonwood, black	0.31
Dogwood, flowering	0.64
Elm	
American	0.46
Rock	0.57
Slippery	0.48
Hackberry	0.49
Hickory, pecan	
Bitternut	0.60
Hickory, true	
Mockernut	0.64
Pignut	0.66
Shagbark	0.64
Shellbark	0.62
Holly, American	0.50
Hophornbeam, eastern	0.63
Laurel, California	0.51
Locust, black	0.66
Madrone, Pacific	0.58
Maple	
Soft	
Bigleaf	0.44
Red	0.49
Silver	0.44
Hard	
Black	0.52
Sugar	0.56
Oak, red	
Black	0.56
California black	0.51
Laurel	0.56
Northern red	0.56
Pin	0.58
Scarlet	0.60
Southern red	0.52
Water	0.56
Willow	0.56
Oak, white	
Bur	0.58
Chestnut	0.57
Live	0.80
Overcup	0.57
Post	0.60
Swamp chestnut	0.60
White	0.60
Persimmon, common	0.64
Sweetgum	0.46
Sycamore, American	0.46
Tanoak	0.58
Tupelo	
Black	0.46
Water	0.46
Walnut, black	0.51
Willow, black	0.36
Yellow-poplar	0.40

Table 1-8—Specific gravity of wood-concluded

Species	Average specific gravity[1]	Species	Average specific gravity[1]
IMPORTED[2]		IMPORTED[2]—continued	
Afrormosia	0.61	Lignumvitae	1.05
Albarco	0.48	Limba	0.38
Andiroba	0.54	Mahogany, African	0.42
Angelique	0.60	Mahogany, true	0.45
Apitong	0.69	Manni	0.58
Avodire	0.48	Merbau	0.64
Balata (Bulletwood)	0.85	Mersawa	0.52
Balsa	0.16	Mora	0.78
Banak	0.42	Obeche	0.30
Benge	0.65		
Bubinga	0.71		
Caribbean pine	0.68		
Cativo	0.40	Ocote pine	0.55
Ceiba	0.25	Okoume	0.33
Cocobolo	0.89	Opepe	0.63
Courbaril	0.71	Parana pine	0.46
Cuangare	0.31	Pau Marfim	0.73
Degame	0.67	Peroba de campos	0.63
Determa	0.52	Peroba rosa	0.66
Ebony, East Indian	0.70	Primavera	0.40
Ebony, African	0.82	Purpleheart	0.67
Gmelina	0.41	Ramin	0.52
Goncalo alves	0.84	Roble (Quercus)	0.70
Greenheart	0.80	Roble (Tabebuia)	0.52
Hura	0.38	Rosewood, Indian	0.75
Ilomba	0.40	Rosewood, Brazilian	0.80
Imbuya	0.53	Rubberwood	0.49
Ipe	0.92	Sande	0.49
Iroko	0.54	Santa Maria	0.52
Jarrah	0.67	Sapele	0.55
Jelutong	0.36	Sepetir	0.56
Kapur	0.64	Spanish cedar	0.41
Karri	0.82	Sucupira (Bowdichia)	0.74
Kempas	0.71	Sucupira (Diplotropis)	0.78
Keruing	0.69	Teak	0.55
Lauan		Wallaba	0.78
Red	0.34		
White	0.55		

[1]Based on ovendry weight and green volume
[2]Refer to table 1-2 for botanical name.

Table 1-9—Calculated weights of wood per thousand board feet actual measure

Species	Approximate correction factor per 1,000 board feet for each 1 percent moisture content change: Below 30 percent moisture content	Above 30 percent moisture content	Weight (lb) per 1,000 actual board feet of various moisture content levels: 6%	15%	25%	40%	60%	80%
SOFTWOODS								
Baldcypress	13.2	21.9	2,527	2,646	2,778	3,063	3,501	3,939
Cedar								
Alaska	14.4	21.9	2,498	2,628	2,772	3,063	3,501	3,939
Atlantic white-	10.9	16.1	1,838	1,936	2,045	2,261	2,583	2,905
Eastern redcedar	16.4	22.9	2,587	2,735	2,899	3,210	3,668	4,126
Incense	13.1	18.2	2,056	2,174	2,305	2,553	2,917	3,281
Northern white	11.1	15.1	1,697	1,797	1,908	2,115	2,417	2,719
Port-Orford	12.6	20.2	2,339	2,452	2,578	2,843	3,247	3,651
Western redcedar	12.2	16.1	1,807	1,917	2,039	2,261	2,583	2,905
Douglas-fir								
Coast type	12.3	23.4	2,753	2,864	2,987	3,283	3,751	4,219
Interior west	13.2	23.9	2,799	2,918	3,050	3,355	3,833	4,311
Interior north	14.0	23.4	2,712	2,838	2,978	3,282	3,750	4,218
Fir								
Balsam	9.9	17.2	1,998	2,087	2,186	2,408	2,752	3,096
California red	10.6	18.7	2,183	2,278	2,384	2,624	2,998	3,372
Grand	10.7	18.2	2,114	2,210	2,317	2,553	2,917	3,281
Noble	10.1	19.2	2,264	2,355	2,456	2,699	3,083	3,467
Pacific silver	10.4	20.8	2,461	2,555	2,659	2,919	3,335	3,751
Subalpine	10.5	16.1	1,848	1,943	2,048	2,262	2,584	2,906
White	12.2	19.2	2,213	2,323	2,445	2,698	3,082	3,466
Hemlock								
Eastern	12.6	19.8	2,271	2,384	2,510	2,771	3,167	3,563
Western	11.5	21.8	2,570	2,674	2,789	3,065	3,501	3,937
Larch, western	11.3	25.0	2,979	3,081	3,194	3,501	4,001	4,501
Pine								
Eastern white	12.3	17.7	2,007	2,118	2,241	2,480	2,834	3,188
Lodgepole	11.5	19.8	2,299	2,402	2,518	2,774	3,170	3,566
Ponderosa	12.6	19.8	2,271	2,384	2,510	2,771	3,167	3,563
Red	12.2	21.3	2,484	2,594	2,716	2,990	3,416	3,842
Southern pine								
Loblolly	12.9	24.4	2,873	2,989	3,118	3,427	3,915	4,403
Longleaf	15.0	28.1	3,298	3,433	3,583	3,939	4,501	5,063
Shortleaf	12.9	24.4	2,873	2,989	3,118	3,427	3,915	4,403
Sugar	12.6	17.7	2,000	2,113	2,239	2,479	2,833	3,187
Western white	10.0	18.2	2,130	2,220	2,320	2,552	2,916	3,280
Redwood								
Old-growth	14.9	19.8	2,215	2,349	2,498	2,771	3,167	3,563
Second-growth	13.2	17.7	1,985	2,104	2,236	2,479	2,833	3,187
Spruce								
Black	11.3	19.8	2,303	2,405	2,518	2,773	3,169	3,565
Engelmann	10.0	17.2	1,994	2,084	2,184	2,406	2,750	3,094
Red	10.6	19.2	2,252	2,347	2,453	2,698	3,082	3,466
Sitka	10.8	19.2	2,246	2,343	2,451	2,697	3,081	3,465
Tamarack	12.0	25.5	3,030	3,138	3,258	3,573	4,083	4,593
HARDWOODS								
Alder, red	9.9	19.2	2,268	2,357	2,456	2,698	3,082	3,466
Apple	10.9	31.7	3,870	3,968	4,077	4,449	5,083	5,717
Ash								
Black	9.3	23.4	2,824	2,908	3,001	3,282	3,750	4,218
Green	14.3	27.6	3,246	3,375	3,518	3,866	4,418	4,970
White	13.9	28.6	3,392	3,517	3,656	4,012	4,584	5,156

Table 1-9—Calculated weights of wood per thousand board feet actual measure-continued

Species	Approximate correction factor per 1,000 board feet for each 1 percent moisture content change: Below 30 percent moisture content	Above 30 percent moisture content.	Weight (lb) per 1,000 actual board feet of various moisture content levels: 8%	15%	25%	40%	60%	80%
			HARDWOODS—continued					
Aspen								
Bigtooth	10.3	18.7	2,191	2,284	2,387	2,626	3,000	3,374
Quaking	10.3	18.2	2,125	2,217	2,321	2,555	2,919	3,283
Basswood, American	6.2	16.6	2,019	2,081	2,143	2,340	2,672	3,004
Beech, American	8.9	29.1	3,579	3,659	3,748	4,084	4,666	5,248
Birch								
Paper	8.8	25.0	3,049	3,128	3,216	3,510	4,010	4,510
Sweet	11.9	31.2	3,779	3,886	4,005	4,377	5,001	5,625
Yellow	9.2	28.6	3,502	3,585	3,677	4,009	4,581	5,153
Buckeye, yellow	8.9	17.2	2,021	2,101	2,190	2,407	2,751	3,095
Butternut	11.3	18.7	2,168	2,270	2,383	2,627	3,001	3,375
Cherry, black	13.8	24.4	2,853	2,977	3,115	3,428	3,916	4,404
Chestnut, American	11.6	20.8	2,430	2,534	2,650	2,916	3,332	3,748
Cottonwood, black	8.5	16.1	1,897	1,974	2,059	2,263	2,585	2,907
Dogwood, flowering	6.8	33.3	4,168	4,229	4,297	4,664	5,330	5,996
Elm								
American	10.2	23.9	2,871	2,963	3,065	3,355	3,833	4,311
Rock	12.2	29.6	3,567	3,677	3,799	4,156	4,748	5,340
Slippery	11.5	25.0	2,974	3,078	3,193	3,501	4,001	4,501
Hackberry	11.8	25.5	3,036	3,142	3,260	3,574	4,084	4,594
Hickory, pecan								
Bitternut	14.7	31.2	3,711	3,843	3,990	4,376	5,000	5,624
Hickory, true								
Mockernut	9.1	33.3	4,113	4,195	4,286	4,665	5,331	5,997
Pignut	9.3	34.3	4,246	4,330	4,423	4,805	5,491	6,177
Shagbark	10.9	33.3	4,071	4,169	4,278	4,666	5,332	5,998
Shellbark	6.6	32.2	4,037	4,096	4,162	4,517	5,161	5,805
Holly, American	8.3	26.0	3,187	3,262	3,345	3,647	4,167	4,687
Hophornbeam, eastern	7.9	32.8	4,076	4,147	4,226	4,594	5,250	5,906
Laurel, California	15.1	26.5	3,093	3,229	3,380	3,721	4,251	4,781
Locust, black	21.2	34.3	3,961	4,152	4,364	4,813	5,499	6,185
Madrone, Pacific	7.8	30.2	3,738	3,808	3,886	4,227	4,831	5,435
Maple								
Soft								
Bigleaf	12.8	22.9	2,673	2,788	2,916	3,209	3,667	4,125
Red	13.1	25.5	3,004	3,122	3,253	3,573	4,083	4,593
Silver	12.4	22.9	2,683	2,795	2,919	3,210	3,668	4,126
Hard								
Black	12.3	27.0	3,228	3,338	3,462	3,793	4,333	4,873
Sugar	12.3	29.1	3,498	3,609	3,732	4,084	4,666	5,248
Oak, red								
Black	11.7	29.1	3,511	3,616	3,733	4,083	4,665	5,247
California black	16.4	26.5	3,061	3,209	3,373	3,720	4,250	4,780
Laurel	6.3	29.1	3,640	3,697	3,760	4,082	4,664	5,246
Northern red	13.6	29.1	3,467	3,589	3,725	4,084	4,666	5,248
Pin	13.0	30.2	3,616	3,733	3,863	4,230	4,834	5,438
Scarlet	13.2	31.2	3,748	3,867	3,999	4,377	5,001	5,625
Southern red	9.6	27.0	3,290	3,376	3,472	3,790	4,330	4,870
Water	10.4	29.1	3,543	3,637	3,741	4,084	4,666	5,248
Willow	6.4	29.1	3,636	3,694	3,758	4,081	4,663	5,245
Oak, white								
Bur	15.4	30.2	3,558	3,697	3,851	4,230	4,834	5,438
Chestnut	10.1	29.6	3,616	3,707	3,808	4,154	4,746	5,338
Live	17.5	41.6	4,997	5,155	5,330	5,833	6,665	7,497
Overcup	10.7	29.6	3,603	3,699	3,806	4,156	4,748	5,340
Post	11.0	31.2	3,799	3,898	4,008	4,375	4,999	5,623
Swamp chestnut	10.7	31.2	3,806	3,902	4,009	4,375	4,999	5,623
White	10.8	31.2	3,803	3,900	4,008	4,374	4,998	5,622

Table 1-9—Calculated weights of wood per thousand board feet actual measure—continued

Species	Approximate correction factor per 1,000 board feet for each 1 percent moisture content change		Weight (lb) per 1,000 actual board feet of various moisture content levels					
	Below 30 percent moisture content	Above 30 percent moisture content	6%	15%	25%	40%	60%	80%
			HARDWOODS—continued					
Persimmon, common	7.0	33.3	4,164	4,227	4,297	4,665	5,331	5,997
Sweetgum	8.9	23.9	2,902	2,982	3,071	3,354	3,833	4,311
Sycamore, American	10.7	23.9	2,858	2,954	3,061	3,354	3,832	4,310
Tanoak	9.0	30.2	3,710	3,791	3,881	4,228	4,832	5,436
Tupelo								
Black	10.4	23.9	2,866	2,960	3,064	3,355	3,833	4,311
Water	12.4	23.9	2,817	2,929	3,053	3,354	3,832	4,310
Walnut, black	13.4	26.5	3,132	3,253	3,387	3,719	4,249	4,779
Willow, black	8.6	18.7	2,232	2,309	2,395	2,625	2,999	3,373
Yellow-poplar	10.6	20.8	2,454	2,549	2,655	2,916	3,332	3,748
			IMPORTED					
Afrormosia	18.9	31.7	3,677	3,847	4,036	4,448	5,082	5,716
Albarco	16.7	25.0	2,851	3,001	3,168	3,501	4,002	4,502
Andiroba	17.1	28.1	3,246	3,400	3,571	3,937	4,499	5,061
Angelique	14.2	31.2	3,724	3,852	3,994	4,377	5,001	5,625
Apitong	12.8	35.9	4,365	4,480	4,608	5,031	5,749	6,467
Avodire	13.5	25.0	2,927	3,049	3,184	3,501	4,001	4,501
Balata	14.1	44.2	5,417	5,544	5,685	6,197	7,081	7,965
Balsa	4.9	8.3	965	1,009	1,058	1,166	1,332	1,498
Banak	10.2	21.8	2,600	2,692	2,794	3,063	3,499	3,935
Benge	15.6	33.8	4,027	4,167	4,323	4,739	5,415	6,091
Bubinga	16.4	36.9	4,415	4,563	4,727	5,178	5,917	6,654
Caribbean pine	17.8	35.4	4,179	4,339	4,517	4,960	5,668	6,376
Cativo	14.0	20.8	2,374	2,500	2,640	2,918	3,334	3,750
Ceiba	7.9	13.0	1,503	1,574	1,653	1,823	2,083	2,343
Cocobolo	34.6	46.3	5,196	5,507	5,853	6,489	7,415	8,341
Courbaril	18.9	36.9	4,356	4,526	4,715	5,179	5,917	6,655
Cuangare	8.7	16.1	1,890	1,968	2,055	2,260	2,582	2,904
Degame	17.0	34.8	4,129	4,282	4,452	4,885	5,581	6,277
Determa	16.5	27.0	3,126	3,275	3,440	3,792	4,332	4,872
Ebony, East Indian	16.2	36.4	4,352	4,498	4,660	5,105	5,833	6,561
Ebony, African	7.0	42.6	5,381	5,444	5,514	5,975	6,827	7,679
Gmelina	14.4	21.3	2,431	2,561	2,705	2,990	3,416	3,842
Goncalo alves	27.4	43.7	5,032	5,279	5,553	6,127	7,001	7,875
Greenheart	12.8	41.6	5,108	5,223	5,351	5,831	6,663	7,495
Hura	14.5	19.8	2,224	2,355	2,500	2,770	3,166	3,562
Ilomba	10.5	20.8	2,456	2,551	2,656	2,916	3,332	3,748
Imbuya	18.4	27.6	3,148	3,314	3,498	3,866	4,418	4,970
Ipe	23.4	47.8	5,670	5,881	6,115	6,710	7,666	8,622
Iroko	19.0	28.1	3,202	3,373	3,563	3,939	4,501	5,063
Jarrah	8.0	34.8	4,343	4,415	4,495	4,883	5,579	6,275
Jelutong	13.4	18.7	2,116	2,237	2,371	2,625	2,999	3,373
Kapur	13.9	33.3	4,001	4,126	4,265	4,668	5,334	6,000
Karri	6.6	42.6	5,391	5,450	5,516	5,975	6,827	7,679
Kempas	15.9	36.9	4,427	4,570	4,729	5,178	5,916	6,659
Keruing	12.8	35.9	4,365	4,480	4,608	5,031	5,749	6,467
Lauan, red and white	10.0-16.1	17.7-28.6	2,064-3,339	2,154-3,484	2,254-3,645	2,481-4,011	2,835-4,583	3,189-5,155
Limba	11.7	19.8	2,293	2,398	2,515	2,772	3,167	3,564
Mahogany, African	14.8	21.8	2,490	2,623	2,771	3,063	3,499	3,935
Mahogany, true	16.7	23.4	2,645	2,795	2,962	3,280	3,748	4,216
Manni	11.5	30.2	3,653	3,757	3,872	4,231	4,835	5,439

Table 1-9—Calculated weights of wood per thousand board feet actual measure—concluded

Species	Approximate correction factor per 1,000 board feet for each 1 percent moisture content change: Below 30 percent moisture content	Above 30 percent moisture content	Weight (lb) per 1,000 actual board feet of various moisture content levels: 6%	15%	25%	40%	60%	80%
			IMPORTED—continued					
Merbau	23.8	33.3	3,762	3,976	4,214	4,666	5,332	5,998
Mersawa	11.5	27.0	3,245	3,349	3,464	3,791	4,331	4,871
Mora	9.1	40.6	5,060	5,142	5,233	5,684	6,496	7,308
Obeche	10.3	15.6	1,785	1,878	1,981	2,188	2,500	2,812
Ocote pine	15.1	28.6	3,362	3,498	3,649	4,010	4,582	5,154
Okoume	9.8	17.2	2,000	2,088	2,186	2,407	2,751	3,095
Opepe	16.9	32.8	3,862	4,014	4,183	4,596	5,251	5,908
Parana pine	13.4	23.9	2,795	2,916	3,050	3,356	3,834	4,312
Pau Marfim	18.2	38.0	4,507	4,671	4,853	5,324	6,084	6,844
Peroba de campos	19.8	32.8	3,791	3,969	4,167	4,594	5,250	5,906
Peroba rosa	19.2	34.3	4,010	4,183	4,375	4,814	5,500	6,186
Primavera	13.8	20.8	2,378	2,502	2,640	2,917	3,333	3,749
Purpleheart	22.0	34.8	4,011	4,209	4,429	4,887	5,583	6,279
Ramin	13.0	27.0	3,210	3,327	3,457	3,792	4,332	4,872
Roble (Quercus)	8.7	36.4	4,528	4,606	4,693	5,102	5,829	6,557
Roble (Tabebuia)	17.5	27.0	3,102	3,260	3,435	3,792	4,332	4,872
Rosewood, Indian	26.8	39.0	4,435	4,676	4,944	5,468	6,248	7,028
Rosewood, Brazilian	28.6	41.6	4,731	4,988	5,274	5,833	6,665	7,497
Rubberwood	18.6	25.5	2,871	3,038	3,224	3,572	4,082	4,592
Sande	14.1	25.5	2,980	3,107	3,248	3,573	4,083	4,593
Santa Maria	12.7	27.0	3,216	3,330	3,457	3,791	4,331	4,871
Sapele	13.0	28.6	3,414	3,531	3,661	4,012	4,584	5,156
Sepetir	17.6	29.1	3,370	3,528	3,704	4,083	4,665	5,247
Spanish cedar	13.1	21.3	2,463	2,581	2,712	2,990	3,416	3,842
Sucupira (Bowdichia)	18.5	38.5	4,568	4,735	4,920	5,397	6,167	6,937
Sucupira (Diplotropis)	22.3	40.6	4,747	4,948	5,171	5,689	6,501	7,314
Teak	21.4	28.6	3,211	3,404	3,618	4,011	4,583	5,155
Wallaba	25.4	40.6	4,673	4,902	5,156	5,689	6,501	7,313

Table 1-10—Shrinkage values of wood, based on its dimensions when green

Species	Shrinkage (percent)						
	Dried to 20-percent moisture content[1]		Dried to 6-percent moisture content[2]		Dried to 0-percent moisture content		
	Radial	Tangential	Radial	Tangential	Radial	Tangential	Volumetric
			SOFTWOODS				
Baldcypress	1.3	2.1	3.0	5.0	3.8	6.2	10.5
Cedar							
Alaska	0.9	2.0	2.2	4.8	2.8	6.0	9.2
Atlantic white-	1.0	1.8	2.3	4.3	2.9	5.4	8.8
Eastern redcedar	1.0	1.6	2.5	3.8	3.1	4.7	7.8
Incense	1.1	1.7	2.6	4.2	3.3	5.2	7.7
Northern white	0.7	1.6	1.8	3.9	2.2	4.9	7.2
Port-Orford	1.5	2.3	3.7	5.5	4.6	6.9	10.1
Western redcedar	0.8	1.7	1.9	4.0	2.4	5.0	6.8
Douglas-fir							
Coast type	1.6	2.5	3.8	6.1	4.8	7.6	12.4
Interior west	1.6	2.5	3.8	6.0	4.8	7.5	11.8
Interior north	1.3	2.3	3.0	5.5	3.8	6.9	10.7
Fir							
Balsam	1.0	2.3	2.3	5.5	2.9	6.9	11.2
California red	1.5	2.6	3.6	6.3	4.5	7.9	11.4
Grand	1.1	2.5	2.7	6.0	3.4	7.5	11.0
Noble	1.4	2.8	3.4	6.6	4.3	8.3	12.4
Pacific silver	1.5	3.1	3.5	7.4	4.4	9.2	13.0
Subalpine	0.9	2.5	2.1	5.9	2.6	7.4	9.4
White	1.1	2.3	2.6	5.6	3.3	7.0	9.8
Hemlock							
Eastern	1.0	2.3	2.4	5.4	3.0	6.8	9.7
Western	1.4	2.6	3.4	6.2	4.2	7.8	12.4
Larch, western	1.5	3.0	3.6	7.3	4.5	9.1	14.0
Pine							
Eastern white	0.7	2.0	1.7	4.9	2.1	6.1	8.2
Lodgepole	1.4	2.2	3.4	5.4	4.3	6.7	11.1
Ponderosa	1.3	2.1	3.1	5.0	3.9	6.2	9.7
Red	1.3	2.4	3.0	5.8	3.8	7.2	11.3
Southern pine							
Loblolly	1.6	2.5	3.8	5.9	4.8	7.4	12.3
Longleaf	1.7	2.5	4.1	6.0	5.1	7.5	12.2
Shortleaf	1.5	2.6	3.7	6.2	4.6	7.7	12.3
Sugar	1.0	1.9	2.3	4.5	2.9	5.6	7.9
Western white	1.4	2.5	3.3	5.9	4.1	7.4	11.8
Redwood							
Old-growth	0.9	1.5	2.1	3.5	2.6	4.4	6.8
Second-growth	0.7	1.6	1.8	3.9	2.2	4.9	7.0
Spruce							
Black	1.4	2.3	3.3	5.4	4.1	6.8	11.3
Engelmann	1.3	2.4	3.0	5.7	3.8	7.1	11.0
Red	1.3	2.6	3.0	6.2	3.8	7.8	11.8
Sitka	1.4	2.5	3.4	6.0	4.3	7.5	11.5
Tamarack	1.2	2.5	3.0	5.9	3.7	7.4	13.6
			HARDWOODS				
Alder, red	1.5	2.4	3.5	5.8	4.4	7.3	12.6
Apple	2.0	3.5	4.7	8.4	5.9	10.5	16.4
Ash							
Black	1.7	2.6	4.0	6.2	5.0	7.8	15.2
Green	1.5	2.4	3.7	5.7	4.6	7.1	12.5
White	1.6	2.6	3.9	6.2	4.9	7.8	13.3
Aspen							
Bigtooth	1.1	2.6	2.6	6.3	3.3	7.9	11.8
Quaking	1.2	2.2	2.8	5.4	3.5	6.7	11.5
Basswood, American	2.2	3.1	5.3	7.4	6.6	9.3	15.8
Beech, American	1.8	4.0	4.4	9.5	5.5	11.9	17.2
Birch							
Paper	2.1	2.9	5.0	6.9	6.3	8.6	16.2
Sweet	2.2	3.0	5.2	7.2	6.5	9.0	15.6
Yellow	2.4	3.2	5.8	7.6	7.3	9.5	16.8

Table 1-10—Shrinkage values of wood, based on its dimensions when green—continued

Species	Shrinkage (percent)						
	Dried to 20-percent moisture content[1]		Dried to 6-percent moisture content[2]		Dried to 0-percent moisture content		
	Radial	Tangential	Radial	Tangential	Radial	Tangential	Volumetric
HARDWOODS—continued							
Buckeye, yellow	1.2	2.7	2.9	6.5	3.6	8.1	12.5
Butternut	1.1	2.1	2.7	5.1	3.4	6.4	10.6
Cherry, black	1.2	2.4	3.0	5.7	3.7	7.1	11.5
Chestnut, American	1.1	2.2	2.7	5.4	3.4	6.7	11.6
Cottonwood, black	1.2	2.9	2.9	6.9	3.6	8.6	12.4
Dogwood, flowering	2.5	3.9	5.9	9.4	7.4	11.8	19.2
Elm							
American	1.4	3.2	3.4	7.6	4.2	9.5	14.6
Rock	1.6	2.7	3.8	6.5	4.8	8.1	14.9
Slippery	1.6	3.0	3.9	7.1	4.9	8.9	13.8
Hackberry	1.6	3.0	3.8	7.1	4.8	8.9	13.8
Hickory, pecan							
Bitternut	1.6	3.0	3.9	7.1	4.9	8.9	13.6
Hickory, true							
Mockernut	2.6	3.7	6.2	8.8	7.7	11.0	17.8
Pignut	2.4	3.8	5.8	9.2	7.2	11.5	17.9
Shagbark	2.3	3.5	5.6	8.4	7.0	10.5	16.7
Shellbark	2.5	4.2	6.1	10.1	7.6	12.6	19.2
Holly, American	1.6	3.3	3.8	7.9	4.8	9.9	16.9
Hophornbeam, eastern	2.8	3.3	6.8	8.0	8.5	10.0	18.5
Laurel, California	1.0	2.8	2.3	6.8	2.9	8.5	11.4
Locust, black	1.5	2.4	3.7	5.8	4.6	7.2	10.2
Madrone, Pacific	1.9	4.1	4.5	9.9	5.6	12.4	18.1
Maple							
Soft							
Bigleaf	1.2	2.4	3.0	5.7	3.7	7.1	11.6
Red	1.3	2.7	3.2	6.6	4.0	8.2	12.6
Silver	1.0	2.4	2.4	5.8	3.0	7.2	12.0
Hard							
Black	1.6	3.1	3.8	7.4	4.8	9.3	14.0
Sugar	1.6	3.3	3.8	7.9	4.8	9.9	14.7
Oak, red							
Black	1.5	3.7	3.5	8.9	4.4	11.1	15.1
California black	1.2	2.2	2.9	5.3	3.6	6.6	10.2
Laurel	1.3	3.3	3.2	7.9	4.0	9.9	19.0
Northern red	1.3	2.9	3.2	6.9	4.0	8.6	13.7
Pin	1.4	3.2	3.4	7.6	4.3	9.5	14.5
Scarlet	1.5	3.6	3.5	8.6	4.4	10.8	14.7
Southern red	1.6	3.8	3.8	9.0	4.7	11.3	16.1
Water	1.5	3.3	3.5	7.8	4.4	9.8	16.1
Willow	1.7	3.2	4.0	7.7	5.0	9.6	18.9
Oak, white							
Bur	1.5	2.9	3.5	7.0	4.4	8.8	12.7
Chestnut	1.8	3.6	4.2	8.6	5.3	10.8	16.4
Live	2.2	3.2	5.3	7.6	6.6	9.5	14.7
Overcup	1.8	4.2	4.2	10.2	5.3	12.7	16.0
Post	1.8	3.3	4.3	7.8	5.4	9.8	16.2
Swamp chestnut	1.7	3.6	4.2	8.6	5.2	10.8	16.4
White	1.9	3.5	4.5	8.4	5.6	10.5	16.3
Persimmon, common	2.6	3.7	6.3	9.0	7.9	11.2	19.1
Sweetgum	1.8	3.4	4.2	8.2	5.3	10.2	15.8
Sycamore, American	1.7	2.8	4.0	6.7	5.0	8.4	14.1
Tanoak	1.6	3.9	3.9	9.4	4.9	11.7	17.3
Tupelo							
Black	1.7	2.9	4.1	7.0	5.1	8.7	14.4
Water	1.4	2.5	3.4	6.1	4.2	7.6	12.5
Walnut, black	1.8	2.6	4.4	6.2	5.5	7.8	12.8
Willow, black	1.1	2.9	2.6	7.0	3.3	8.7	13.9
Yellow-poplar	1.5	2.7	3.7	6.6	4.6	8.2	12.7

Table 1-10—Shrinkage values of wood, based on its dimensions when green—continued

Species	Shrinkage (percent) Dried to 20-percent moisture content[1] Radial	Dried to 20-percent moisture content[1] Tangential	Dried to 6-percent moisture content[2] Radial	Dried to 6-percent moisture content[2] Tangential	Dried to 0-percent moisture content Radial	Dried to 0-percent moisture content Tangential	Dried to 0-percent moisture content Volumetric
			IMPORTED[3]				
Afrormosia	1.0	2.1	2.4	5.1	3.0	6.4	10.7
Albarco	0.9	1.8	2.2	4.3	2.8	5.4	9.0
Andiroba	1.0	2.5	2.5	6.1	3.1	7.6	10.4
Angelique	1.7	2.9	4.2	7.0	5.2	8.8	14.0
Apitong	1.7	3.6	4.2	8.7	5.2	10.9	16.1
Avodire	1.5	2.2	3.7	5.4	4.6	6.7	12.0
Balata (Bulletwood)	2.1	3.1	5.0	7.5	6.3	9.4	16.9
Balsa	1.0	2.5	2.4	6.1	3.0	7.6	10.8
Banak	1.5	2.9	3.7	7.0	4.6	8.8	13.7
Benge	1.7	2.9	4.2	6.9	5.2	8.6	13.8
Bubinga	1.9	2.8	4.6	6.7	5.8	8.4	14.2
Caribbean pine	2.1	2.6	5.0	6.2	6.3	7.8	12.9
Cativo	0.8	1.8	1.9	4.2	2.4	5.3	8.9
Ceiba	0.7	1.4	1.7	3.3	2.1	4.1	10.4
Cocobolo	0.9	1.4	2.2	3.4	2.7	4.3	7.0
Courbaril	1.5	2.8	3.6	6.8	4.5	8.5	12.7
Cuangare	1.4	3.1	3.4	7.5	4.2	9.4	12.0
Degame	1.6	2.9	3.8	6.9	4.8	8.6	13.2
Determa	1.2	2.5	3.0	6.1	3.7	7.6	10.4
Ebony, East Indian	1.8	2.9	4.3	7.0	5.4	8.8	14.2
Ebony, African	3.1	3.6	7.4	8.6	9.2	10.8	20.0
Gmelina	0.8	1.6	1.9	3.9	2.4	4.9	8.8
Goncalo alves	1.3	2.5	3.2	6.1	4.0	7.6	10.0
Greenheart	2.9	3.2	7.0	7.7	8.8	9.6	17.1
Hura	0.9	1.5	2.2	3.6	2.7	4.5	7.3
Ilomba	1.5	2.8	3.7	6.7	4.6	8.4	12.8
Imbuya	0.9	2.0	2.2	4.8	2.7	6.0	9.0
Ipe	2.2	2.7	5.3	6.4	6.6	8.0	13.2
Iroko	0.9	1.3	2.2	3.0	2.8	3.8	8.8
Jarrah	2.6	3.7	6.2	8.8	7.7	11.0	18.7
Jelutong	0.8	1.8	1.8	4.4	2.3	5.5	7.8
Kapur	1.5	3.4	3.7	8.2	4.6	10.2	14.8
Karri	2.6	4.1	6.2	9.9	7.8	12.4	20.2
Kempas	2.0	2.5	4.8	5.9	6.0	7.4	14.5
Keruing	1.7	3.6	4.2	8.7	5.2	10.9	16.1
Lauan, red and white	1.3	2.6	3.0	6.2	3.8	7.7	11.5
Limba	1.5	2.1	3.6	5.0	4.5	6.2	10.8
Mahogany, African	0.8	1.5	2.0	3.6	2.5	4.5	8.8
Mahogany, true	1.0	1.4	2.4	3.3	3.0	4.1	7.8
Manni	1.9	3.2	4.6	7.8	5.7	9.7	15.6
Merbau	0.9	1.5	2.2	3.7	2.7	4.6	7.8
Mersawa	1.3	3.0	3.2	7.2	4.0	9.0	14.6
Mora -	2.3	3.3	5.5	7.8	6.9	9.8	18.8
Obeche	1.0	1.8	2.4	4.3	3.0	5.4	9.2
Ocote pine	1.5	2.5	3.7	6.0	4.6	7.5	12.3
Okoume	1.4	2.0	3.3	4.9	4.1	6.1	11.3
Opepe	1.5	2.8	3.6	6.7	4.5	8.4	12.6
Parana pine	1.3	2.6	3.2	6.3	4.0	7.9	11.6
Pau Marfim	1.5	2.9	3.7	7.0	4.6	8.8	13.4
Peroba de campos	1.3	2.2	3.0	5.3	3.8	6.6	10.5
Peroba rosa	1.3	2.1	3.0	5.1	3.8	6.4	11.6
Primavera	1.0	1.7	2.5	4.1	3.1	5.1	9.1
Purpleheart	1.1	2.0	2.6	4.9	3.2	6.1	9.9
Ramin	1.4	2.9	3.4	7.0	4.3	8.7	13.4
Roble (Quercus)	2.1	3.9	5.1	9.4	6.4	11.7	18.5
Roble (Tabebuia)	1.2	2.0	2.9	4.9	3.6	6.1	9.5
Rosewood, Indian	0.9	1.9	2.2	4.6	2.7	5.8	8.5
Rosewood, Brazilian	1.0	1.5	2.3	3.7	2.9	4.6	8.5
Rubberwood	0.8	1.7	1.8	4.1	2.3	5.1	7.4
Sande	1.3	2.6	3.1	6.2	3.9	7.8	11.7

Table 1-10—Shrinkage values of wood, based on its dimensions when green-concluded

	Shrinkage (percent)						
	Dried to 20-percent moisture content[1]		Dried to 6-percent moisture content[2]		Dried to O-percent moisture content		
Species	Radial	Tangential	Radial	Tangential	Radial	Tangential	Volumetric
			IMPORTED—continued				
Santa Maria	1.5	2.7	3.7	6.4	4.6	8.0	13.6
Sapele	1.5	2.5	3.7	5.9	4.6	7.4	14.0
Sepetir	1.2	2.3	3.0	5.6	3.7	7.0	10.5
Spanish cedar	1.4	2.1	3.4	5.0	4.2	6.3	10.3
Sucupira (Bowdichia)	1.7	2.6	4.0	6.2	5.0	7.8	13.4
Sucupira (Diplotropis)	1.5	2.3	3.7	5.6	4.6	7.0	11.8
Teak	0.8	1.9	2.0	4.6	2.5	5.8	7.0
Wallaba	1.2	2.3	2.9	5.5	3.6	6.9	10.0

[1]These shrinkage values have been taken as 1/3 of the shrinkage to the ovendry condition as given in columns 5 and 6 of this table.
[2]These shrinkage values have been taken as 4/5 of the shrinkage to the ovendry condition as given in columns 5 and 6 of this table.
[3]Refer to table 1-1 for botanical name.

Table 1-11—Average electrical resistance along the grain, for selected species, as measured at 80°F between two pairs of needle electrodes 1-1/4 inches apart and driven to a depth of 5/16 inch

	Electrical resistance (megohms) at different levels of moisture content (percent)																		
Species	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Softwoods																			
Cypress, southern	12,600	3,980	1,410	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	1.78	1.26	0.91	0.66	0.51	0.42
Douglas-fir (coast type)	22,400	4,780	1,660	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	2.14	1.51	1.10	0.79	0.60	0.46
Fir, California red	31,600	6,760	2,000	725	315	150	83	48	28.8	18.2	11.8	7.6	5.01	3.31	2.29	1.58	1.15	0.83	0.63
Fir, white	57,600	15,850	3,980	1,120	415	180	83	46	26.9	16.6	11.0	6.6	4.47	3.02	2.14	1.55	1.12	0.86	0.62
Hemlock, western	*22,900*	*5,620*	*2,040*	*850*	*400*	*185*	*98*	*51*	*28.2*	*16.2*	*10.0*	*6.0*	*3.89*	*2.52*	*1.58*	*1.05*	*0.72*	*0.51*	*0.37*
Larch, western	39,800	11,200	3,980	1,445	560	250	120	63	33.9	19.9	12.3	7.6	5.02	3.39	2.29	1.62	1.20	0.87	0.66
Pine, eastern white	20,900	5,620	2,090	850	405	200	102	58	33.1	19.9	12.3	7.9	5.01	3.31	2.19	1.51	1.05	0.74	0.52
Pine, longleaf	25,000	8,700	3,160	1,320	575	270	135	74	41.7	24.0	14.4	8.9	5.76	3.72	2.46	1.66	1.15	0.79	0.60
Pine, ponderosa	39,800	8,910	3,310	1,410	645	300	150	81	44.7	25.1	14.8	9.1	5.62	3.55	2.34	1.62	1.15	0.87	0.69
Pine, shortleaf	43,600	11,750	3,720	1,350	560	255	130	69	38.9	22.4	13.8	8.7	5.76	3.80	2.63	1.82	1.29	0.93	0.66
Pine, sugar	22,900	5,250	1,660	645	280	140	76	44	25.7	15.9	10.0	6.6	4.36	3.02	2.09	1.48	1.05	0.75	0.56
Redwood	22,400	4,680	1,550	615	250	100	45	22	12.6	7.2	4.7	3.2	2.29	1.74	1.32	1.05	0.85	0.71	0.60
Spruce, Sitka	22,400	5,890	2,140	830	365	165	83	44	25.1	15.5	9.8	6.3	4.27	3.02	2.14	1.58	1.17	0.91	0.71
Hardwoods																			
Ash, commercial white	12,000	2,190	690	250	105	55	28	14	8.3	5.0	3.2	2.0	1.32	0.89	0.63	0.50	0.44	0.40	0.40
Basswood	36,300	1,740	470	180	85	45	27	16	9.6	6.2	4.1	2.8	1.86	1.32	0.93	0.69	0.51	0.39	0.31
Birch	87,000	19,950	4,470	1,290	470	200	96	53	30.2	18.2	11.5	7.6	5.13	3.55	2.51	1.78	1.32	0.95	0.70
Elm, American	18,200	2,000	350	110	45	20	12	7	3.9	2.3	1.5	1.0	0.66	0.48	0.42	0.40	0.40	0.40	0.40
Hickory, true	—	31,600	2,190	340	115	50	21	11	6.3	3.7	2.3	1.5	1.00	0.71	0.52	0.44	0.40	0.40	0.40
Kahya[1]	44,600	16,200	6,310	2,750	1,260	630	340	180	105.0	60.2	35.5	21.9	14.10	9.33	6.16	4.17	2.82	1.99	1.44
Magnolia	43,700	12,600	5,010	2,040	910	435	205	105	56.2	29.5	16.2	9.1	5.25	3.09	1.86	1.17	0.74	0.50	0.32
Mahogany, American	20,900	6,760	2,290	870	380	180	85	43	22.4	12.3	7.2	4.4	2.69	1.66	1.07	0.72	0.49	0.35	0.26
Maple, sugar	72,400	13,800	3,160	690	250	105	53	29	16.6	10.2	6.8	4.5	3.16	2.24	1.62	1.23	0.98	0.75	0.60
Oak, commercial red[2]	14,400	4,790	1,590	630	265	125	63	32	18.2	11.3	7.3	4.6	3.02	2.09	1.45	0.95	0.80	0.63	0.50
Oak, commercial white	17,400	3,550	1,100	415	170	80	42	22	12.6	7.2	4.3	2.7	1.70	1.15	0.79	0.60	0.49	0.44	0.41
Shorea[3]	*2,890*	*690*	*220*	*80*	*35*	*15*	*9*	*5*	*2.8*	*1.7*	*1.1*	*0.7*	*0.45*	*0.30*	*0.21*	*0.16*	*0.12*	*0.09*	*0.07*
Sweetgum	38,000	6,460	2,090	815	345	160	81	45	25.7	15.1	9.3	6.0	3.98	2.63	1.78	1.26	0.87	0.63	0.46
Tupelo, black[2]	31,700	12,600	5,020	1,820	725	275	120	58	27.6	13.0	6.9	3.7	2.19	1.38	0.95	0.63	0.46	0.33	0.25
Walnut, black	51,300	9,770	2,630	890	355	155	78	41	22.4	12.9	7.8	4.9	3.16	2.14	1.48	1.02	0.72	0.51	0.38
Yellow-poplar[2]	24,000	8,320	3,170	1,260	525	250	140	76	43.7	25.2	14.5	8.7	5.76	3.81	2.64	1.91	1.39	1.10	0.85

[1]Known in the trade as "African mahogany."
[2]The values for this species were calculated from measurements on veneer.
[3]A Philippine hardwood, identified as tanguile or some similar species.

Appendix— Equations for Relating Temperature, Humidity, and Moisture Content

In this appendix, we present a series of equations that relate wet- and dry-bulb temperatures to specific and relative humidities, and equations that relate EMC to relative humidity (RH) and temperature. A psychrometric chart and an example of how to calculate specific and relative humidities are included.

Wet-bulb Temperature and Relative Humidity

When unsaturated air is brought in contact with water, the air is humidified and cooled. If the system is operated so that no heat is gained or lost to the surroundings, the process is adiabatic. Thus, if the water remains at constant temperature, the latent heat of evaporation must equal the sensible heat released by the air in cooling. If the temperature reached by the air when it becomes saturated is the same as the water temperature, this temperature is called adiabatic saturation temperature or the thermodynamic wet-bulb temperature.

When unsaturated air is passed over a wetted thermometer bulb, so that water evaporates from the wetted surface and causes the thermometer bulb to cool, an equilibrium temperature (called the true wet-bulb temperature) is reached. At this point, the rate of heat transfer from the wetted surface is equal to the rate at which the wetted surface loses heat in the form of latent heat of evaporation. The thermodynamic wet-bulb and true wet-bulb temperatures are not necessarily equal, but in the range of 215°F to 300°F the difference between these temperatures is negligible. Thus, the RH values based on the difference between the dry-bulb temperature and the thermodynamic wet-bulb temperature do not differ significantly from RH values based on the difference between the dry-bulb temperature and the true wet-bulb temperature. The maximum difference is 0.54 percent RH; on the average, the difference is +0.25 percent RH.

Relative humidity can be calculated from the adiabatic saturation temperature by the following procedure (Hawkins 1978). By writing energy and mass balances for the process of adiabatic saturation

$$Y = Y_s - \frac{(0.24 + 0.44Y_s)(T_{db} - T_s)}{1094 + 0.44T_{db} - T_s} \qquad (1)$$

where

Y is specific humidity (lb water/lb dry air),

Y_s specific humidity for saturation at T_s (lb water/lb dry air),

T_{db} dry-bulb temperature (°F),

T_s adiabatic saturation temperature (°F),

and

$$Y_s = \frac{\rho_s}{1.61(\rho_t - \rho_s)} \qquad (2)$$

where

ρ_s is vapor pressure at T_s (inHg) and

ρ_t total pressure (inHg).

To calculate relative vapor pressure at T_{db}, it is necessary to calculate partial pressure ρ at T_{db} as follows:

$$\rho = \frac{1.61Y\rho_t}{1 + 1.61Y} \qquad (3)$$

and relative vapor pressure h is

$$h = \frac{\rho}{\rho^*} \qquad (4)$$

where ρ^* is saturated vapor pressure at T_{db} (inHg).

The RH is then defined as

$$\mathrm{RH} = h \times 100 \qquad (5)$$

Example: Given T_{db} = 140°F, T_s = 120°F, and ρ_t = 29.92 inHg, calculate the specific and relative humidities.

Step 1: Find the specific humidity at Y_s from equation (2). To do this we need to know the ρ_s of water at T_s. From table 1-A-1, ρ_s at 120°F is 3.446 inHg.

Thus, from equation (2)

$$Y_s = \frac{3.446}{1.61(29.92 - 3.446)} = 0.0808 \text{ lb/lb}$$

Step 2: Calculate Y at T_{db} = 140°F. From equation (1)

$$Y = 0.0808 - \frac{(0.24 + 0.44(0.0808))(140^\circ - 120^\circ}{1,094 + 0.44(140^\circ - 120^\circ)}$$
$$= 0.0755 \text{ lb/lb}$$

Step 3: Calculate ρ at the dry-bulb temperature from equation (3).

$$\rho = \frac{(1.61)(0.0755)(29.92)}{1 + 1.61(0.0755)} = 3.242 \text{ inHg}$$

Step 4: To calculate relative vapor pressure h at the dry-bulb temperature, we need to know the saturated vapor pressure ρ^* at T_{db}. From table 1-A-1, ρ^* at T_{db} = 140°F is 5.881 inHg. From equation (4)

$$h = \frac{3.242}{5.881} = 0.551$$

or

$$\text{RH} = h \times 100 = 55.1 \text{ percent}$$

Relative Humidity and Equilibrium Moisture Content

The EMC and RH temperature relationships of tables 1-6 and 1-7 can be expressed in equation form, which is sometimes more convenient than table form. Useful equations can be derived from theories for the adsorption of water on hygroscopic materials. One such equation that works particularly well is

$$M = \frac{1800}{W}\left[\frac{kh}{1 - kh} + \frac{k_1kh + 2k_1k_2k^2h^2}{1 + k_1kh + k_1k_2k^2h^2}\right] \quad (6)$$

where

M is moisture content (percent),

h relative vapor pressure, and

$$W = 330 + 0.452T_{db} + 0.00415T^2_{db} \quad (7)$$
$$k = 0.791 + 0.000463T_{db} - 0.000000844T^2_{db} \quad (8)$$
$$k_1 = 6.34 + 0.000775T_{db} - 0.0000935T^2_{db} \quad (9)$$
$$k_2 = 1.09 + 0.0284T_{db} - 0.0000904T^2_{db} \quad (10)$$

Equations (6) to (10) represent least squares regression fits of the data in tables 1-6 and 1-7. As such, they give estimates close to but not exactly the same as those in the tables. For example, the EMC at T_{db} = 140°F and T_s = 120°F from table 1-6 is 8.0 percent. From equations (6) to (10), the EMC is 8.4 percent at 55.1 percent RH.

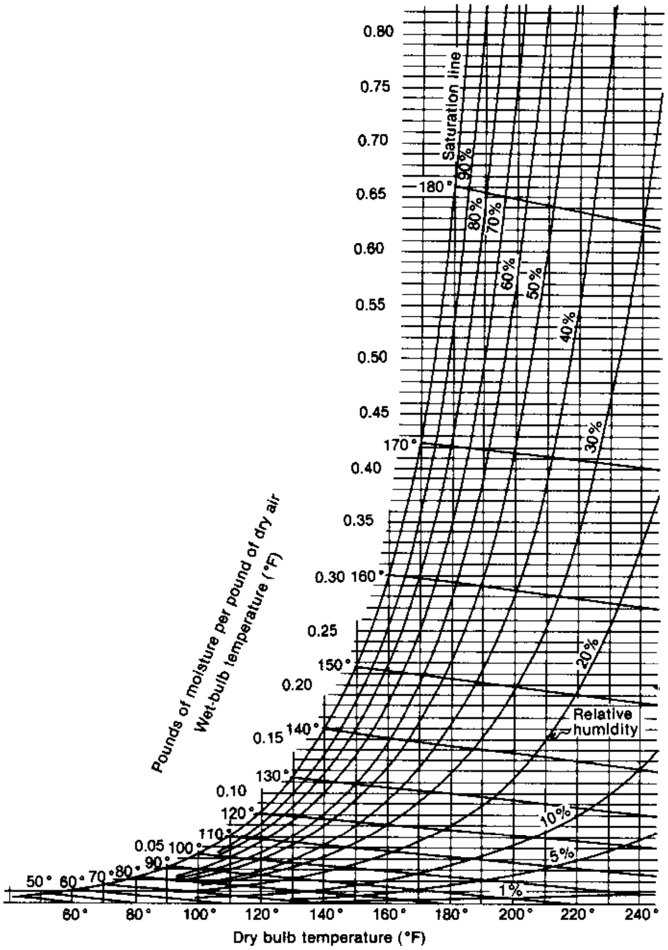

Figure 1-A-1—Psychrometric chart. (ML88 5580)

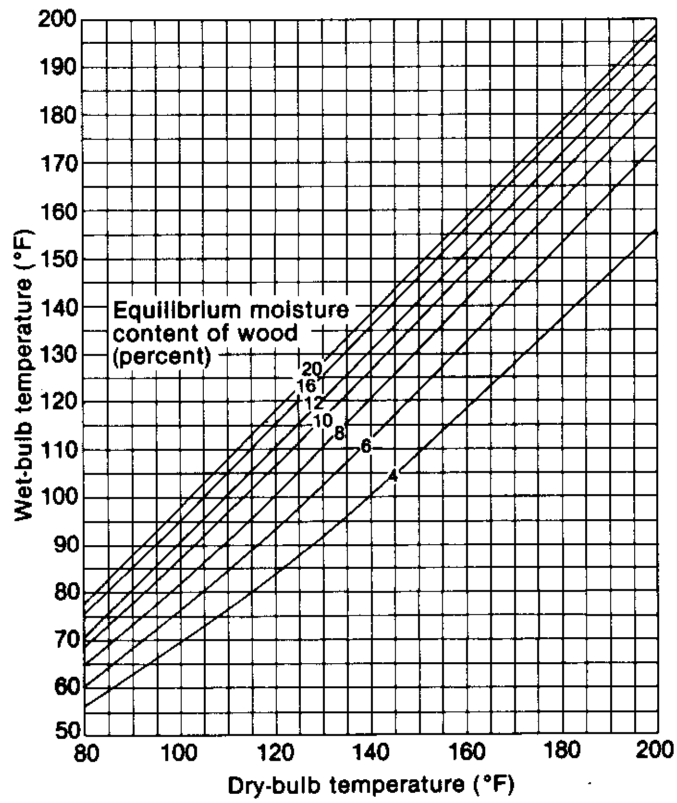

Figure 1-A-2—Lines of constant equilibrium moisture *content. (ML88 5577)*

Psychrometric Charts

Psychrometric charts are another useful way to represent wet- and dry-bulb temperatures and absolute and relative humidities. Figure 1-A-1 is a typical psychrometric chart showing the relationship between these four variables. Using the example T_{db} = 140°F and T_s = 120°F, the specific humidity at the intersection of these two temperature lines is approximately 0.075 lb/lb and the RH, 55 percent. Figure 1-A-2 shows the relationship between wet- and dry-bulb temperatures and EMC. At the intersection of 140°F dry-bulb temperature and 120°F wet-bulb temperature, the EMC is 8 percent.