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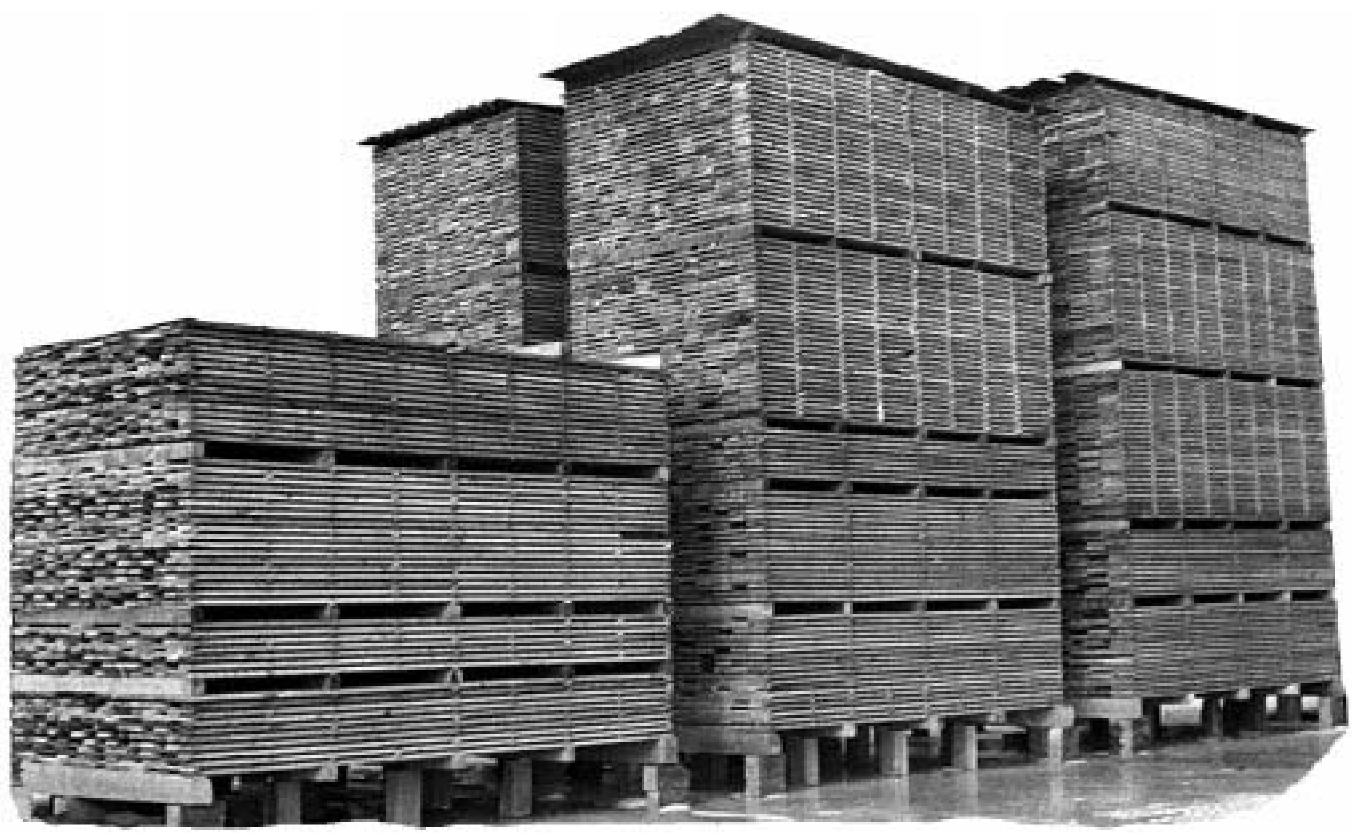
Air Drying of Lumber



Abstract

This report describes how lumber can be air-dried most effectively under outdoor conditions and illustrates the principles and procedures of air-drying lumber that were developed through field investigations and observations of industrial practices. Particular emphasis is placed on the yarding of lumber in unit packages. Included are topics such as why lumber is dried, advantages and limitations of the drying process, properties of wood in relation to drying, layout of the drying yard, piling methods, causes and remedies of air-drying defects, and protection of air-dried lumber.

Keywords: drying lumber, air dry, wood structure, wood shrinkage, drying rate, wood defects

Preface

This manual is a revision of the 1971 edition of *Air Drying of Lumber: A Guide to Industry Practice* by Raymond C. Rietz and Rufus H. Page. A major contributor to the 1971 edition was Edward C. Peck, formerly a wood drying specialist at the Forest Products Laboratory.

The major reason for this revison is the continued interest in and requests for the manual, even almost 30 years after initial publication. Because of this continued interest, we maintained the same basic framework in the revision. Our main objective was to update with new or more current information where necessary, keeping in mind that our audience will range from small industry (perhaps new to lumber drying) to larger industry (perhaps having substantial experience in air drying). Involved in this revision were

William T. Simpson, Research Forest Technologist,

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of the Forest Products Laboratory.

Acknowledgments

Special recognition is given to Edward C. Peck, formerly a Wood Drying Specialist at the USDA Forest Service, Forest Products Laboratory, for his research and related contributions that formed the basis for most of this publication. We also appreciate the cooperation of lumber-producing industries in providing photographs of their operations.

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Air Drying of Lumber

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Contents

Introduction

Trees contain a considerable amount of water. Most of this water must be evaporated before the lumber obtained from a tree can be converted into consumer products. The lumber from which most wood products are manufactured must be dried.

Of all the methods to remove large quantities of water from wood, air drying has the least capital costs, especially in the early stages of drying. However, air drying offers little opportunity to control the drying process.

Drying wood by allowing natural forces to evaporate the water is not a new idea. Over the years, people learned how to utilize these forces effectively. However, this information accumulated slowly, and many individuals are aware of only part of the technology. This publication assembles information on air drying learned through research and information that has evolved from many years of experience.

This report gives plant managers, yard supervisors, lumber handlers, and others in related areas an overview of the principles of air drying. It will also assist them in analyzing their air-drying practices. Drying wood by any means is expensive, so operators are constantly on the alert to reduce costs. Application of general air-drying principles may lead to changes in yarding methods that will result in faster drying of lumber and improved quality.

The results of efficient air drying benefit consumers of forest products and are of key importance in utilization of the Nation’s forest resource. Efficient air drying helps to conserve supplies of wood, thereby the timber resource, by reducing loss of product from drying degrade. Air drying also reduces the need to burn fuels for energy to dry lumber, thus conserving these fuels and reducing atmospheric emissions. In addition, air drying helps to ensure continued markets for wood products by contributing to customer satisfaction. Both conservation of the timber resource and customer satisfaction contribute to the wise use of timber, which has long been an accepted tenet of the USDA Forest Service’s conservation policy.

The emphasis of this publication is practicality. After touching on the variety of reasons for drying lumber and the wood properties that relate to drying, the basics of the air-drying process are presented. Then, descriptions are given of the drying yard, methods of piling lumber for air drying, defects that occur in air drying, and protection of the air-dried lumber. Finally, an appendix summarizes the information in this report and serves as a convenient means of checking specific points in an individual operation. As in any industry, specific terminology has evolved and shades of meaning show up geographically, between hardwood and softwood production or between a plant operator and a researcher. For this reason, a glossary is included to delineate how words are used in this publication. Wood species are generally listed in this report by their common names. However, different common names are often used for the same species; therefore, both common and botanical names are given in Table 1.

Table 1—Average moisture content of green wood, by species

Species	Botanical name	Moisture content[a] (%) Heartwood	Sapwood	Mixed heartwood and sapwood
Hardwoods				
Alder, red	*Alnus rubra*	—	97	—
Ash, black	*Fraxinus pigra*	95	—	—
Ash, green	*F. pennsylvanica*	—	58	—
Ash, white	*F. americana*	46	44	—
Aspen, bigtooth	*Populus grandidentata*	95	113	—
Aspen, quaking	*P. tremuloides*	95	113	—
Basswood, American	*Tilia americana*	81	133	—
Beech, American	*Fagus grandifolia*	55	72	—
Birch, paper	*Betula papyrifera*	89	72	—
Birch, sweet	*B. lenta*	75	70	—
Birch, yellow	*B. alleghaniensis*	74	72	—
Butternut	*Juglans cinerea*	—	—	104
Cherry, black	*Prunus serotina*	58	—	65
Cottonwood, black	*Populus trichocarpa*	162	146	—
Cottonwood, eastern	*P. deltoides*	160	145	—
Elm, American	*Ulmus americana*	95	92	—
Elm, rock	*U. thomasii*	44	57	—
Hackberry	*Celtis occidentalis*	61	65	—
Hickory,	*Carya spp*	71	51	—
Magnolia, southern	*Magnolia grandiflora.*	80	104	—
Maple, bigleaf	*Acer macrophyllum*	77	138	—
Maple red	*A. rubrum*	—	—	70
Maple, silver	*A. saccharinum*	58	97	—
Maple, sugar	*A. saccharum*	65	72	—
Oak, northern red	*Quercus rubra*	80	69	—
Oak, northern white	*Q. alba*	64	78	—
Oak, southern red	*Q. falcata*	83	75	—
Oak, southern white (chestnut)	*Q. prinus*	72	—	—
Pecan	*Carya illinoensis*	71	62	—
Sweetgum	*Liquidambar styraciflua*	79	137	—
Sycamore, American	*Platanus occidentalis*	114	130	—
Tanoak	*Lithocarpus densiflorus*	—	—	89
Tupelo, black	*Nyssa sylvatica*	87	115	—
Tupelo, water	*N. aquatica*	150	116	—
Walnut, black	*Juglans nigra*	90	73	—
Willow, black	*Salix nigra*	—	—	139
Yellow-poplar	*Liriodendron tulipifera.*	83	106	—

Species	Botanical name	Moisture content[a] (%) Heartwood	Sapwood	Mixed heartwood and sapwood
Softwoods				
Baldcypress	*Taxodium distichum.*	121	171	—
Cedar, Alaska`	*Chamaecyparis nootkatensis.*	32	166	—
Cedar, Atlantic white	*Chamaecyparis thyoides.*	—	—	35
Cedar, eastern red	*Juniperus virginiana*	33	—	—
Cedar, incense	*Libocedrus decurrens.*	40	213	—
Cedar, Northern white	*Thuja occidentalis*	32	240	93
Cedar, Port-Orford	*Chamaecyparis lawsoniana.*	50	98	—
Cedar, western red	*Thuja plicata*	58	249	62
Douglas-fir, coast type[b]	*Pseudotsuga menziesii*	37	115	45
Douglas-fir, intermediate type	*P. menziesii*	34	154	
Douglas-fir, Rocky Mountain type	*P. menziesii*	30	112	43
Fir, balsam	*Abies balsamea*	88	173	117
Fir,, California red	*A. magnifica*	—	—	108
Fir, grand	*A. grandis*	91	136	—
Fir, noble	*A. procera*	34	115	—
Fir, Pacific silver	*A. amabilis*	55	164	—
Fir, subalpine	*A. lasiocarpa*	—	—	47
Fir, white	*A. concolor*	98	160	—
Hemlock, eastern	*Tsuga canadensis*	97	119	—
Hemlock, western	*T. heterophylla*	85	170	—
Larch, western	*Larix occidentalis.*	54	119	—
Pine, eastern white	*Pinus strobus*	50	175	90
Pine, jack	*P. banksiana*	—	—	70
Pine, lodgepole	*P. contorta*	41	120	—
Pine, ponderosa	*P. ponderosa*	40	148	—
Pine, red	*P. resinosa*	32	134	—
Pine, Southern, loblolly	*P. taeda*	33	110	—
Pine, Southern, longleaf	*P. palustris*	31	106	—
Pine, Southern, shortleaf	*P. echinata*	32	122	—
Pine, Southern, slash	*P. elliottii*	30	100	—
Pine, sugar	*P. lambertiania*	98	219	—
Pine, western white	*P. monticola*	62	148	—
Redwood, old growth	*Sequoia sempervirens.*	86	210	—
Spruce, black	*P. moriana*	52	113	77
Spruce, Engelmann	*Picea engelmannii*	51	173	—
Spruce, red	*P. rubens*	—	—	55
Spruce, Sitka	*P. sitchensis*	41	142	43
Spruce, white	*P. glauca*	—	—	55

[a]Based on weight when ovendried.

[b]Coast Douglas-fir is defined as Douglas-fir growing in the states of Oregon and Washington west of the summit of the Cascade Mountains. Interior West includes the California and all counties in Oregon and Washington east of but adjacent to the Cascade summit. Interior North includes the remainder of Oregon and Washington and the States of Idaho, Montana, and Wyoming. Interior South is made up of Utah, Colorado, Arizona, and New Mexico.

Chapter 1

Why Dry Lumber?

Most water in the cut tree must be removed before useful products can be made from the wood. The rough, green lumber sawn from the log must be dried before it is processed into most end products. Drying the lumber at this stage has a number of distinct and important advantages:

- Drying reduces weight, thereby reducing shipping and handling costs.
- The shrinkage that accompanies drying takes place before the wood is used as a product.
- As wood dries, most strength properties increase.
- The strength of joints made with nails and screws is greater in dry wood than in green wood.
- Wood must be relatively dry before it can be glued or treated with preservatives and fire-retardant chemicals.
- Drying reduces the likelihood of mold, stain, or decay.
- Drying increases thermal insulating properties and improves finishing characteristics.

Drying Methods

Several methods can be used to dry lumber, ranging from air and kiln drying to special seasoning processes. Basically, all methods involve moving moisture from the inside of the wood to the surface, where it is evaporated into the air. Heat and air movement speed up the drying process. Although this publication deals with air drying only, a brief description of other major methods is included to clarify how they differ from air drying.

Air Drying

To air dry, the lumber is arranged in layers, or courses, with separating stickers, and built up into unit packages and piles outdoors so that atmospheric air can circulate through the piles and carry away moisture (Fig. 1). One modification of air drying is shed drying, where the lumber to be dried is placed in a shed having open sides (Fig. 2). The roofed structure protects the lumber from rain and direct solar radiation but allows outdoor air to circulate through the stickered lumber to dry it.

Fan Shed Air Drying

To accelerate air drying, stickered unit packages of lumber are placed in an unheated shed or building that has fans on one side and is open on the other. The fans create air movement through the spaces between the courses of wood (Fig. 3).

Forced Air Drying and Predrying

In more complex drying processes, stickered packages of lumber are placed in closed buildings that have fans to recirculate heated air through the lumber piles. Both forced air dryers and predryers are commonly considered low temperature, forced-air circulation, ventilated dry kilns (Fig. 4).

Kiln Drying

To kiln dry, lumber is dried in a closed chamber by controlling the temperature, relative humidity, and air circulation until the wood reaches a predetermined moisture content (Fig. 5).

Special Drying Processes

To reduce drying time and degrade, several processes for drying lumber have been investigated. Solar energy has gained popularity with small drying operations. Vacuum drying, especially when combined with radio frequency or microwave delivery of energy to evaporate water, has also gained attention in recent years. The main advantage of vacuum drying is reduced drying time without increased drying defects. Other special drying processes in limited use are press drying between heated platens, solvent seasoning, and boiling in oil.

Choice of Methods

Factors that determine the lumber drying process used at a plant are generally related in one way or another to economics. A sawmill that produces a considerable volume of a rather slow-drying wood (such as oak) often selects air drying followed by kiln drying. However, softwoods are often kiln dried green from the saw.

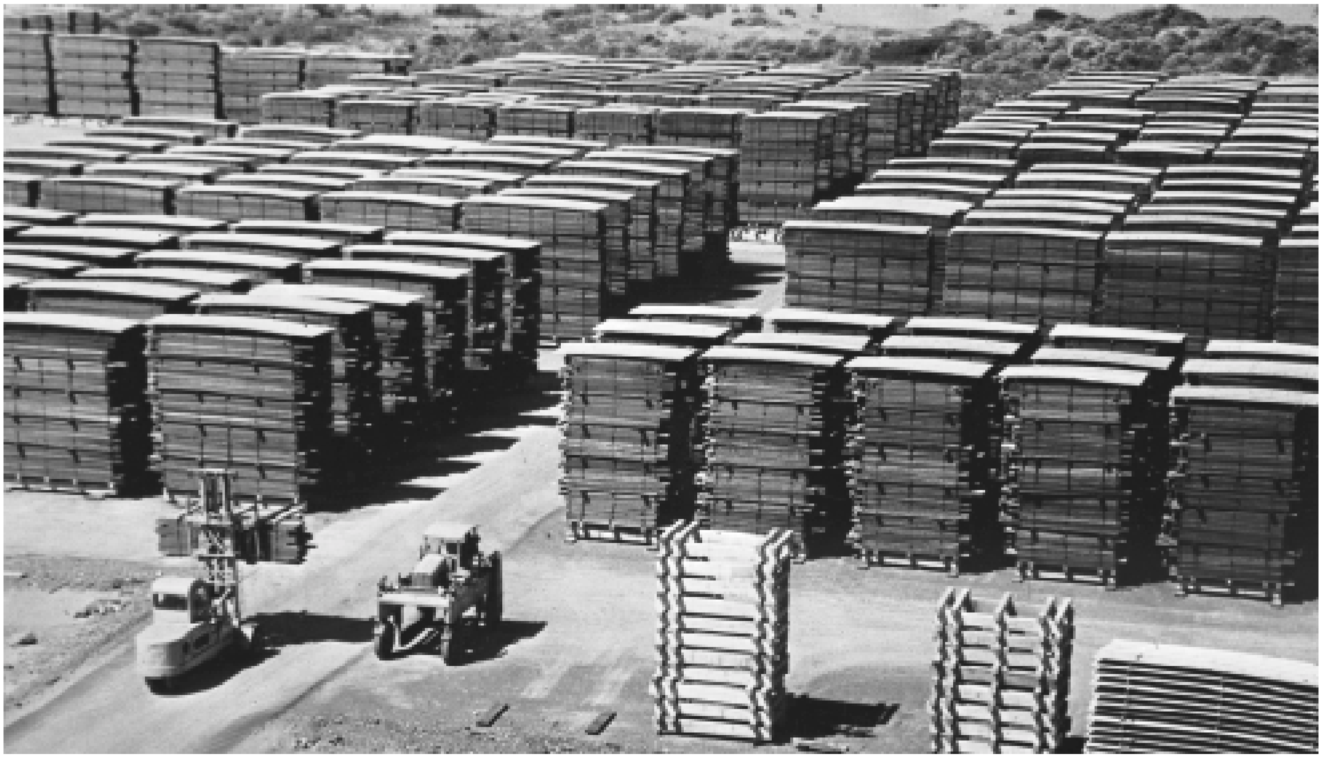

Figure 1—An air-drying yard arranged for good circulation of air around the piles of packaged lumber.

Figure 2—Shed for drying lumber protects the lumber from the weather.

Objectives

The main purpose for air drying lumber is to evaporate as much water as possible while minimizing capital expenditures for dry-kiln capacity and without incurring a cost for the energy required. In air drying, lumber is usually left on stickers in the yard until it reaches a moisture content between 20% and 25%. The lumber may then be ready for further processing, depending upon its end use. If it must be dried to lower moisture content levels, such as for use in furniture factories, the lumber will be kiln dried.

When lumber use does not require a low moisture content, air drying is usually sufficient. Lumber used for outdoor furniture and other outdoor exposures, or for building structures such as barns, pole sheds, and garages that are not heated, can usually be air dried to a low enough moisture content. Rough sawn hardwoods are often air dried at the producing sawmills to reduce weight so that shipping costs are reduced. In addition, air drying reduces subsequent kiln-drying time.

The main benefit of the air-drying process, particularly for hardwoods, is that it offers a way to add value while the inventory of lumber is being held. To meet production of shipping schedules during periods of the year when the sawmill cannot be operated to capacity, the yard inventory is built up when sawing conditions are favorable and the lumber is air dried while being held. Air drying is sometimes used to reduce the moisture content in wood, such as railroad ties, to a level suitable for preservative treatment.

Air drying further reduces the chance that mold and decay may develop in transit, storage, or subsequent use. Blue stain and wood-destroying fungi cannot grow in wood with a moisture content of 20% or less. However, green lumber may have to be treated with a fungicide to protect it from these fungi in the early stages of the air-drying process. Drying is also a protective measure against damage from most insects that bore holes in wood.

Figure 3—Fan shed air dryer draws air through the stickered packages of lumber.

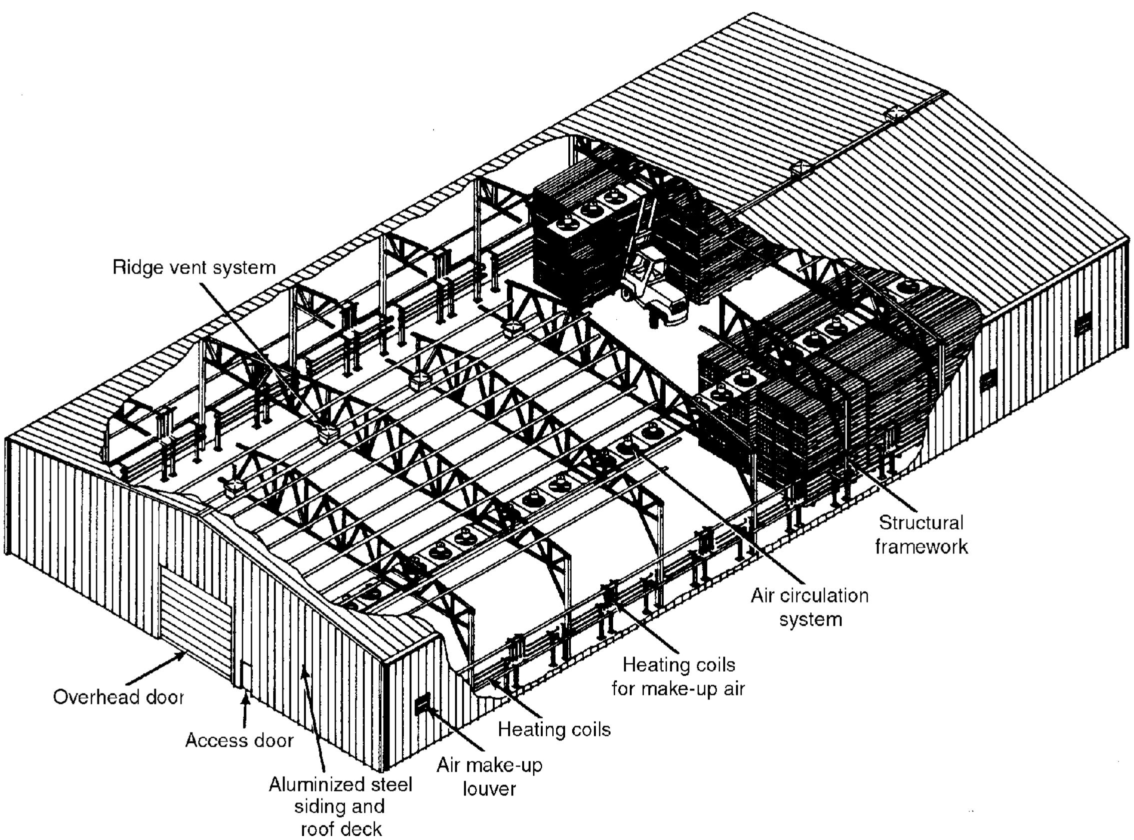

Figure 4—Predryers are large structures that provide some means of controlling the drying conditions. The forklift in the background provides size comparison.

Advantages and Limitations

The greatest advantage of air drying lumber when compared with drying by other processes is low capital costs. However, as the value of the wood increases, kiln drying green wood becomes more feasible. Species such as beech, birch, and maple are often kiln dried green from the saw. The limitations of air drying are associated with the uncontrollable nature of the process. The drying rate is very slow during the cold winter months in the northern sector of the country. At other times, hot, dry winds may increase degrade and volume losses as a result of severe surface checking and end splitting. Production schedules depend on changing climatic conditions of temperature, relative humidity, rainfall, sunshine, and winds. Warm, humid, or sultry periods with little air movement encourage the growth of blue stain and aggravate chemical brown and gray stain.

Figure 5—Typical package-loaded dry kiln.

Chapter 2

Wood Properties and Moisture

The structure of wood, the location and amount of moisture contained in green wood, and the physical properties of wood greatly influence its drying characteristics and reactions to air-drying conditions.

Structure

Bark, Wood, and Pith

A cross section of a tree shows well-defined features from the outside to the center (Fig. 6). The bark is divided into two layers—the corky, outer dead portion and the inner living portion. The light-colored zone of wood next to the bark is called sapwood and the darker inner zone of wood is called heartwood. In the center of the tree is a very small, soft core known as pith.

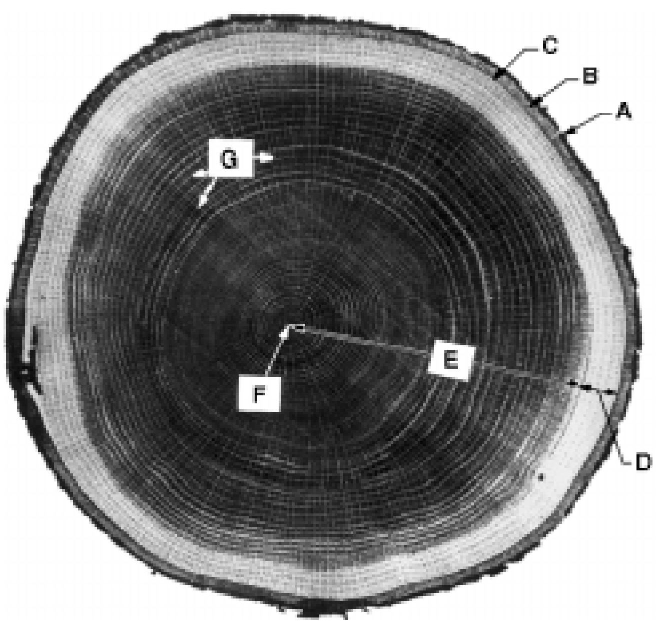

Figure 6—Cross section of an oak tree: A, Outer bark or corky layer is composed of dry dead tissue, gives general protection against external injuries. B, Inner bark is moist and soft, carries prepared food from leaves to all growing parts of the tree. C, Cambium layer is inside of the inner bark and forms wood and bark cells. D, Sapwood is the light-colored wood beneath the bark; it carries sap from the roots to leaves. D, Heartwood (inactive. is formed by a gradual change in the sapwood; it gives the tree strength. F, Pith is the soft tissue about which the first wood growth takes place in the newly formed twigs. G, Wood rays are strips of cells that extend radially within the tree and serve primarily to store and transport food.

Hardwoods and Softwoods

Typically, hardwoods are trees with broad leaves, and softwoods are trees with needle-like or scale-like leaves. These terms do not apply to the hardness or density of the woods. Some softwoods, such as southern yellow pine, are harder than some hardwoods, such as basswood or cottonwood.

The structure of hardwoods is generally more complex than that of softwoods. Figure 7 shows the vessels and other cells in a hardwood cube highly magnified. Figure 8 shows a similar cube of softwood. Many hardwoods contain relatively large wood rays, and some softwoods contain resin ducts. Both rays and resin ducts are related to increased susceptibility to surface checking during drying.

Cellular Structure

Wood is composed of hollow, tube-like cells called fibers, usually closed at both ends. Thin spots or pit membranes are located in the walls of cells, through which the sap flows in the living tree or moisture moves during the drying of lumber. Most cells lie nearly parallel to the long axis of the tree trunk, but some lie perpendicular to the long axis of the tree on radial lines from the pith to the bark. These cells are called wood rays. Each year, several layers of new cells are produced on the outside of the sapwood by the thin living layer called the cambium.

Earlywood and Latewood

A cross section of a tree grown in a temperate climate shows well-defined concentric layers of wood, which correspond closely to yearly increments of growth. For that reason, they are commonly called annual growth rings. Earlywood, sometimes called springwood, is formed during the early part of each growing season. The cells of the earlywood are generally larger in cross section and thinner walled than those formed later in the season. Consequently, earlywood is softer, weaker, and generally lighter in color than latewood or summerwood.

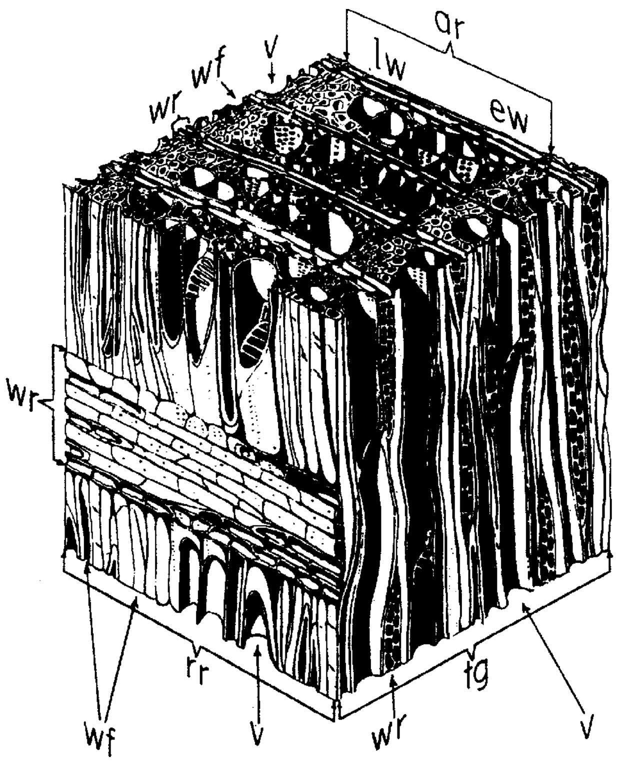

Figure 7—A section of hardwood highly magnified: rr, radial surface; tg, tangential surface; ar, annual growth ring; ew, earlywood; lw, latewood; wr, wood ray; wf, wood fiber; v, vessels or pores.

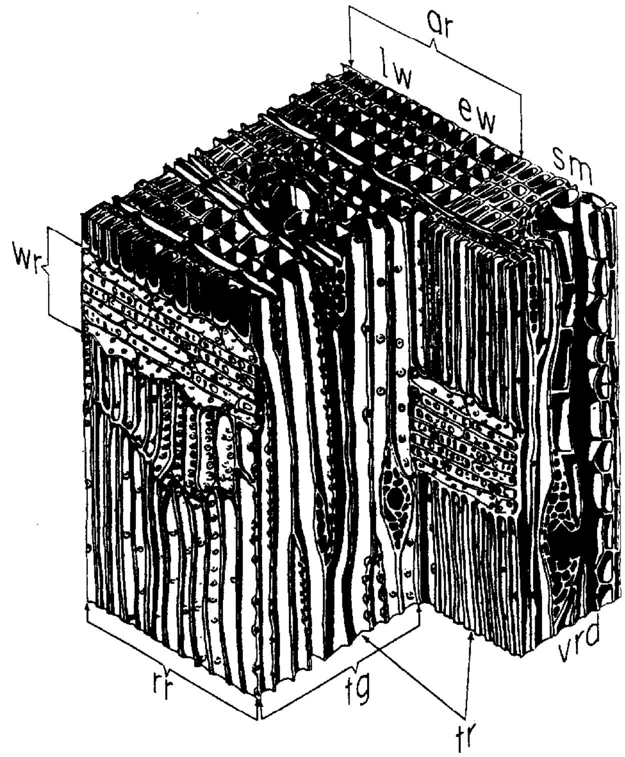

Figure 8—A section of a softwood highly magnified: rr, radial surface; tg, tangential surface; ar, annual growth ring; ew, earlywood; lw, latewood; wr, wood ray; tr, trachied or fiber; vrd, vertical resin ducts. The large hole near the center of the top section and the passage along the right edge (vrd) are vertical resin ducts.

Sapwood and Heartwood

In the living tree, the sapwood layer, which is near the bark, contains many living cells that serve mainly in the transfer and storage of food. Some of the cells that store food are associated with stain. These cells remain alive after the tree is cut, and they release enzymes that convert the sugars into a brown chemical. However, most sapwood cells are dead and serve only as channels for sap to move upward in the tree and to help support the tree.

The central part of the trunk is called heartwood. All heartwood cells are dead, and their principal function is to supply strength to the trunk and store extraneous materials. As a tree increases in diameter by adding new layers of sapwood under the bark, the zone of heartwood also enlarges at substantially the same rate. The living cells of the sapwood die and become infiltrated with gums, resins, coloring matter, and other materials. The circumference of the heartwood may be irregular and does not necessarily follow the annual growth rings closely.

The relative amounts of sapwood and heartwood vary considerably, both between species and in trees of the same species. A tree of small diameter has more sapwood proportionately than a similar tree of larger diameter. Within a species, sapwood is thickest in the most vigorously growing trees.

Heartwood, as a rule, is less permeable to liquids than is sapwood. For this reason, heartwood dries more slowly than does sapwood. In resinous woods, the heartwood usually contains more resin than does the sapwood.

Juvenile Wood

The wood adjacent to the pith is called juvenile wood. This wood shrinks more parallel to the grain than does the surrounding wood and may contribute to warping longitudinally (Fig. 9).

Reaction Wood

The growing tree develops wood with distinctive properties in parts of leaning or crooked trunks and in branches. This wood is called compression wood in softwoods and tension wood in hardwoods.

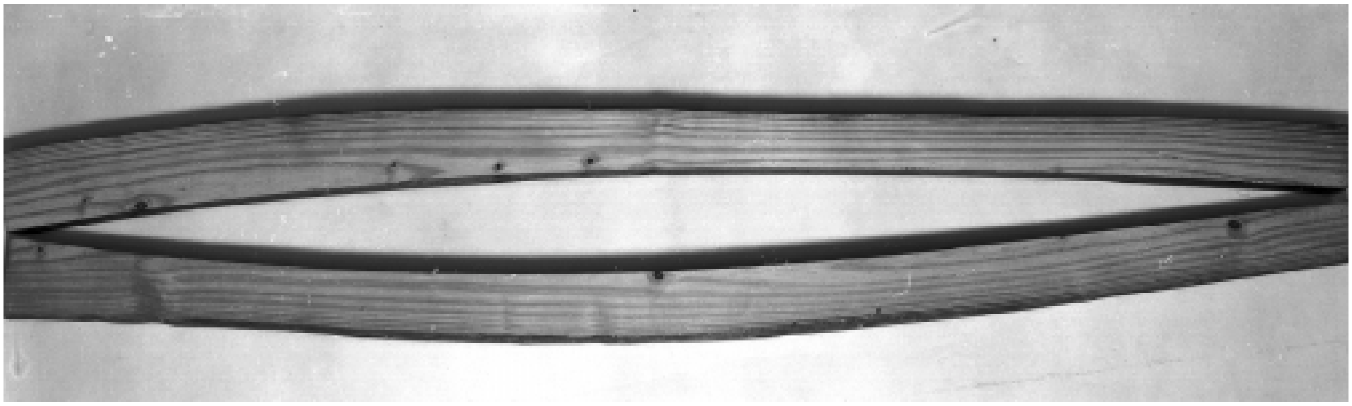

Figure 9—When the board was ripped in two, each piece crooked because of longitudinal shrinkage of juvenile wood in the center of the board.

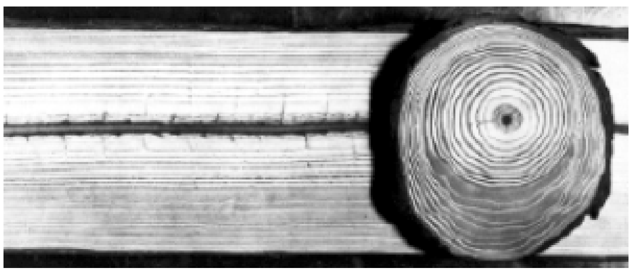

Figure 10—Eccentric growth around the pith in a cross section containing compression wood. The dark area in the lower third of the cross section is compression wood.

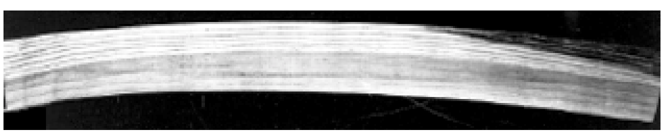

Figure 11—Crook resulted when the band of compression wood (darker strip running length of piece) shrank more longitudinally than did the lighter colored normal wood.

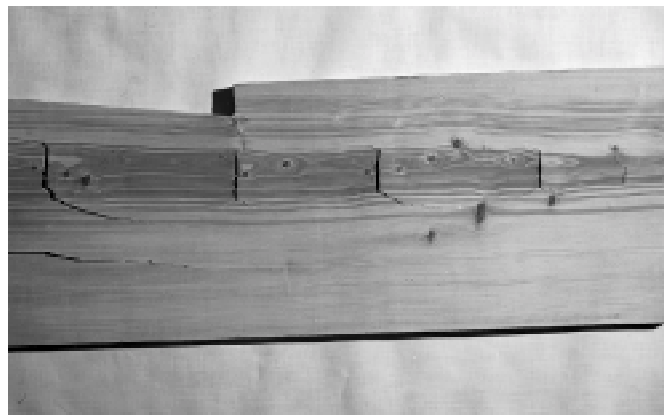

Figure 12—Board with dark band of compression wood with cross breaks caused by longitudinal shrinkage.

Compression wood (Fig. 10) occurs on the underside of the trunks of leaning softwood trees and on the underside of limbs. Annual growth rings in compression wood are usually wider than normal rings; latewood rings are unusually wide but do not appear as dense as normal latewood. A lack of color contrast between earlywood and latewood gives a lifeless appearance to compression wood. It is usually yellowish or brownish in color and may also have a reddish tinge. Streaks of compression wood are frequently interspersed with normal wood. Compression wood shrinks more longitudinally than does normal wood and may cause warping (Fig. 11) or develop cross breaks (Fig. 12) during drying.

Tension wood occurs in hardwoods, on the upper side of leaning tree trunks and on the upper side of limbs. It can cause a stressed condition in the log and later contributes to splitting in sawn products. Tension wood also shrinks abnormally, thus possibly contributing to warp during drying. When lumber is machined, zones of tension wood are indicated by torn grain (Fig. 13).

Structural Irregularities

The length of the wood cells is usually parallel to the length of the tree trunk. Sometimes the length of the wood cells forms an angle with the length of the tree trunk. If this orientation of the fibers continues around the circumference and upward in the trunk, spiral grain results. Spiral grain shows up on the surface of boards as grain that is at an angle to the edge of the board. Another cause for disoriented grain is a log that is sawn parallel to the pith rather than to the bark, and these boards will have a diagonal grain. Both spiral and diagonal grain are termed cross grain or slope of grain in boards or other sawn products. The principal drying defect resulting from cross grain is warp. Cross grain also causes mechanical weakness.

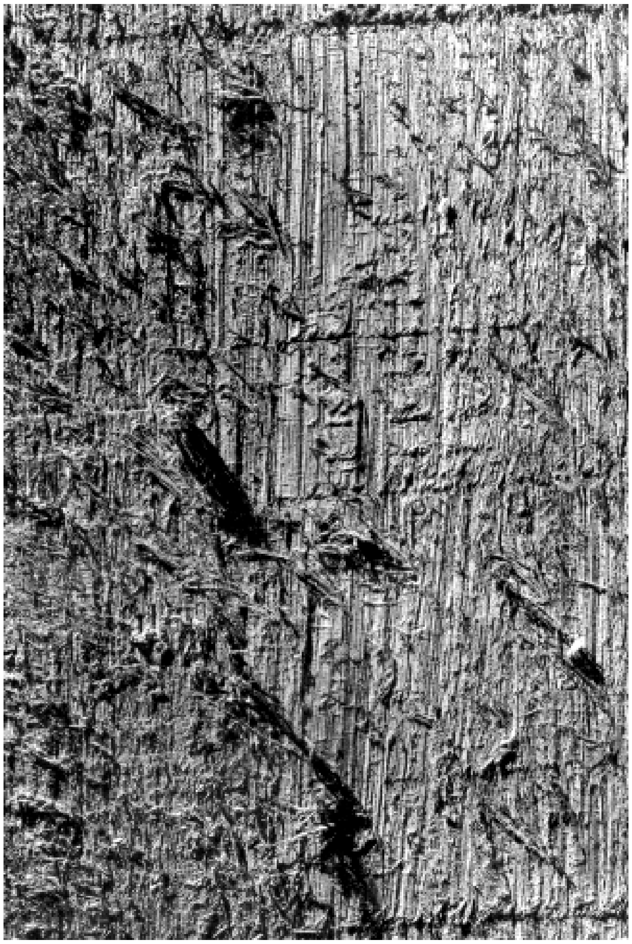

Figure 13—Area of tension wood is indicated by grain torn during machining.

Knots

A knot is revealed when lumber is cut from the portion of a tree containing an embedded branch. Normally, a knot starts at the pith and grows outward through the bark. Knots are generally objectionable because the distortion and the discontinuity of the grain around knots weakens the wood. Furthermore, knots cause irregular shrinkage and warping. When lumber dries, knots and the wood adjacent to them tend to check. Knots can also become loose because of their change in size. In addition, loose knots are formed when a tree grows around a dead branch. When the lumber is sawn, the dead knot may fall out because it is not connected to the rest of the tree.

Moisture Content

The liquid in freshly cut lumber is often called sap. Sap is composed primarily of water, with varying amounts of other dissolved materials. Moisture in wood exists in two forms: as free water in the cell cavities and as bound moisture held within the cell walls. Sapwood usually contains more moisture than does heartwood, particularly in softwoods. Table 1 lists moisture content values of green wood for several species.

The moisture content of wood can vary at different heights in the tree; species and growing conditions are involved. Butt logs of sugar pine, western larch, redwood, and western red cedar sometimes sink in water because their density at these high moisture content levels exceed that of water, although the upper logs from the same trees float. In addition to having a higher moisture content, these “sinker” logs can have a higher specific gravity or more wood substance per unit volume.

Methods to Determine Moisture Content

The performance of wood is influenced by the amount of moisture it contains; for many uses, wood serves best at specific levels of moisture content. Therefore, knowing the moisture content is an essential part of determining the readiness of wood for use. The amount of moisture in wood is expressed as a percentage of the weight of the dry wood substance. Moisture content of wood can be determined by the oven-drying method, a distillation method, or the use of electric moisture meters (Figs.14,15).

Oven-Drying Method

The oven-drying method is the standard way of determining the moisture content of wood. A cross section is cut from a board, then completely dried in a heated oven. The method consists of the five following steps:

1. Cut a cross section from a board about 25 mm (1 in.) thick along the grain.
2. Immediately after sawing, remove all loose splinters and weigh the section.
3. Put the section in an oven maintained at 105°C (220°F) and dry until constant weight is attained, usually about 24 h.
4. Weigh the dried section to obtain the ovendry weight.
5. Subtract the ovendry weight from the initial weight and divide the difference by the ovendry weight, multiplying the result by 100 to obtain the percentage of moisture in the section:

   moisture content (%) = 100 × (initial weight − ovendry weight)/ ovendry weight

   A short-cut formula convenient to use is

   moisture content (%) = 100 × (initial weight/ovendry weight −1)

Several types of balances are used in weighing specimens to determine moisture content. One inexpensive type is the triple beam balance (Fig 16). A direct reading automatic balance is very convenient (Fig. 16) when several specimens are weighed in and out of the drying oven. Self-calculating

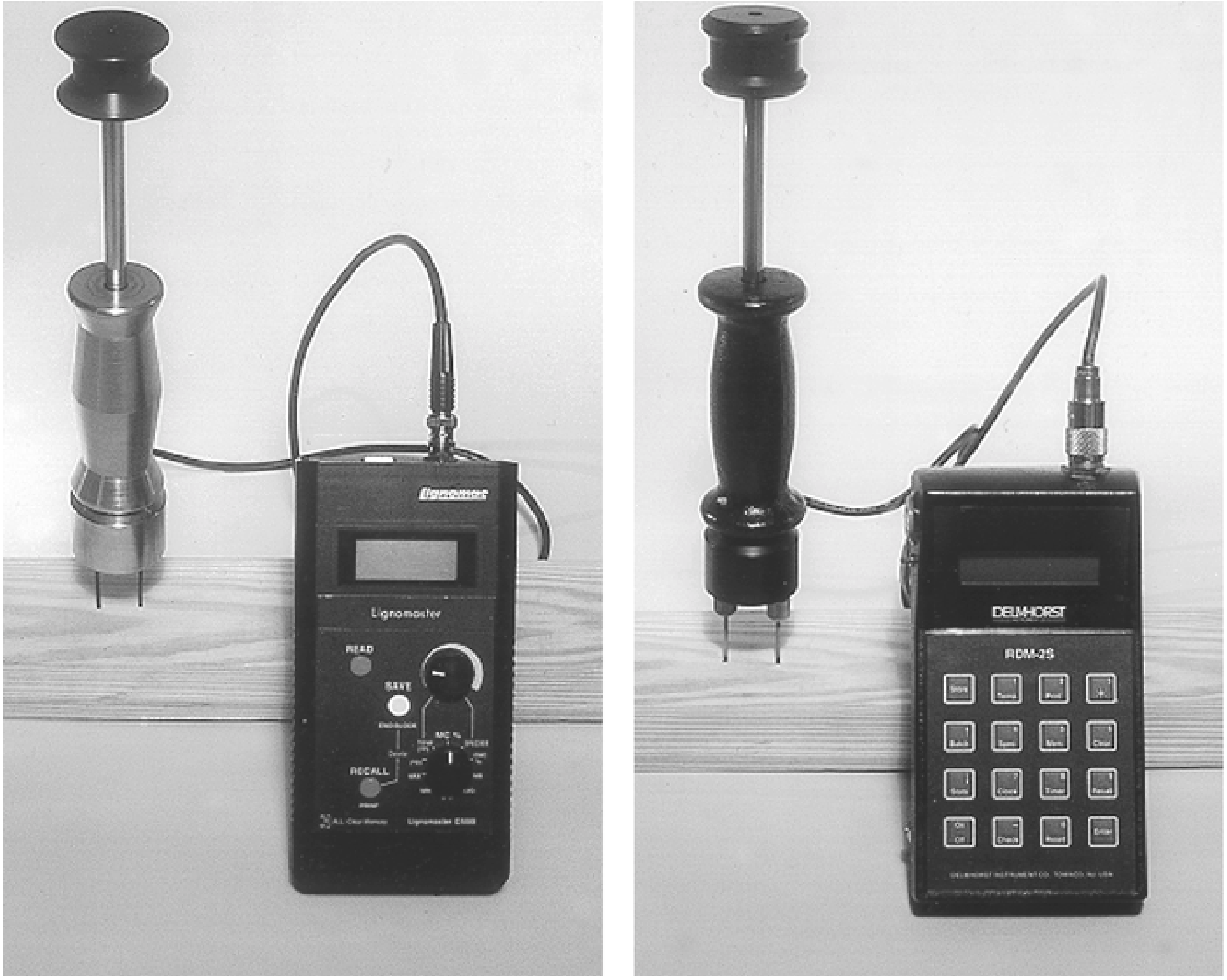

Figure 14—Conductance-type electrical moisture meters.

balances are also available (Fig. 17). The moisture content calculation is carried out on the balance by following the prescribed sequence of operations supplied by the manufacturer. The ovens used for drying the moisture sections should be large enough to accommodate several specimens with space between them. Ovens should also be well ventilated to allow the evaporated moisture to escape. The temperature of the oven must be controlled with a reliable thermostat. Excessive temperatures will char the specimens, introducing errors in the moisture analysis.

Electrical Methods

Electric moisture meters permit the determination of moisture content without cutting or seriously marring the board. Such meters are rapid and reasonably accurate through the range from 7% to 25% moisture content. Several tests can be made with the electric moisture meter on a board or a lot of lumber to arrive at a better overall average, canceling out the inaccuracies that might exist in individual measurements. With some types of electrodes, a minor consideration is that small needlepoint holes are made in the lumber being tested.

Electric moisture meters are extensively used, particularly the portable or hand meters. Two types, each based on a different fundamental relationship, have been developed: (1) the resistance, or pin type, which uses the relationship between moisture content and electrical resistance (Fig. 14); and (2) the capacitance type, which uses the relationship between moisture content and the dielectric properties of wood and its included water (Fig. 15).

Portable, battery-operated, resistance-type moisture meters are wide range ohmmeters. Most models have a direct reading meter, calibrated in percentage for one species; the manufacturer provides corrections for other species, either

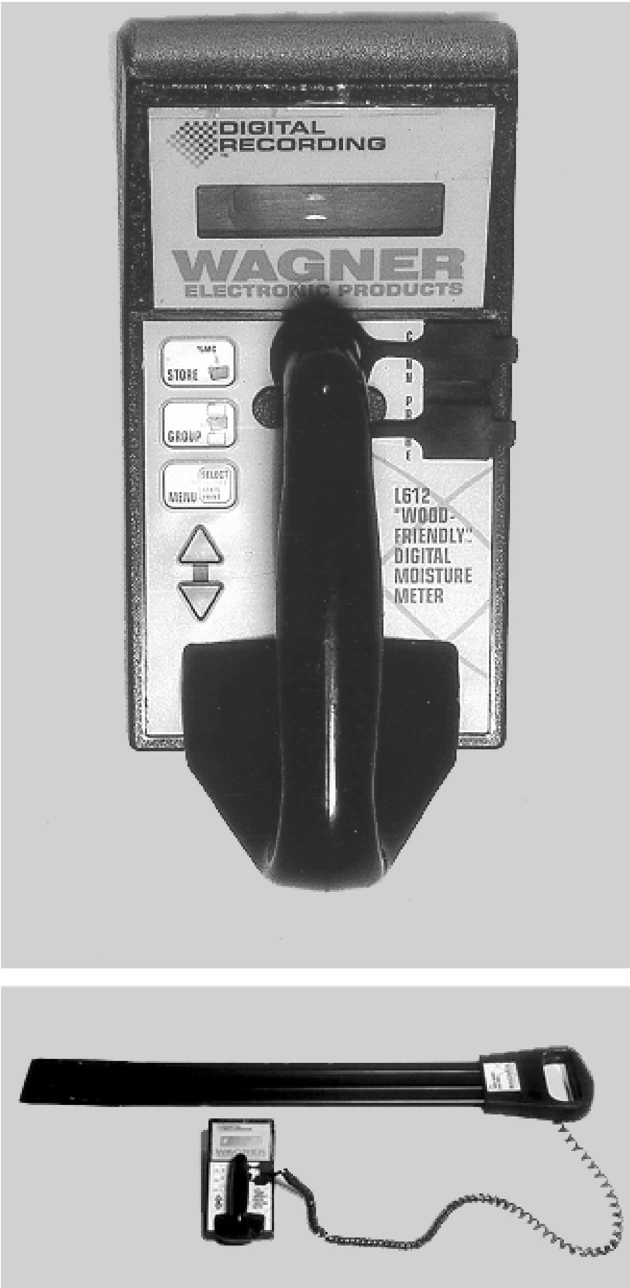

Figure 15—Capacitance-type electrical moisture meter.

built into the meter or in the form of tables. The manufacturer also provides a temperature correction chart or table for correcting the meter reading when tests are made on wood warmer than 32°C (90°F) or cooler than 21°C (70°F).

Resistance-type meters are generally supplied with two pin-type electrodes that are driven into the wood being tested. Lengthy, two-pin electrodes that are insulated except for the tip are also available for use on lumber thicker than 41 mm (1-5/8 in.). Valid estimates of the average moisture content of the drying board are obtained by driving the pins deep enough in the lumber so that the tip reaches a fifth to a fourth of the thickness of the board. If the surface of the lumber has been wetted by rain, the meter indications are likely to be much greater than the actual average moisture content unless insulated shank pins are used.

Capacitance-type hand meters use surface contact-type electrodes. The electric field radiating from the electrode penetrates about 19 mm (3/4-in.) into the wood so that lumber thicknesses to about 38 mm (1-1/2 in.) can be tested. However, the moisture content of the surface layers of the lumber has a predominant effect on the meter readings, simply because the electric field is stronger near the surface in contact with the electrode.

Temperature correction charts or tables are not provided by the manufacturers of capacitance-type meters. However, they do provide species correction tables for converting the meter scale reading of the instrument to moisture content for individual species.

Moisture Movement

During air drying, water at or near the lumber surface evaporates first. Then, water deeper in the wood moves from zones of high moisture content to zones of lower moisture content in an effort to reach a moisture equilibrium throughout the board. This means that moisture from the interior of a wet board moves to the drier surface zones. Outdoor air must not be restricted from circulating over the green lumber to dry the surfaces and draw moisture from the interior of the board.

Moisture moves through several kinds of passageways in the wood. The principal ones are the cavities in the cells, the pit chambers, and pit membrane openings in the cell walls. Movement of moisture in these passageways occurs not only lengthwise in the cells but also sideways from cell to cell through pit membranes toward the drier surfaces of the wood.

When wood dries, several moisture-driving forces may be operating to reduce its moisture content. These forces, which may be acting at the same time, include the following:

- Capillary action that causes the free water to move through the cell cavities, pit chambers, and pit membrane openings (the same action that causes a liquid to wet a wick)
- Differences in relative humidity that cause moisture in the vapor state to flow through cell cavities, pit chambers, pit membrane openings, and intercellular spaces to regions of lower humidity
- Moisture content differences that cause movement of moisture to regions of lower moisture content through the passageways within the cell walls

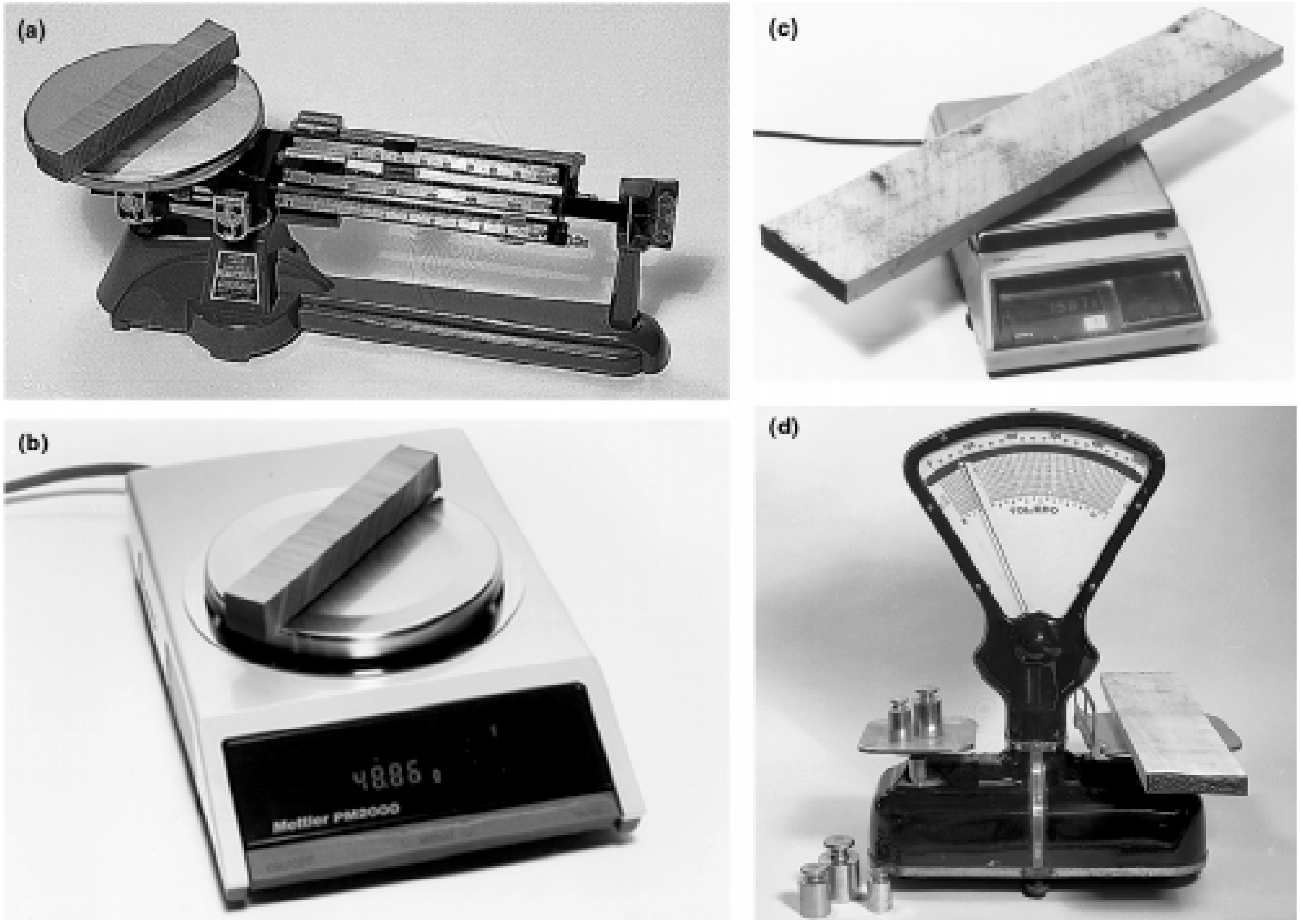

Figure 16—Three types of balances that can be used to weigh moisture sections and kiln samples: (a) triple beam balance for moisture sections, (b) electronic top loading balance for moisture sections, (c) electronic top loading balance for kiln samples, (d) non-electronic balance for kiln samples.

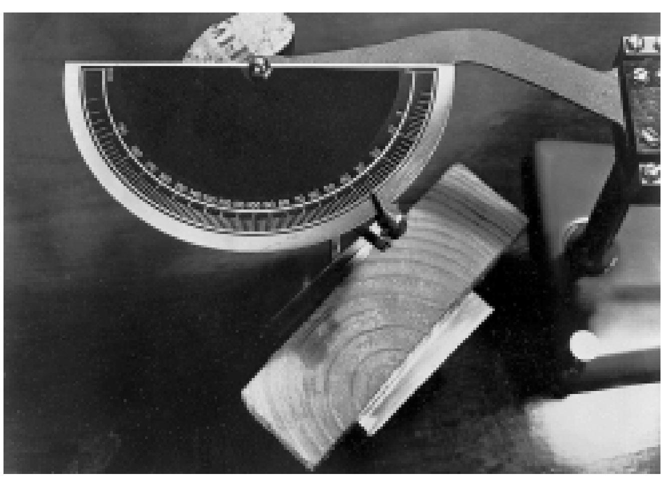

Figure 17—Self-calculating moisture content balance. The triple beam balance is provided with a special scale on the specimen pan that is used to calculate the moisture content after the section is ovendried.

When green wood starts to dry, evaporation of water from openings in the surface cells creates a capillary pull on the free water in the cell cavity and in adjacent cells. Free water moves from one tubular cell to another toward the wood surface by capillary action. When the free water has evaporated in the cells, the moisture remaining is in the form of vapor in the cell cavities or bound water in the cell walls.

The movement of water vapor through void spaces in wood depends on how much water vapor is contained in the air in the voids or in the air surrounding the wood. If the air surrounding the wood has a low relative humidity, water vapor will move from the wet wood to the air. Thus, rapid drying depends on the surface moisture content of the wood being dried and whether a difference in moisture content can be developed between the surface and the interior of a board.

The higher the temperature to which the drying wood is subjected, the faster the combined vapor and moisture movement. This is why the air-drying rate is faster in summer than in winter.

Equilibrium Moisture Content

Wood is a hygroscopic material. It gives off or takes on moisture until it is in equilibrium with the relative humidity of the surrounding air. When the moisture content of the wood has reached equilibrium, it is said to have reached its equilibrium moisture content (EMC). The EMC of wood can be predicted by knowing the temperature and relative humidity conditions of the air in contact with the surface of the drying lumber; this relationship is shown in Table 2. Table 3 shows the average monthly EMC values for various cities in the United States.

The air temperature in a lumber drying yard is determined with a dry-bulb thermometer. To determine the relative humidity of the air, a wet-bulb thermometer can also be used. If the two thermometers are mounted on a single base, the instrument is called a hygrometer (Fig. 18). The wet-bulb thermometer has the bulb covered with a clean, soft cloth wick that dips into a reservoir of pure, clean water. Water in the reservoir wets the wick by capillary action. As a result of the cooling caused by evaporation from the wet surface of the wick, the wet-bulb thermometer will give a lower reading than the dry-bulb thermometer. This difference in readings, called the wet-bulb depression, is a measure of the relative humidity of the air. To obtain a true reading with the wet-bulb thermometer, the hygrometer must be placed in a strong current of air. Table 4 gives relative humidity and EMC values for various dry-bulb temperatures and wet-bulb depressions. In addition to wet- and dry-bulb thermometers, direct reading hygrometers are also available, although they may not be as accurate as the measurement using wet- and dry-bulb thermometers.

Fiber Saturation Point

As previously stated, the moisture in the cell cavity is called free water, and that held in the cell walls is called bound water. Conceptually, the moisture content when all the free-water in the cell cavity is removed but the cell wall remains saturated is called the fiber saturation point (fsp). For most practical purposes, this condition exists at a cell moisture content of about 30%. Note that the definition of fsp applies to cells or localized regions but not to the moisture content of an entire board. During drying, the center of a board may be at a relatively high moisture content (for example, 40%), and the surface fibers may be much dryer (for example, 12%). Overall, this board may be at an average moisture content of 30%, but it is not correct to say that the entire board is at fsp.

Comparatively large changes in the physical and mechanical properties of wood occur with changes of moisture content around the fsp. The moisture removed below this point comes from the cell wall; therefore, the fsp is the moisture content level at which shrinkage begins. More energy is required to evaporate the bound water, because the attraction between the wood and water must be overcome.

Shrinkage

When the cells in the surface layers of a board dry below the fsp, about 30%, the cell walls shrink. Shrinkage of cells in the surface region of the board can be sufficient to squeeze the core of the board and cause a slight overall shrinkage of the board. For most practical purposes, the shrinkage of wood is considered as being directly proportional to the amount of moisture lost below 30%. Shrinkage varies with the species and the orientation of the fibers in the piece. Normally, shrinkage is expressed as a percentage of the green dimension. The reduction in size parallel to the growth ring, or circumferentially, is called tangential shrinkage. The reduction in size parallel to the wood rays, or radially, is called radial shrinkage. Tangential shrinkage is about twice as great as radial shrinkage in most species. This explains the characteristic shrinkage and distortion of several wood shapes shown in Figure 19.

Table 2—Moisture content of wood in equilibrium with stated dry-bulb temperature and relative humidity

Dry-bulb temperature (°C (°F))	Moisture content (%) for the following relative humidity values																		
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
–1.1 (30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4 (40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0 (50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6 (60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1 (70)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
26.7 (80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2 (90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8 (100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3 (110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9 (120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0

Table 3—Average monthly EMC values for various U.S. cities[a]

State	City	Equilibrium moisture content (%)											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AK	Juneau	16.5	16.0	15.1	13.9	13.6	13.9	15.1	16.5	18.1	18.0	17.7	18.1
AL	Mobile	13.8	13.1	13.1	13.3	13.4	13.3	14.2	14.4	13.9	13.0	13.7	14.0
AZ	Flagstaff	11.8	11.4	10.8	9.3	8.8	7.5	9.7	11.1	10.3	10.1	10.8	11.8
AZ	Phoenix	9.4	8.4	7.9	6.1	5.1	4.6	6.2	6.9	6.9	7.0	8.2	9.5
AR	Little Rock	13.8	13.2	12.8	13.1	13.7	13.1	13.3	13.5	13.9	13.1	13.5	13.9
CA	Fresno	16.4	14.1	12.6	10.6	9.1	8.2	7.8	8.4	9.2	10.3	13.4	16.6
CA	Los Angeles	12.2	13.0	13.8	13.8	14.4	14.8	15.0	15.1	14.5	13.8	12.4	12.1
CO	Denver	10.7	10.5	10.2	9.6	10.2	9.6	9.4	9.6	9.5	9.5	11.0	11.0
DC	Washington	11.8	11.5	11.3	11.1	11.6	11.7	11.7	12.3	12.6	12.5	12.2	12.2
FL	Miami	13.5	13.1	12.8	12.3	12.7	14.0	13.7	14.1	14.5	13.5	13.9	13.4
GA	Atlanta	13.3	12.3	12.0	11.8	12.5	13.0	13.8	14.2	13.9	13.0	12.9	13.2
HI	Honolulu	13.3	12.8	11.9	11.3	10.8	10.6	10.6	10.7	10.8	11.3	12.1	12.9
ID	Boise	15.2	13.5	11.1	10.0	9.7	9.0	7.3	7.3	8.4	10.0	13.3	15.2
IL	Chicago	14.2	13.7	13.4	12.5	12.2	12.4	12.8	13.3	13.3	12.9	14.0	14.9
IN	Indianapolis	15.1	14.6	13.8	12.8	13.0	12.8	13.9	14.5	14.2	13.7	14.8	15.7
IA	Des Moines	14.0	13.9	13.3	12.6	12.4	12.6	13.1	13.4	13.7	12.7	13.9	14.9
KS	Wichita	13.8	13.4	12.4	12.4	13.2	12.5	11.5	11.8	12.6	12.4	13.2	13.9
KY	Louisville	13.7	13.3	12.6	12.0	12.8	13.0	13.3	13.7	14.1	13.3	13.5	13.9
LA	New Orleans	14.9	14.3	14.0	14.2	14.1	14.6	15.2	15.3	14.8	14.0	14.2	15.0
ME	Portland	13.1	12.7	12.7	12.1	12.6	13.0	13.0	13.4	13.9	13.8	14.0	13.5
MA	Boston	11.8	11.6	11.9	11.7	12.2	12.1	11.9	12.5	13.1	12.8	12.6	12.2
MI	Detroit	14.7	14.1	13.5	12.6	12.3	12.3	12.6	13.3	13.7	13.5	14.4	15.1
MN	Minneapolis–St.Paul	13.7	13.6	13.3	12.0	11.9	12.3	12.5	13.2	13.8	13.3	14.3	14.6
MS	Jackson	15.1	14.4	13.7	13.8	14.1	13.9	14.6	14.6	14.1	14.1	14.3	14.9
MO	St. Louis	14.5	14.1	13.2	12.4	12.8	12.6	12.9	13.3	13.7	13.1	14.0	14.9
MT	Missoula	16.7	15.1	12.8	11.4	11.6	11.7	10.1	9.8	11.3	12.9	16.2	17.6
NE	Omaha	14.0	13.8	13.0	12.1	12.6	12.9	13.3	13.8	14.0	13.0	13.9	14.8
NV	Las Vegas	8.5	7.7	7.0	5.5	5.0	4.0	4.5	5.2	5.3	5.9	7.2	8.4
NV	Reno	12.3	10.7	9.7	8.8	8.8	8.2	7.7	7.9	8.4	9.4	10.9	12.3
NM	Albuquerque	10.4	9.3	8.0	6.9	6.8	6.4	8.0	8.9	8.7	8.6	9.6	10.7
NY	New York	12.2	11.9	11.5	11.0	11.5	11.8	11.8	12.4	12.6	12.3	12.5	12.3
NC	Raleigh	12.8	12.1	12.2	11.7	13.1	13.4	13.8	14.5	14.5	13.7	12.9	12.8
ND	Fargo	14.2	14.6	15.2	12.9	11.9	12.9	13.2	13.2	13.7	13.5	15.2	15.2
OH	Cleveland	14.6	14.2	13.7	12.6	12.7	12.7	12.8	13.7	13.8	13.3	13.8	14.6
OK	Oklahoma City	13.2	12.9	12.2	12.1	13.4	13.1	11.7	11.8	12.9	12.3	12.8	13.2
OR	Pendleton	15.8	14.0	11.6	10.6	9.9	9.1	7.4	7.7	8.8	11.0	14.6	16.5
OR	Portland	16.5	15.3	14.2	13.5	13.1	12.4	11.7	11.9	12.6	15.0	16.8	17.4
PA	Philadelphia	12.6	11.9	11.7	11.2	11.8	11.9	12.1	12.4	13.0	13.0	12.7	12.7
SC	Charleston	13.3	12.6	12.5	12.4	12.8	13.5	14.1	14.6	14.5	13.7	13.2	13.2
SD	Sioux Falls	14.2	14.6	14.2	12.9	12.6	12.8	12.6	13.3	13.6	13.0	14.6	15.3
TN	Memphis	13.8	13.1	12.4	12.2	12.7	12.8	13.0	13.1	13.2	12.5	12.9	13.6
TX	Dallas–Ft.Worth	13.6	13.1	12.9	13.2	13.9	13.0	11.6	11.7	12.9	12.8	13.1	13.5
TX	El Paso	9.6	8.2	7.0	5.8	6.1	6.3	8.3	9.1	9.3	8.8	9.0	9.8
UT	Salt Lake City	14.6	13.2	11.1	10.0	9.4	8.2	7.1	7.4	8.5	10.3	12.8	14.9
VA	Richmond	13.2	12.5	12.0	11.3	12.1	12.4	13.0	13.7	13.8	13.5	12.8	13.0
WA	Seattle–Tacoma	15.6	14.6	15.4	13.7	13.0	12.7	12.2	12.5	13.5	15.3	16.3	16.5
WI	Madison	14.5	14.3	14.1	12.8	12.5	12.8	13.4	14.4	14.9	14.1	15.2	15.7
WV	Charleston	13.7	13.0	12.1	11.4	12.5	13.3	14.1	14.3	14.0	13.6	13.0	13.5
WY	Cheyenne	10.2	10.4	10.7	10.4	10.8	10.5	9.9	9.9	9.7	9.7	10.6	10.6

[a]EMC values were determined from the average of 30 or more years of relative humidity and temperature data available from the National Climatic Data Center of the National Oceanic and Atmospheric Administration.

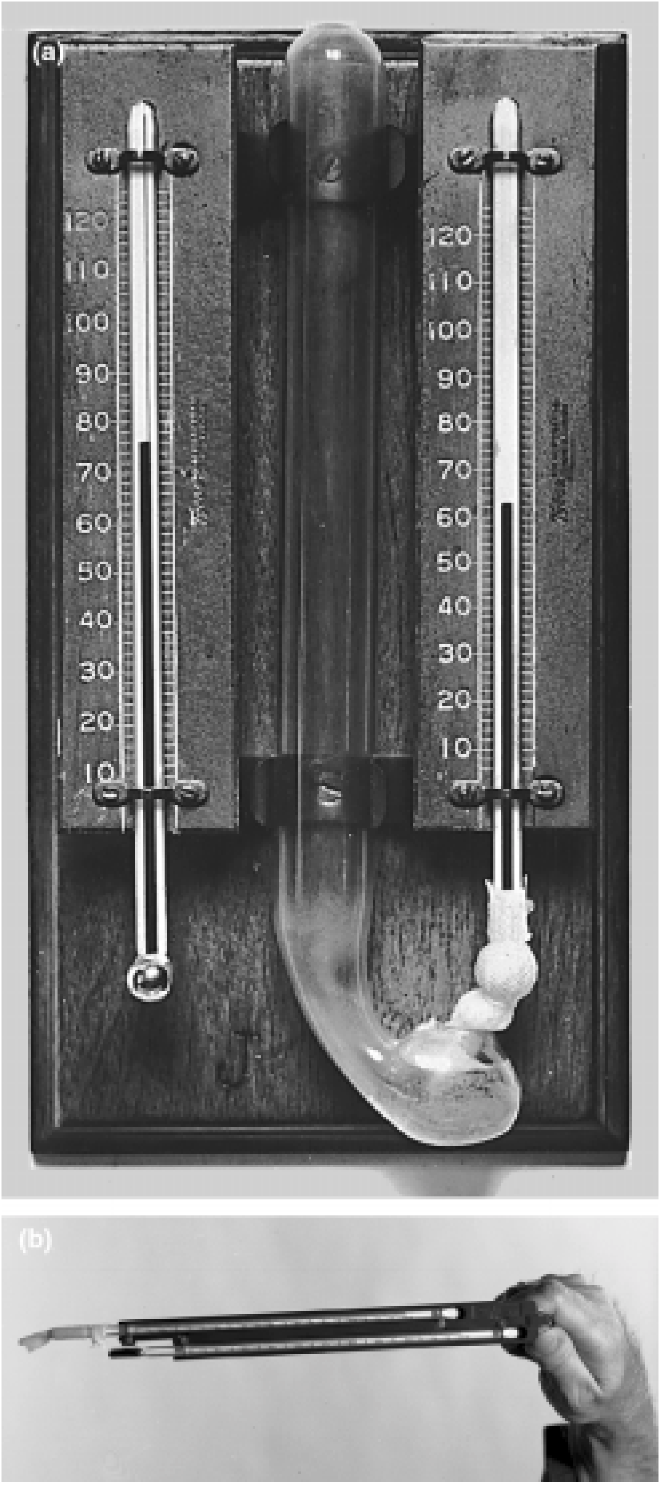

Figure 18—(a) Stationary dry- and wet-bulb thermometers indicating 24°C (75°F) dry-bulb and 17°C (63°F) wet-bulb, for a relative humidity of 66% and EMC of 12.0% (Table 3). (b) A sling psychrometer to enhance air velocity over the wet-bulb wick for greater accuracy.

A flatsawn (or plainsawn) board (Fig. 20) shrinks tangentially in width and radially in thickness. A quartersawn (or vertical grain) board (Fig. 20) shrinks radially in width, tangentially in thickness. Table 5 gives tangential and radial shrinkage values for the wood of many species. The longitudinal shrinkage of wood is generally slight, 0.1% to 0.2% of the green dimension. If reaction wood and juvenile wood are in the board, the longitudinal shrinkage may be appreciably increased.

The values in Table 5 can be converted into dimensional changes by using the following formula:

$$S = \frac{(M_{\mathrm{I}} - M_{\mathrm{F}})D}{\left(\dfrac{30}{S_{\mathrm{T}} \text{ or } S_{\mathrm{R}}} - 30\right) + M_{\mathrm{I}}}$$

where S is shrinkage or swelling (mm, in., or any linear unit); M_{I} is initial moisture content (%); M_{F} is final moisture content (%); D is dimension at initial moisture content (linear units); 30 is fiber saturation point (%); S_{T} and S_{R} are tangential and radial shrinkage divided by 100. Neither the initial nor the final moisture content can be greater than 30%. Examples using this formula to determine dimensional changes are given in the following:

Example 1: Determine the shrinkage in width of a 152-mm (6-in.), flatsawn, sugar maple board in drying from the green condition to a moisture content of 15%. The average green moisture content of sugar maple, sapwood and heartwood combined, is about 69% (Table 1). This board is flat grained; therefore, use a total tangential shrinkage value of 9.9% (Table 5). Substituting in the formula:

$$S = \frac{(30-15)152}{\left(\dfrac{30}{0.099} - 30\right) + 30} = \frac{2280}{303} = 7.5 \text{ mm}$$

$$S = \frac{(30-15)6}{\left(\dfrac{30}{0.099} - 30\right) + 30} = \frac{90}{303} = 0.30 \text{ in.}$$

Example 2: Determine the shrinkage in width of a vertical grained, old-growth redwood board, 8.5 in. (216 mm) wide, in drying from a moisture content of 24% to 5%. Table 5 gives the radial shrinkage of redwood as 2.6%.

$$S = \frac{(24-5)216}{\left(\dfrac{30}{0.026} - 30\right) + 24} = \frac{4104}{1147.8} = 3.6 \text{ mm}$$

$$S = \frac{(24-5)8.5}{\left(\dfrac{30}{0.026} - 30\right) + 24} = \frac{161.5}{1147.8} = 0.14 \text{ in.}$$

Table 4—Relative humidity[a] and equilibrium moisture content[b] at various dry-bulb and wet-bulb temperatures

Dry bulb temperature	Wet-bulb depression																																				
	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.6	11.1	11.7	12.2	12.2	13.3	13.9	14.4	15.0	15.6	16.1	16.7	17.8	18.9	20.0	21.1	22.2	25.0	27.8 °C
(°F (°C))	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	49	45	50 °F
30 (–1.1)	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 (1.7)	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 (4.4)	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 (7.2)	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 (10.0)	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 (12.8)	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 (21.2)	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	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	2.3	1.3	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
65 (18.3)	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	8	6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	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	3.8	3.0	2.3	1.4	0.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70 (21.1)	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3	—	—	—	—	—	—	—	—	—	—	—	—
	—	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	4.9	4.3	3.7	2.9	2.3	1.5	0.7	—	—	—	—	—	—	—	—	—	—	—	—
75 (25.9)	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	21	18	15	12	10	7	4	1	—	—	—	—	—	—	—	—	—
	—	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	5.6	5.1	4.7	4.1	3.5	2.9	2.3	1.7	0.9	0.2	—	—	—	—	—	—	—	—	—
80 (26.7)	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	—	—	—	—	—	—	—
	—	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	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 (29.9)	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38	36	33	30	28	25	23	20	18	15	13	11	9	4	—	—	—	—	—	—
	—	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	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 (32.2)	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	—	—	—	—
	—	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	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 (35.0)	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	—	—	—
	—	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	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	—	—	—
100 (37.8)	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	—	—
	—	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	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 (40.6)	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	—	—
	—	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	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 (43.3)	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	—
	—	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	81	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 (46.1)	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	—	21.4	19.0	17.5	16.2	15.1	14.1	13.4	12.7	12.1	11.5	0.9	10.4	10.0	9.6	9.3	8.9	8.6	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 (48.9)	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	—	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	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

[a]Relative humidity values not italic (first row).
[b]Equilibrium moisture content values italic (second row).

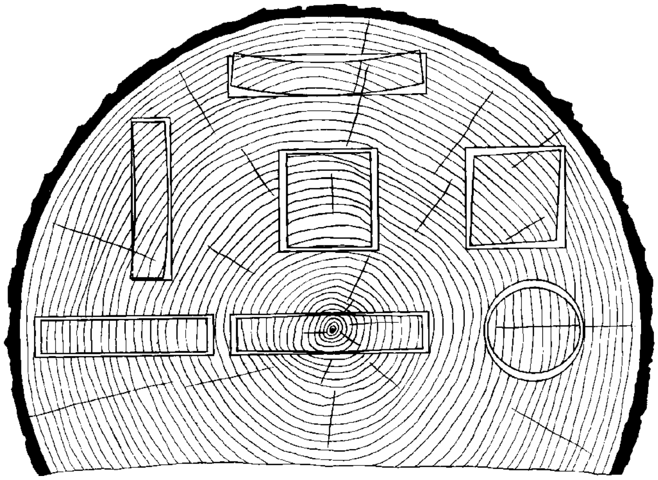

Figure 19—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of annual growth rings.

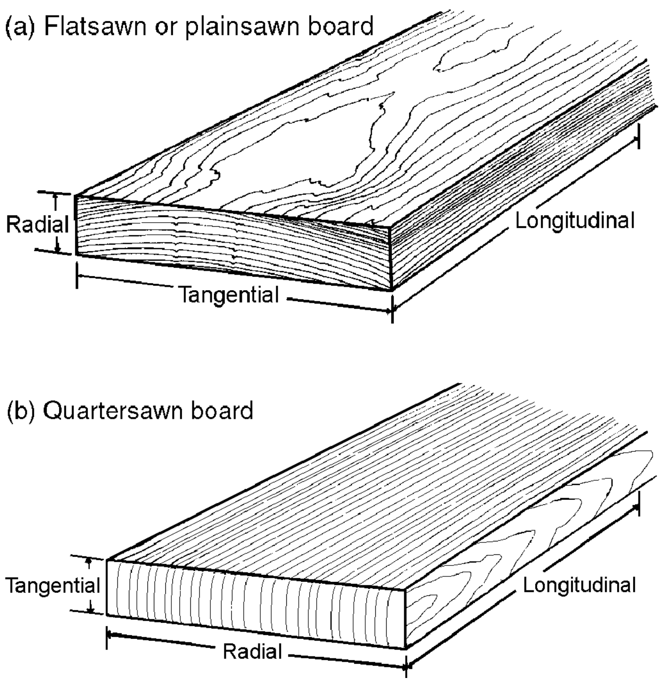

Figure 20—Shrinkage direction in (a) flatsawn (plainsawn) and (b) quartersawn (vertical grain) boards.

Example 3: Determine the swelling in width of a flatsawn, sugar maple flooring strip machined to 57 mm (2.25 in.), in changing from 5% to 13% moisture content.

$$S = \frac{(5-13)57}{\left(\frac{30}{0.099}-30\right)+5} = \frac{-456}{278} = -1.6 \text{ mm}$$

$$S = \frac{(5-13)2.25}{\left(\frac{30}{0.099}-30\right)+5} = \frac{-18.0}{278} = -0.065 \text{ in.}$$

The negative shrinkage obtained denotes swelling. Using the swelling of 1.644 mm per 57.15 mm (0.0647 in. per 2.25 in). of width, a 12.2-m- (40-ft-) wide floor will swell

$$\frac{1.644}{57.15}\times 12.2\times 1000 = 351 \text{ mm}$$

$$\frac{0.0647}{2.25}\times 40\times 12 = 13.8 \text{ in.}$$

Weight

The weight of lumber decreases as its moisture content is reduced. One benefit of air drying is a reduction in shipping weight. All wood substance, containing no air spaces and regardless of the species from which it comes, has an ovendry specific gravity of approximately 1.54. This means that 0.0283 m^3 (1 ft^3) of ovendry wood substance weighs 1.54 times the weight of 0.0283 m^3 (1 ft^3) of water, or 28.4 ×1.54 = 43.7 kg (62.5 × 1.54 = 96.3 lb). Usually, the specific gravity of wood is based on the volume of the wood when green and its weight when ovendry. Thus, if the specific gravity of a specimen of green wood is listed as being 0.5, the ovendry weight of the wood substance in 0.0283 m^3 (1 ft^3) of green wood is half the weight of a cubic foot of water, or 14 kg (31.3 lb).

The differences in specific gravity between species are due to differences in the size of the cells and the thickness of the cell walls. The average specific gravity, based on ovendry weight and green volume of commercial woods, varies from 0.31 for western red cedar and black cottonwood to 0.64 for the hickories, and can be as high as 1.1 for some tropical species. The moisture in the wood adds to the weight of a given volume. Most species of wood, even when green, float in water because of air entrapped in the cells.

Table 6 gives the specific gravity and lumber weight of commercial species per 2.36 m^3 (1,000 board feet) at a moisture content of 25%.

Color

The sapwood of most species is light colored and ranges in color from white to yellowish white. The heartwood of most species is distinctly darker than the sapwood. Considerable variation exists in the heartwood color of various species. The colors are generally a combination of yellow, brown, and red. Sometimes a greenish or purplish tint is present. The color of wood exposed to air and light becomes duller and darker. In air-drying yards, wood also becomes discolored by ultraviolet degradation, wetting, and airborne dust. These naturally caused surface discolorations do not penetrate far into the wood, except into surface checks, and can be removed by planing the wood.

Table 5—Shrinkage values of domestic woods[a]

Species	Shrinkage[a] (%) from green to ovendry moisture content		Species	Shrinkage[a] (%) from green to ovendry moisture content	
	Radial	Tangential		Radial	Tangential
Hardwoods			**Softwoods**		
Alder, red	4.4	7.3	Baldcypress	3.8	6.2
Ash			Cedar		
Black	5.0	7.8	Alaska	2.8	6.0
Green	4.6	7.1	Atlantic white	2.9	5.4
White	4.9	7.8	Eastern redcedar	3.1	4.7
Aspen			Incense	3.3	5.2
Bigtooth	3.3	7.9	Northern white	2.2	4.9
Quaking	3.5	6.7	Port-Orford	4.6	6.9
Basswood, American	6.6	9.3	Western redcedar	2.4	5.0
Beech, American	5.5	11.9	Douglas-fir		
Birch			Coast[b]	4.8	7.6
Paper	6.3	8.6	Interior north[b]	3.8	6.9
Sweet	6.5	9.0	Interior west[b]	4.8	7.5
Yellow	7.3	9.5	Fir		
Butternut	3.4	6.4	Balsam	2.9	6.9
Cherry, black	3.7	7.1	California red	4.5	7.9
Cottonwood			Grand	3.4	7.5
Black	3.6	8.6	Noble	4.3	8.3
Eastern	3.9	9.2	Pacific silver	4.4	9.2
Elm			Subalpine	2.6	7.4
American	4.2	9.5	White	3.3	7.0
Rock	4.8	8.1	Hemlock		
Hackberry	4.8	8.9	Eastern	3.0	6.8
Hickory	7.4	11.4	Western	4.2	7.8
Magnolia, southern	5.4	6.6	Larch, western	4.5	9.1
Maple			Pine		
Bigleaf	3.7	7.1	Eastern pine	2.1	6.1
Red	4.0	8.2	Jack	3.7	6.6
Silver	3.0	7.2	Lodgepole	4.3	6.7
Sugar	4.8	9.9	Ponderosa	3.9	6.2
Oak			Pine		
Northern red	4.0	8.6	Red	3.8	7.2
Northern white	5.6	10.5	Southern		
Southern red	4.7	11.3	Loblolly	4.8	7.4
Southern white (chestnut)	5.3	10.8	Longleaf	5.1	7.5
Pecan	4.9	8.9	Shortleaf	4.6	7.7
Sweetgum	5.3	10.2	Slash	5.4	7.6
Sycamore, American	5.0	8.4	Sugar	2.9	5.6
Tanoak	4.9	11.7	Western white	4.1	7.4
Tupelo			Redwood		
Black	5.1	8.7	Old growth	2.6	4.4
Water	4.2	7.6	Young growth	2.2	4.9
Walnut, black	5.5	7.8	Spruce		
Willow, black	3.3	8.7	Engelmann	3.8	7.1
Yellow-poplar	4.6	8.2	Red	3.8	7.8
			Sitka	4.3	7.5
			White	4.7	8.2

[a]Expressed as a percentage of the green dimension.

Table 6—Average specific gravity and approximate weight of 2.36 m^3 (1,000 board feet) of various species of lumber at 25% moisture content

Species	Average specific gravity[a]	Average weight of 2.36 m^3 (1,000 board feet) (kg	(lb))	Species	Average specific gravity[a]	Average weight of 2.36 m^3 (1,000 board feet) (kg	(lb))
Hardwoods				**Softwoods**			
Alder, red	0.37	1,114	(2,456)	Baldcypress	0.42	1,260	(2,778)
Ash				Cedar			
Black	0.45	1,361	(3,001)	Alaska	0.42	1,257	(2,772)
Green	0.53	1,595	(3,518)	Atlantic white	0.31	927	(2,045)
White	0.55	1,658	(3,656)	Eastern redcedar	0.44	1,315	(2,899)
Aspen				Incense	0.35	1,045	(2,305)
Bigtooth	0.38	1,083	(2,387)	Northern white	0.29	865	(1,908)
Quaking	0.35	1,053	(2,321)	Port-Orford	0.40	1,169	(2,578)
Basswood, American	0.32	972	(2,143)	Western redcedar	0.31	925	(2,039)
Beech, American	0.56	1,700	(3,748)	Douglas-fir			
Birch				Coast[b]	0.45	1,355	(2,987)
Paper	0.48	1,458	(3,216)	Interior north[b]	0.45	1,351	(2,978)
Sweet	0.60	1,816	(4,005)	Interior west[b]	0.46	1,383	(3,050)
Yellow	0.55	1,668	(3,678)	Fir			
Butternut	0.36	1,081	(2,383)	Balsam	0.34	991	(2,186)
Cherry, black	0.47	1,413	(3,115)	California red	0.36	1,081	(2,384)
Cottonwood				Grand	0.35	1,051	(2,317)
Black	0.31	934	(2,059)	Noble	0.37	1,114	(2,456)
Eastern	0.37	1,111	(2,450)	Pacific silver	0.40	1,206	(2,659)
Elm				Subalpine	0.31	929	(2,048)
American	0.46	1,390	(3,065)	White	0.37	1,109	(2,445)
Rock	0.57	1,723	(3,799)	Hemlock			
Hackberry	0.49	1,478	(3,260)	Eastern	0.38	1,138	(2,510)
Hickory	0.64	1,944	(4,287)	Western	0.42	1,265	(2,788)
Maple				Larch, western	0.48	1,448	(3,194)
Bigleaf	0.44	1,322	(2,916)	Pine			
Red	0.49	1,475	(3,253)	Eastern white	0.34	1,016	(2,241)
Silver	0.44	1,324	(2,919)	Lodgepole	0.38	1,142	(2,518)
Sugar	0.56	1,692	(3,732)	Ponderosa	0.38	1,138	(2,510)
Oak				Red	0.41	1,232	(2,716)
Northern red	0.56	1,689	(3,725)	Southern			
Northern white	0.60	1,818	(4,008)	Loblolly	0.47	1,414	(3,118)
Southern red	0.52	1,575	(3,472)	Longleaf	0.54	1,625	(3,583)
Southern white (chestnut)	0.57	1,818	(4,009)	Shortleaf	0.46	1,414	(3,118)
Pecan	0.60	1,809	(3,990)	Sugar	0.35	1,015	(2,239)
Sweetgum	0.46	1,393	(3,071)	Western white	0.36	1,052	(2,320)
Sycamore, American	0.46	1,388	(3,061)	Redwood			
Tanoak	0.56	1,760	(3,881)	Old growth	0.38	1,133	(2,498)
Tupelo				Young growth	0.33	1,014	(2,236)
Black	0.46	1,390	(3,064)	Spruce			
Water	0.46	1,385	(3,053)	Engelmann	0.32	990	(2,184)
Walnut, black	0.51	1,536	(3,387)	Red	0.38	1,112	(2,453)
Willow, black	0.34	1,086	(2,395)	Sitka	0.37	1,112	(2,451)
Yellow-poplar	0.40	1,204	(2,655)				

[a]Based on weight when ovendried and green volume.

Chapter 3

Air-Drying Process

The air drying of lumber involves exposing piles of stickered lumber to the outdoor air. The dry-bulb temperature of the air, its relative humidity as indicated by the wet-bulb depression, and the rate of air circulation are important factors in successful air drying. Lumber in the pile dries most rapidly when the temperature is high, the wet-bulb depression is large, and air movement is brisk through the stickered layers of lumber. The drying rate and the minimum moisture content attainable at any time in any place depend almost entirely on the weather. Therefore, air drying of lumber cannot be a closely controlled drying process.

Utilizing Air Movement

Green lumber dries because air conducts heat to the wood surface and carries away the evaporated moisture. Thus, the air must move within and through the lumber in the pile. As warm, dry air enters the lumber pile, it takes up moisture from the wood and the air temperature decreases. As the cool, damp air leaves the pile, fresh air enters and drying continues. The way air moves within a lumber pile depends on the construction of the pile, its location within the yard, and the yard layout and arrangement.

Boards are usually placed as close to edge-to-edge as possible in each course of a package, and there is limited opportunity for the air to drop downward through the package as it cools and becomes heavier. Consequently, the air must move laterally across the boards. A downward movement of air can be encouraged in lumber piles by building vertical flues, chimneys, or spacing boards within the pile (Fig. 21). Air enters the pile near the top or from the sides, passes over the broad faces of the boards, cools, and drops downward through the pile openings. A high and open pile foundation permits the moist air to pass out readily from beneath the pile and promotes the general downward movement of air. Chimneys are not necessary in kiln drying and are not commonly used when packages go directly from the air-drying yard to the kiln without restacking.

Boards in the upper parts of a pile dry quicker than do those in the lower parts because the top boards are more exposed to wind than are the lower boards. The air near the surface of the ground and the bottom of the pile is generally cooler and consequently has a higher relative humidity than the air near the top of the pile. This cool, moist air entering the sides of the lumber pile in the lower portions will not induce as rapid drying as will the hotter, drier air entering the upper parts of the lumber pile.

Factors That Influence Drying Rate

The rate at which green lumber will dry after it is placed in the air-drying yard depends on factors that involve the wood itself, the pile, the yard, and climatic conditions.

Species

Some woods dry quickly, others slowly. Softwoods and some lightweight hardwoods dry rapidly under favorable air-drying conditions. The heavier hardwoods require longer drying periods to reach the desired average moisture content. Specific gravity is a physical property of wood that can guide estimations of drying rates or overall drying time. Southern Pine will dry much faster in the yard than will southern oak. In contrast, the lower density hardwoods like willow, yellow poplar, and some of the gums will dry quickly. Sugar maple will usually dry faster in northern yards than will northern red oak. However, both species have about the same specific gravity.

Thickness

One common rule of thumb is that drying time increases at a rate of approximately the thickness raised to the 1.5 power. This means that 50-mm- (2-in.-) thick lumber will require about three times longer to lose a given amount of moisture than will 25-mm- (1-in.-) thick lumber.

Grain Patterns

Quartersawn lumber dries more slowly than does flatsawn lumber. Wood rays aid the movement of moisture, and in quartersawn lumber, few wood rays are exposed on the broad surfaces of the boards.

Sapwood and Heartwood

In softwoods, the moisture content of sapwood is usually much greater than that of the heartwood (Table 1). However, sapwood air dries faster. Usually it will be just as dry as the heartwood, and perhaps drier, when the heartwood reaches

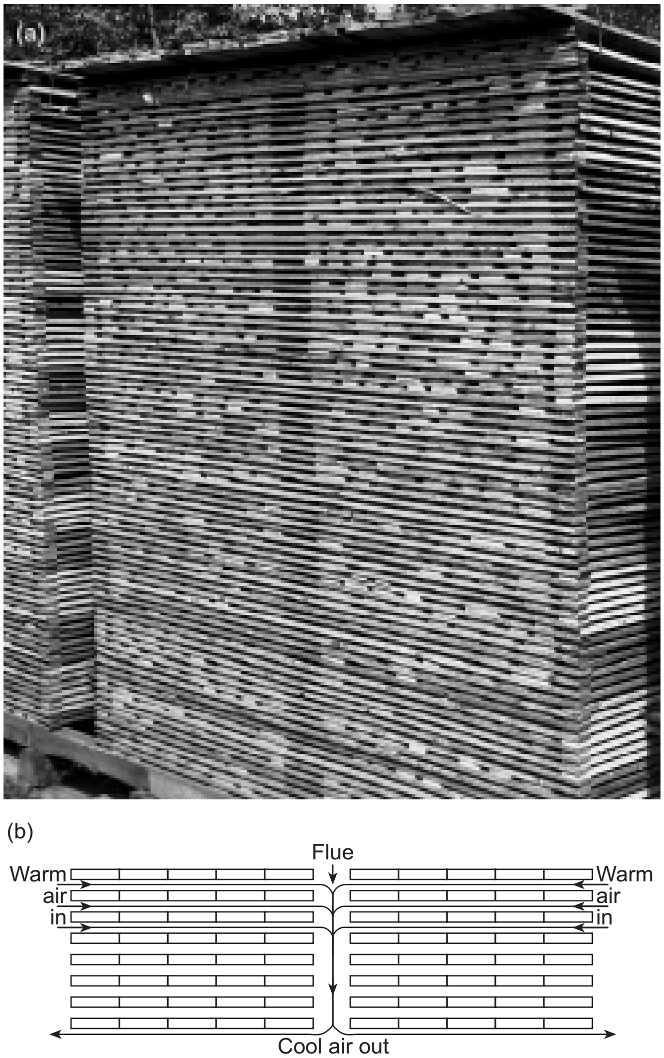

Figure 21—(a) Random width boards in this hand-built pile are spaced on each layer in addition to the chimney to aid circulation within the pile; (b) shows air flow through lumber pile and chimney.

the desired moisture content. In hardwoods, the sapwood moisture content is often not much greater than the heartwood and is generally lower when air drying is terminated.

Piling Methods

The drying rate of lumber is affected by the way the boards are stacked. For instance, lumber dries faster in air drying when air spaces are left between the boards of a package than when the boards are placed edge-to-edge. However, this is not true in forced air circulation such as a dry kiln. Chimneys built into packages promote better air flow through the lumber stack, thus speeding up drying.

The drying yard can be opened up for faster drying by spacing the piles farther apart. Placing piles on the outer fringes

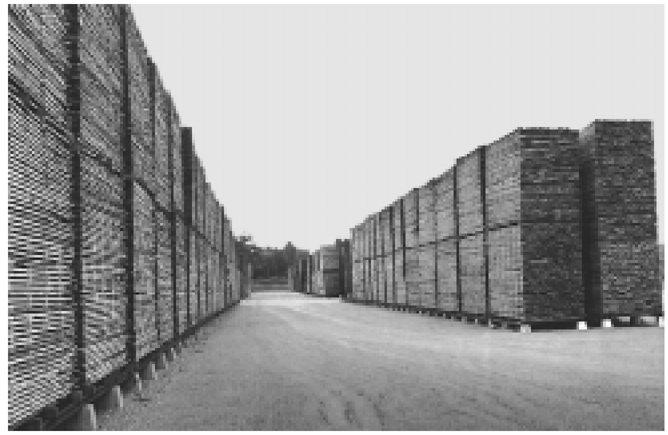

Figure 22—Well-graded and surfaced main alleys aid drainage and restrict growth of weeds.

of the yard will generally increase drying rate compared with piles placed in the central portion of the yard.

Height and Type of Pile Foundation

Although downward air circulation within a pile is created by natural convection, it is stimulated by winds carrying away the cool moisture laden air underneath the pile. The foundation under the pile should be reasonably high (460–610 mm; 18–24 in.) to allow the prevailing winds to create a brisk air movement under the piles. Pile foundations should not obstruct air flow, and weeds or other debris should not be allowed to block the air passage.

Yard Surface

The drying efficiency of a yard depends to some extent on how well the ground surface is graded, paved, and drained (Fig. 22). If water stands in a yard after a rain, it will decrease the drying rate and increase the risk of developing stain. The yard should also be kept clean. Vegetation and debris in the form of broken stickers, boards, or pieces of timber from pile foundations interfere with the movement of air over the ground surface. Vegetation, in particular, may prevent air from passing out from beneath the bottom of the piles and interfere with the circulation of air through the lower courses of lumber.

Climate

The climate of the region in which the air-drying yard is located can greatly influence the air-drying rate (Fig. 23). Perhaps the most influential factor is temperature, but relative humidity and rainfall are also important factors. In northern lumber-producing regions, the low temperature retards the drying rate during the winter months. In the southern part of the country, where the winter dry-bulb temperature is higher, better drying conditions are expected. Unfortunately, these higher temperatures may be offset,

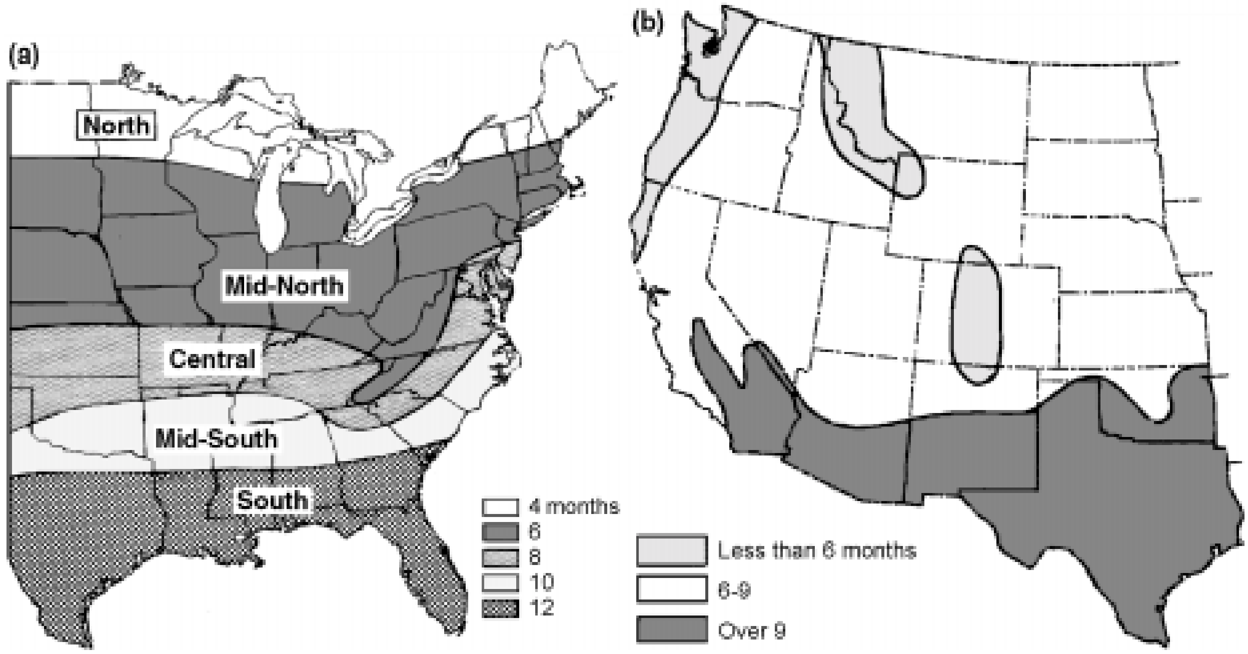

Figure 23—Eastern (a) and western (b) United States showing the length of good air-drying conditions each year. (Note: These maps are from different sources and do not agree exactly where they overlap.

for instance in the Southeast, by rains that wet the lumber and extend the drying time. In the Southwest, arid conditions can make it difficult to keep degrade losses within bounds.

Typically, the drying rate does not change a great deal from week to week, but in some areas hot, dry winds can accelerate drying. Periods of high relative humidity may retard drying. Precipitation is particularly important in air drying lumber. Rewetting of the drying lumber results in a significant decrease in the drying rate, and the added moisture must be evaporated.

In addition to the general climatic conditions for a region, local geographical features influence climatic conditions, thereby influencing air-drying results. Yard sites at low elevations, such as those near swamps or marshes or those bordering on bodies of water, are likely to be damper than surrounding areas. Such sites cause a decrease in drying rate and encourage the development of mold, stain, and decay. Elevated sites are more likely to be dry. Open sites, in contrast to those in valleys and those surrounded by tall trees, hills, or buildings, are conducive to rapid drying because of the greater movement of winds through them. Note that a high, dry site encourages rapid drying but may cause surface checking and end splitting in the lumber. Most importantly, yearly variation of the weather can create a significantly different drying rate compared with the expected average drying rate.

Sunshine is also a factor. Solar radiation heats the land areas, exposed areas of the lumber piles, and surrounding buildings. Air moving over these warmed areas and structures is heated and its drying potential increases. Black material absorbs more solar energy and becomes hotter than light-colored material. Thus, black topping the roadways and sometimes the entire area can be advantageous in air-drying yards.

Drying Time and Final Moisture Content

The time required to air dry lumber to a predetermined average moisture content depends not only on yard site, yard layout, piling methods, and climatic conditions, but on species, grain angle, and thickness. As previously mentioned, lumber of low specific gravity will dry faster than will the heavier woods. The approximate air-drying times for 25-mm (1-in.) softwood and hardwood lumber (Table 7) are based on climatic conditions for the region in which the particular species is cut. These data are based on experience with hand-stacked piles that vary in width from 2 to 5 m (6 to 16 ft).

Piles of lumber in packages, less than 2 m (6 ft wide), would presumably dry in shorter periods. The minimum period given applies to lumber piled during good drying weather, generally during spring and summer. Lumber piled too late in the period of good drying weather to reach 20% moisture content, or lumber that is piled during the fall or winter, usually will not reach a moisture content of 20% until the following spring. This accounts for the maximum periods given in Table 7. For example, 25-mm (1-in.) northern red oak is often air dried to an average moisture content of about

Table 7—Approximate time to air dry green 25-mm (1-in.) lumber to 20% moisture content

Species	Time (days)	Species	Time (days)
Hardwoods		**Softwoods**	
Alder, red	20 to 180	Baldcypress	100 to 300
Ash		Cedar[a]	
Black	60 to 200	Douglas-fir	
Green	60 to 200	Coast	20 to 200
White	60 to 200	Interior north	20 to 180
Aspen		Interior south	10 to 100
Bigtooth	50 to 150	Interior west	20 to 120
Quaking	50 to 150	Fir[a]	
Basswood, American	40 to 150	Hemlock	
Beech, American	70 to 200	Eastern	90 to 200
Birch		Western	60 to 200
Paper	40 to 200	Larch, western	60 to 120
Sweet	70 to 200	Pine	
Yellow	70 to 200	Eastern white	60 to 200
Butternut	60 to 200	Jack	40 to 200
Cherry, Black	70 to 200	Lodgepole	15 to 150
Cottonwood		Ponderosa	15 to 150
Black	60 to 150	Red	40 to 200
Eastern	50 to 150	Southern	
Elm		Loblolly	30 to 150
American	50 to 150	Longleaf	30 to 150
Rock	80 to 180	Shortleaf	30 to 150
Hackberry	30 to 150	Slash	30 to 150
Hickory	60 to 200	Sugar	
Magnolia, Southern	40 to 150	Light	15 to 90
Maple		Sinker	45 to 200
Bigleaf	60 to 180	Western white	15 to 150
Red	30 to 120	Redwood	
Silver	30 to 120	Light	60 to 185
Sugar	50 to 200	Sinker	200 to 365
Oak		Spruce	
Northern red	70 to 200	Engelmann	20 to 120
Northern white	80 to 250	Red	30 to 120
Southern red	100 to 300	Sitka	40 to 150
Southern white (chestnut)	120 to 320	White	30 to 120
Pecan	60 to 200		
Sweetgum			
Heartwood	70 to 300		
Sapwood	60 to 200		
Sycamore, American	30 to 150		
Tanoak	180 to 365		
Tupelo			
Black	70 to 200		
Water	70 to 200		
Walnut, black	70 to 200		
Willow, black	30 to 150		
Yellow-poplar	40 to 150		

[a]These species are usually kiln dried.

20% in southern Wisconsin in about 60 days when yarded in June or July. If piled in the late fall and winter, the stock must stay on sticks for 120 days or more. Local yard and weather conditions and yard layout should be considered as well as the seasonal weather pattern in estimating the time required for air drying. Table 8 gives the air-drying times of hardwood lumber in four regions of the United States. Drying time estimates are available for a few species in a few locations (Table 9), where the drying time is estimated for lumber stacked in each month of the year.

Deterioration of Lumber

Losses in lumber value resulting from degrade that develops during air drying are reflected in the overall cost of drying. Air-drying degrade may be caused by shrinkage, fungal infection, insect infestation, or chemical action. Shrinkage causes surface checking, end checking and splitting, honeycomb, and warp. Fungus infection causes blue or sap stain, mold, and decay. Insect infestation results in damage as a result of pith flecks, pinholes, and grub holes left in the wood. Chemical reactions cause brown stain, gray stain, and sticker marking. Ultraviolet radiation degrades the surface of lumber and causes it to turn gray. However, this discoloration is limited to a thin layer and can be planed off. If kept in the yard for an extended time, the lumber may appear excessively weathered because of an accumulation of sawdust and windborne dirt.

Table 8—Estimated time to air dry green 25- and 50-mm (1- and 2-in.) eastern hardwood lumber to approximately 20% average moisture content

		Estimated time by region (days)			
Species	Size (mm)	South	Mid-South	Central	Mid-North
Ash	25	45 to 70	45 to 75	45 to 80	60[a] to 165
	50	180 to 210	180 to 220	180 to 230	No data
Aspen	25	—	—	—	50[a] to 120
	50	—	—	—	No data
Basswood, American	25	40 to 65	40 to 70	40 to 75	40[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data
Beech, American	25	45 to 70	45 to 75	45 to 80	60[a] to 165
	50	180 to 210	180 to 220	180 to 230	No data
Birch, paper	25	—	—	—	40[a] to 120
	50	—	—	—	170 to 220
Birch, sweet; yellow	25	—	50 to 85	50 to 90	70[a] to 165
	50	—	190 to 240	190 to 250	No data
Butternut	25	—	40 to 70	40 to 75	60[a] to 165
	50	—	170 to 220	170 to 220	No data
Cherry	25	45 to 70	45 to 75	45 to 80	60[a] to 165
	50	180 to 210	180 to 220	180 to 230	No data
Cottonwood, eastern	25	40 to 65	40 to 70	40 to 75	50[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data
Elm, American; slippery	25	40 to 65	40 to 70	40 to 75	50[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data
Elm, rock; cedar; winged	25	50 to 80	50 to 85	50 to 90	80[a] to 150
	50	190 to 230	190 to 240	190 to 250	No data
Hackberry, sugarberry	25	40 to 65	40 to 70	40 to 75	30[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data
Hickory	25	50 to 80	50 to 95	50 to 90	60[a] to 165
	50	190 to 230	190 to 240	190 to 250	No data
Magnolia	25	40 to 75	—	—	—
	50	170 to 220	—	—	—
Maple, red; silver	25	40 to 65	40 to 70	40 to 75	30[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data
Maple, sugar; black	25	45 to 70	45 to 75	45 to 80	50[a] to 165
	50	180 to 210	180 to 220	180 to 230	No data
Oak, lowland	25	100[a] to 280	—	—	—
	50	No data	—	—	—
Oak, red (upland)	25	60 to 120	55 to 100	50 to 90	60[a] to 165
	50	240 to 360	215 to 300	190 to 250	No data
Oak, white (upland)	25	60 to 120	55 to 100	50 to 90	70[a] to 200
	50	240 to 360	215 to 300	190 to 250	No data
Pecan	25	60 to 120	65 to 100	50 to 90	60[a] to 165
	50	240 to 360	215 to 300	190 to 250	No data
Sweetgum, heartwood (red gum)	25	50 to 80	50 to 95	50 to 90	70[a] to 200
	50	190 to 230	180 to 240	190 to 250	No data
Sweetgum, sapwood (sap gum)	25	40 to 65	40 to 70	40 to 75	60[a] to 165
	50	170 to 200	170 to 210	170 to 220	No data
Sycamore	25	40 to 65	40 to 70	40 to 75	30[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data
Tupelo (and blackgum)	25	60 to 110	45 to 90	45 to 80	70[a] to 165
	50	210 to 300	180 to 220	180 to 230	No data
Walnut, black	25	45 to 70	45 to 75	45 to 80	70[a] to 165
	50	180 to 210	180 to 220	180 to 230	No data
Willow, black	25	30 to 65	35 to 70	40 to 75	30[a] to 120
	50	150 to 200	160 to 210	170 to 220	No data
Yellow-poplar	25	40 to 65	40 to 70	40 to 75	40[a] to 120
	50	170 to 200	170 to 210	170 to 220	No data

[a]To an average moisture content of 25%.

Table 9—Approximate days of air drying for lumber stacked in various locations at various times of the year to specified final moisture content

	Air drying time (days)												
Stack date	Northern red oak 25 mm (1 in) Madison, WI 20% MC	Northern red oak 25 mm (1 in) Roanoke, VA[a]	Hard maple 25 mm (1 in) Amasa, MI 20% MC	Beech 25 mm (1 in) Philadel-phia, PA 20% MC	Yellow poplar 25 mm (1 in) Roanoke, VA 20% MC	Ponderosa pine 25 mm (1 in) Flagstaff, AZ 15% MC	Ponderosa pine 38 mm (1 in) Snowflake, AZ 15% MC	Ponderosa pine 38 mm (1-1/2 in.) Flagstaff, AZ 15% MC	Ponderosa pine 50 mm (2 in.) Snowflake, AZ 15% MC	Sitka spruce 25 mm (1 in) Vancouver, BC 20% MC	Douglas-fir 25 mm (1 in) Everett, WA 20% MC	Douglas-fir 50 mm (2 in.) Everett, WA 20% MC	Western hemlock 25 mm (1 in) Vancouver, BC 20% MC
January	115										90	158	133
February	107										68	133	96
March	91										35	102	67
April	75	60 (21)	50	35	18	10	10	43	19	31	33	90	32
May	65	60 (21)	39	35	18	10	6	25	10	18	31	79	30
June	70	60 (20)	40	35	15	7	7	25	10	20	27	67	31
July	72	60 (21)	42	35	14	41	32	52	55	28	22	54	38
August	86	70 (25)	45	35	15	34	26	40	34	35	18	43	51
September	212	60 (28)	205	35	20	9	9	130	17	40	206	227	61
October	188	60 (30)	170	125	43	94	83	110	104	167	179	199	197
November	173	160 (22)	155	105	141	79	59	97	87	151	151	167	171
December	151	130 (22)	126	85	111	62	44	95	75	146	125	162	146

[a]Final moisture content in parentheses.

Chapter 4

Air-Drying Yard

The air-drying yard is generally located near the sawmill that produces the lumber or close to the factory that uses the wood for manufacturing finished products, and the yard is usually laid out for convenient transport. The main roadways or alleys of the air-drying yard are wide enough for the type of lumber handling equipment being used (Fig. 24). Most yarding operations build-up piles of lumber for air drying with prestacked packages handled by a forklift truck or other mechanized equipment. In some yards, piles have been built by hand, either from the ground level or elevated trams or docks.

Yard Layout and Orientation

An efficient yard layout should provide good drainage of rain and melting snow, free movement of air in and out of the yard, and easy transportation and piling of lumber. A yard laid out for rapid drying potential should be on high, well-drained ground with no obstructions to prevailing winds. However, the need to keep the yard close to the plant limits site selection, and convenient areas are not always favorable to rapidly air drying lumber and providing a minimum of degrade. Yard sites bounded by buildings or with standing water or streams nearby should be avoided because this retards lumber drying.

Figure 24—In an air-drying yard, the alleys must be wide enough to enable the forklift to travel down the roadway and maneuver the package onto the pile.

Most yards are laid out in a rectangular scheme. The alleys or roadways cross each other at right angles, and the areas occupied by the piles are rectangular. Specific areas may be designated for certain species, grades, or thicknesses of lumber. The alleys serve as routes for transporting the lumber, as pathways for the movement of air through the yard, and as protection against the spread of fire. The alleys in an air-drying yard are classified as main and cross alleys (Figs. 25, 26). Main alleys are for access to the lumber stacks and cross alleys are for access to the main alleys. In large air-drying yards, blocks or areas are often separated by still wider roadways or strips of land to protect the lumber from the spread of fire and to meet insurance requirements. These wide alleys are sometimes called fire alleys.

The sides of the lumber piles are parallel to the main alleys, which means air flows through the lumber stacks from one main alley to an adjacent main alley. Spaces between the sides and ends of the piles are also part of the yard layout. These spaces form additional passageways for air movement.

Yards can be oriented in either of two ways. The main alleys run north and south to obtain faster roadway drying after rain or faster snow melt. With this orientation, the roadways are exposed to solar radiation more than when the main alleys are oriented east and west, where the lumber piles shade the main alley roadways and retard roadway drying and snow melt. This orientation might be best suited for areas of high precipitation, especially snowfall. It is also desirable to orient the main alleys as close as possible to parallel with the prevailing winds. With this orientation, the wind can blow unimpeded through the main alleys. As a result of complex patterns of air velocities through adjacent main alleys, air pressure varies within, which causes air to flow through the lumber packages from one main alley to the next. If the prevailing winds are directly west–east, it is impossible to satisfy both the advantages of solar radiation and prevailing winds. However, there is often a north–south component to prevailing winds that does allow some air flow parallel to the main alleys. The problem with north–south main alley orientation and direct west–east winds is that drying from the first row of lumber stacks upwind increases the relative humidity of the air exiting that row, thus slowing the drying in rows

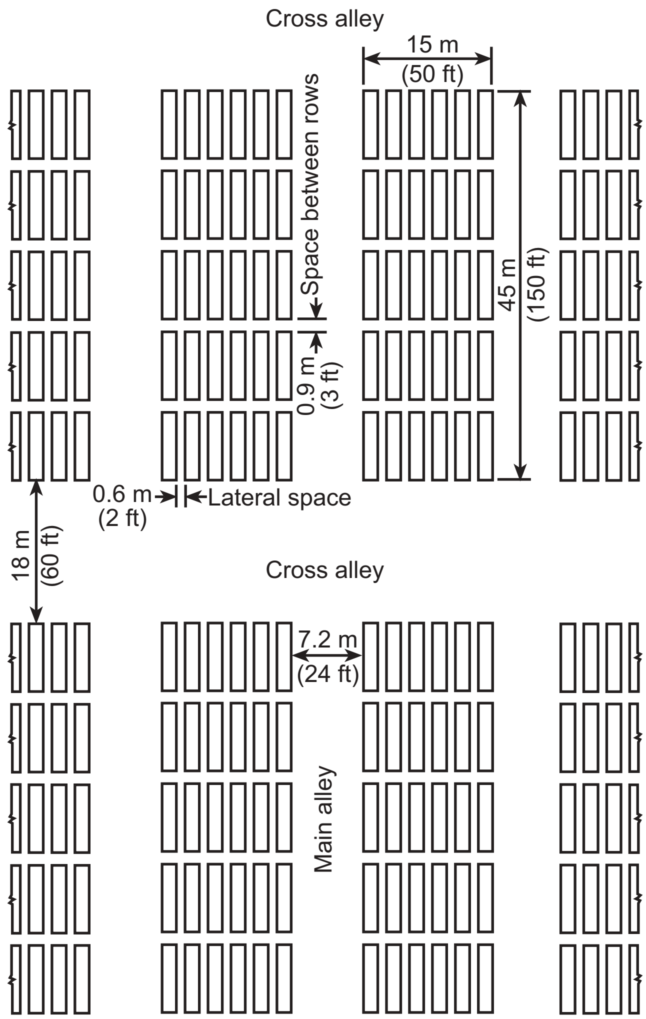

Figure 25—General arrangement of a row-type air-drying yard.

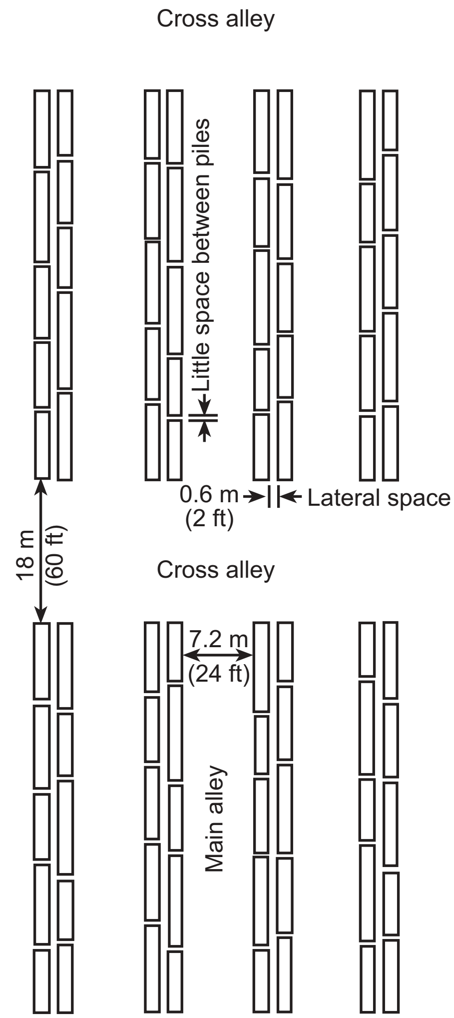

Figure 26—General arrangement of a line-type air-drying yard.

further downwind. This orientation also results in upwind rows blocking air flow to packages downwind.

Alley Size

Lumber piles are arranged either in rows of approximately six piles (Fig. 25) or in lines of two piles (Fig. 26). The line arrangement is used when the maximum air-drying rate is desired because air only has to flow through two piles rather than six as in the row arrangement. The main alleys are generally 7 to 9 m (24 to 30 ft) wide. Cross alleys intersect the main alleys at right angles and provide access to the main alleys. Cross alleys also afford protection against the spread of fire and may be 18 m (60 ft) or more in width and spaced every 61 or 91 m (200 or 300 ft). In addition to providing ample room for the forklift truck to maneuver in and out of the rows, alleys must be wide enough to allow clearance for the longest lumber being handled.

Row Spacing

Spaces between the ends of lumber piles aligned in rows should be large enough so that a lift truck can operate easily. The rows should be a minimum of about 1 m (3 ft) apart (Fig. 25). In a line-type yard, the spacing between lines is usually 0.6 m (2 ft).

Lateral Pile Spacing

The spacing between piles varies with differences in climate, yard site, and the character of the lumber. Pile spacing also varies with the different specific drying defects to be avoided. Where surface checking is the defect most likely to occur, the width of the spaces should be reduced. Where staining is likely to occur, it is desirable to increase the spacing. In arid regions, during the hot, dry season, piles should be placed closer together than they are during the cool, moist season. In a row-type yard, the space between the piles within the rows should be about 0.6 m (2 ft) but may be as much as 2.4 m (8 ft) in the middle of the row when variable spacing is practiced. The spaces between the ends of piles in a line-type yard are usually 0.3 to 0.6 m (1 to 2 ft). If the lift truck has a side shifter, the space can be minimized if air movement needs to be reduced.

Pile Width

For air drying, the width of the lumber pile varies from about 1 to 2.4 m (3-1/2 to 8 ft). Piles only 1 m (3-1/2 ft) wide usually consist of several packages of lumber that are to be placed on kiln trucks after air drying.

Pile Height

Pile height usually ranges from about 1.2 to 4.6 m (4 to 15 ft). Sometimes 9-m- (30-ft-) high piles are built using forklift trucks by stacking packages separated by bolsters. High piles of narrow packages are often tied together with long bolsters for stability.

Yard Transportation Methods

In a forklift yard, the unit packages are already stickered when they are carried out to the yard for piling. Bumping, jarring, and rough handling will displace stickers. The most practical remedial measure is to improve the roadways so that transport can be rapid without jolting the stickered package. Some companies have found it advantageous to blacktop the entire yard surface. Blacktop absorbs and stores solar radiation and acts as a moisture vapor barrier against ground water.

In yards where only the main and cross alleys are improved roadways, the initial arrangement of the rows of piles within blocks becomes permanent. The surface in the rows may be graded and graveled.

Pile Foundations

A pile foundation, or pile bottom, supports the lumber pile and provides clearance (Fig. 27) between the lumber and the ground. However, pile foundations must allow the air that has moved downward through the pile to be readily exhausted. Fixed pile foundations are an integral part of the yard layout, because they determine the location of the piles or rows or lines of piles. Pile foundations represent a considerable capital investment, and they should be well designed and made of materials that will contribute to a long life and low maintenance.

A pile foundation can consist of the following parts: mud sills or sleepers, posts or piers, stringers, and crossbeams (Fig. 28). Mud sills or sleepers rest on the surface of the ground or slightly below the surface and support the piers or posts. Wood mud sills should be pressure treated with a preservative or be of the heartwood of a decay-resistant species. When the entire surface of the yard is paved with concrete or blacktop, mud sills are unnecessary, and the posts or piers may rest directly on the pavement.

Figure 27—The main features of well-constructed pile foundations and lumber piles in an air-drying yard.

Posts or piers may be made from round or square pieces of wood, concrete, cement building blocks, or masonry. Square wood posts should be about 150 by 150 mm (6 by 6 in.) in cross section, and round wood posts should be 150 to 200 mm (6 to 8 in.) in diameter. Diagonal bracing may be fastened between the posts to prevent lateral tipping. When posts or piers are set in the ground, they should extend beneath the frost line and be supported by footings designed to carry the estimated load. This arrangement requires no bracing.

Cross beams may consist of wood timbers, steel angle irons, or old rails and must be aligned with the stickers. If they are made of wood, they should be 100 by 150 mm (4 by 6 in.) in dimension and placed on edge. Stringers and cross beams are not as susceptible to attack by decay fungi as are mud sills and posts. However, stringers can decay where they come in contact with the tops of the posts or with the cross beams. A thorough brush treatment with a wood preservative at these areas will reduce the decay hazard.

Pile foundations should not obstruct or block air movement in any direction. An arrangement that restricts air movement over the surface of the yard and from beneath the lumber pile, such as laying several long planks or timbers on top of one another to form foundations, is to be avoided. In this instance, air beneath the pile is permitted to move only in the direction parallel to the foundation timbers.

Forklift Yard

Pile foundations should be high enough to allow air drift under the bottom package. Foundations for piles in a forklift yard are usually level and often are movable or temporary. These foundations frequently consist of short timbers, 150 by 150 mm (6 by 6 in.) in dimension, placed directly upon the ground immediately before building the pile (Fig. 28).

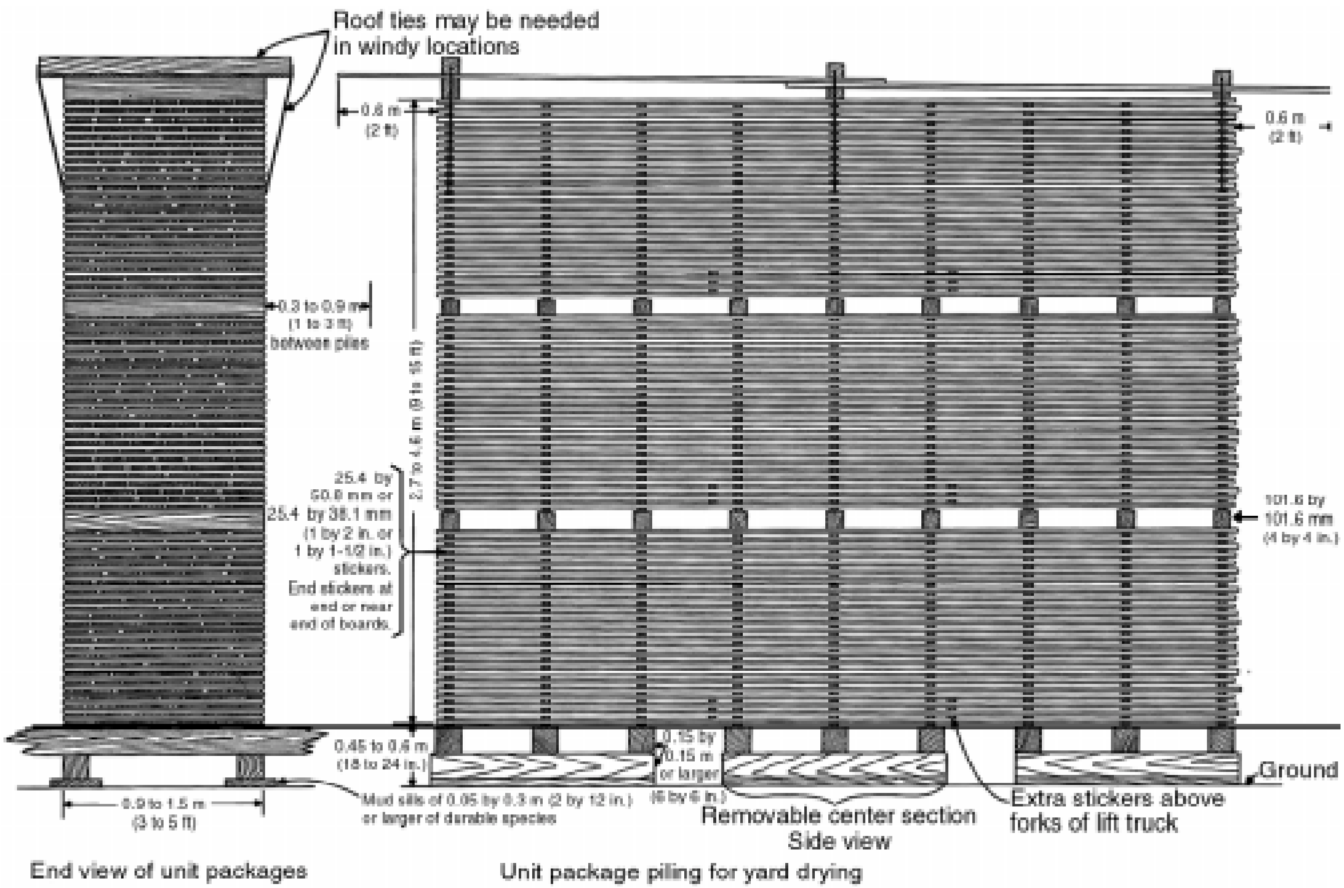

Figure 28—Features of a level pile of packages and the design of all wood movable foundations.

Sometimes 150- by 230-mm (6- by 9-in.) preservative-treated timbers are placed with the broad face on the ground. All timbers except the outer ones are moved aside when the forklift truck travels up and down the space for the row of piles.

Lumber Pile Protection

One disadvantage of yard air drying is exposing lumber to the weather. Exposure to direct sunshine and rain or melted snow causes alternate drying and absorption of moisture, which in turn causes checking and splitting. Roofs and covers of various types can protect lumber while it dries and reduce degrade and loss in value that will occur when exposed alternately to liquid water and sunshine.

Pile Roofs or Covers

An effective pile roof is an essential feature of a good air-drying practice. A roof protects the upper courses of lumber and, to a lesser extent, the lower parts of the pile from direct sunshine and precipitation. Without a roof, the lumber in the upper courses, and particularly the top course, will warp, check, and split. Rain or snow penetrating the pile may retard drying, contribute to the development of fungus stains and chemical sticker stain, and cause surface checks to increase in size.

To afford maximum protection, a roof should project beyond the ends and sides of the pile. For a level pile of packages, the roof should project about 0.3 m (1 ft) at both ends. The roof on a package does not usually project on the sides, because the roof would be in the way of the forklift. A sloped roof will permit the water to drain (Fig. 28).

Piles of lumber may be roofed with waterproof paper, building paper, or roll roofing laid directly on the top course of lumber and weighted. These materials may also be combined with boards to form a panel roof. A pile roof may consist of a single panel or a pair. A single panel is usually designed to slope from one end of the pile to the other. When two panels are used, they should overlap at the center. Paper or roofing felt provides water tightness, while the boards support the paper or roofing in a flat sheet and permit the panel roof to be anchored to the pile by clamps (Fig. 29) or other forms of tie-downs. The narrowness of package piles encourages the use of numerous materials in the design of pile roofs. Materials such as exterior grade plywood, or hardboard, may be used. Sheets of galvanized corrugated iron and corrugated aluminum are also satisfactory; several roofing materials are available. The choice of a suitable roofing material should be based on the cost and expected life of the material. Pile roofs can be reused many times, and their cost is small when

Figure 29—Loose sheets of corrugated metal are tied to the package with a "C" clamp. A sticker is laid across the top of the package on which the clamp is placed.

compared with the cost of lumber degrade that would occur if no pile covers were used.

Shade Cloth

Refractory woods, such as the oaks and beech, exposed to hot, dry winds may surface check badly. By baffling the air movement through the stickered lumber with shade cloth, the surface EMC conditions are modified enough to reduce surface checks and improve lumber brightness (Fig. 30). A shade cloth also prevents rain from blowing into the pile.

End Coatings

Moisture-resistant coatings should be applied to the end grain surfaces of green lumber to retard end drying and minimize the formation of end checks and end splits. The wood beneath the coating is maintained at a higher moisture content than if the coating were not used. To be effective, the coatings must be applied to the freshly trimmed green lumber before any checking has started.

Many kinds of end coatings are commercially available, but there are two basic types: those that are applied cold and those that are applied hot. Cold coatings are most widely used for lumber products. They are applied by swab, brush, or spray and are often wax emulsions. It is important to obtain a thick coating. If the end coating material is thinned for easier application, additional coatings may be necessary. The costs of an end coating and its application are often justified by the value of the lumber saved.

Figure 30—Shade cloth or any loose weave fabric can be used in air drying and shed drying to reduce degrade resulting from uncontrolled rapid drying and exposure to the sun and rewetting.

Shed Drying

Lumber, particularly the more valuable grades, is sometimes air dried in open sheds (Fig. 31). Drying sheds are usually pole-type structures, although other structural materials such as steel posts and metal trusses and roofing may be used. The air-drying shed has a permanent roof so that the lumber is not rewetted by rain. In areas or regions where rain wetting unduly extends the drying time in a conventional air-drying yard, shed drying reduces the time required to attain the desired moisture content and maintain quality.

Sheds are generally open so that the sides and ends do not obstruct air movement. Under certain conditions, shade cloth may be used to form walls. It keeps the lumber clean and reduces surface checking of refractory woods.

Shed-dried lumber is usually brighter in appearance than is lumber air dried in a yard because weathering from ultraviolet radiation or discoloration caused by rewetting is prevented (Fig. 32). The shed roof usually extends beyond the piles and protects the lumber from sunshine; therefore, end checking and splitting are also greatly reduced.

Drying sheds are usually loaded by forklift trucks. Pile foundation requirements are the same as for the forklift yard. The shed floor may or may not be paved. If not, grading may be required, depending upon soil conditions, and perhaps gravel or crushed stone application can be justified.

The drying shed can be fairly wide to make up long rows of piles within the bays. Entry to the rows would usually be from both ends of the rows or both sides of the shed. In contrast, the drying shed may be long and narrow with two lines similar to a line-type forklift yard.

Figure 31—Packages are protected from the sun and rewetting in this open drying shed.

Figure 32—The protection provided by a drying shed can be seen by comparing the air-dried (on top) with the shed-dried package (bottom).

Yard Operation and Maintenance

Supervision of an air-drying yard involves considerable responsibility and skill. The yard superintendent is often required to maintain existing yards while laying out new air-drying yards and expand or extend old ones. Site, orientation of main alleys, sizes of main and cross alleys, length of lines or rows, row and pile spacing within rows and lines, and size of blocks all require consideration for the inventory of lumber anticipated.

Roadways in an air-drying yard are often busy highways for several kinds of transport trucks. Grading, graveling, or crushed stone fill or paving are investments to maintain the brightness of the lumber and improve the mobility of wheeled equipment. Frequent inspections of road conditions are a responsibility of the yard superintendent. In northern areas, snow removal equipment is needed to keep the alleys open for yard traffic.

The design, installation, and repair of pile foundations also require considerable attention. Sagging foundations cause warped lumber and pile tipping.

Sometimes the yard superintendent is responsible for sorting and package stacking at the sawmill. Sorted length stacking or box piling involves decisions about sticker spacing and alignment. Hand-built piles may require use of a frame for sticker guides. Automatic or semiautomatic stacking equipment requires routine inspection and maintenance.

As a result of the large number of stickers required in drying, the total investment can be expensive. Therefore, investment in stickers justifies careful attention to their fabrication and storage. Dry storage of stickers is recommended to minimize infecting green lumber with stain and decay fungi. Excessive sticker breakage requires a determination of causes and corrective measures. Sticker replacement costs may justify salvage operations.

The design, fabrication, handling, and storage of pile roofs or covers and sun shields are a yarding operational task. Reduced degrade and footage losses can make pile protection pay off.

Weed control and preventing the accumulation of debris that creates fire hazards are other functions of yard operational supervision. Fire prevention policies and regulations must be formulated and routine inspections made for compliance.

Air drying is a moisture content reduction process; therefore, check tests with portable electric moisture meters every few weeks enable the yard supervisor to determine when lumber in certain blocks or areas in the yard is ready for removal. Yarding costs not only involve time in the yard but grade and volume losses, thus the yard supervisor should conduct degrade studies to determine how and where yarding practices should be changed to significantly reduce these losses.

Records of the lumber placed in an air-drying yard must be kept. An inventory tracking system best suited for the operation is essential. The location of lumber in the yard by species, thickness, grade, volume, and placement time must be readily available. Packages or hand-built piles should be ticketed to show date of piling, species, thickness, length, grade, and volume of the lumber; duplicates should be systematically filed in the yard supervisor’s office. Package or pile tickets are sometimes placed on a large panel in which the air-drying yard is outlined, showing where the lumber is located. Plants that use computerized cost accounting systems or automatic data processing equipment would probably also use this equipment for inventory control purposes.

Chapter 5

Piling Methods For Air Drying

To prepare lumber for air drying, it is usually laid up into courses or layers with separating stickers (Fig. 33). The objective is to expose the board surfaces throughout the pile to air circulation. The lumber packages are often made of lumber previously sorted by species, size, and grade.

Sorting Lumber

Lumber coming from the sawmill is generally sorted into classifications based on similar drying characteristics before it is sent to the stacker. Sorting facilitates the stacking operations.

Species

Although several softwoods and hardwoods have similar drying characteristics, the species sort is usually made for merchandising purposes. Those woods that dry rapidly without serious degrade can be yarded in areas where drying conditions are favorable. Species that dry slowly and are likely to surface check can be air dried in yard areas where drying conditions are less severe.

Thickness

The time required to air dry lumber to a predetermined moisture content is greatly influenced by board thickness. For example, 50-mm- (2-in.-) thick lumber may require about three times longer to dry than 25-mm- (1-in.-) thick lumber of the same species. Therefore, it is usual practice to segregate the rough sawn lumber by thickness classes for air drying. Miscut lumber is difficult to stack, and thinner parts of the board cannot be held flat. One thick board in a course may allow adjacent well-manufactured boards to warp because of lack of restraint. Presurfacing miscut lumber to a uniform thickness facilitates stacking and reduces warp, sticker breakage, and sticker deformation.

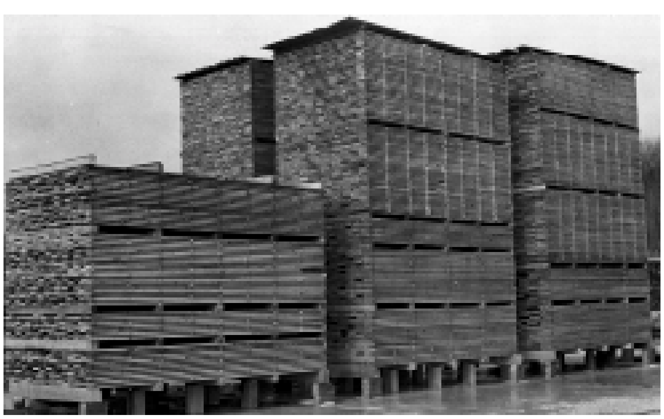

Figure 33—Good arrangement of stickers, foundations and piles, which allow for air flow through the stack.

Width

Some softwood lumber is sawn in the mill to produce certain final dry dressed sizes. These width classes are kept together for drying to reduce sorting and rehandling costs after drying. Hardwoods are most often sawn to random widths in the sawmill, and width segregation is seldom practical.

Length

Good package buildup by hand or mechanical stackers is best accomplished by sorted length stacking. The main objective is to gain as much restraint to distortion as possible and maintain uniform air flow by good stickering practices. The advantages of sorting for length apply to both softwoods and hardwoods.

Grain

A flatsawn board dries faster than a quartersawn board, and mills specializing in producing quartersawn lumber may find it advantageous to sort for this characteristic. Flatsawn lumber is more susceptible to surface checking than is quartersawn lumber and is often yarded in areas where the drying potential is less severe. When relatively few quartersawn boards are produced along with the major production of flatsawn boards, they are seldom segregated.

Grade

The separation of green lumber by grade is generally a matter of keeping like-value lumber together. Higher grades of lumber may be given better protection in the piles or may be shed dried.

Sorting Equipment

Several types of sorting equipment have been developed to segregate lumber into various classifications for air drying.

Conventional Green Chain

In conventional green chain, sawmill lumber items are separated into the predetermined sorts by pulling the pieces from a conveyor chain that carries the lumber out of the mill (Fig. 34). The lumber is bulk piled in units for transportation to the stacker by carrier, forklift truck, or transfer chains. Sometimes the lumber is stacked and stickered in bins alongside the green chain, particularly if the packages are small, such as those for forklift truck operation. Most often, however, the units on the green chain are solid-piled handling units that are transported elsewhere for stacking.

Edge Sorter

The edge sorter usually consists of a long continuous row of live rolls with a number of slots into which the operator feeds the boards for the various length, grade, and width combinations. An improved sorter, in which the number of slots is reduced, separates the lumber by 0.6- (2-ft) increments using electrical or mechanical devices. A two-slot edge sorter, for example, may have 25-mm (1-in.) lumber fed into one slot and 50-mm (2-in.) lumber put down on the other side with the boards electrically or mechanically separated into all length and width combinations. Lumber is manually stacked at the sorter or transported to a mechanical stacker. In manual operations, two people move as a team from bay to bay to remove the lumber from the bin and place it on the stack. Mechanization can also be provided; when a full package of lumber has been collected, an operator can empty the bay by pushing a button to activate the chains in the bottom of the bay. The lumber is automatically fed to a transfer belt that carries the stock to the stacker.

Pocket Drop Sorter

In the pocket drop sorter, lumber is transferred crosswise and carried on an overhead lug chain. The boards are dropped into dump buggies according to predetermined length, width, thickness, and grade. The dump buggies move on rails; full buggies are transferred to a buggy dumper that feeds a mechanical stacker.

The boards may also be dropped into slings (Fig. 35) rather than buggies. When a sling is full, the operator feeds the boards onto a transfer chain located under the slings. This transfer chain feeds the mechanical stacker.

One factor that limits sorting is the time required to accumulate enough of a particular item. If the sorting is carried too far, the lumber of each kind accumulates so slowly that it takes too long to complete a pile. Lumber in the lower parts may become quite dry before the pile is completed. This problem is generally more critical when lumber is stacked in hand-built piles, because the piles usually are wider and contain more lumber than do package piles. Consequently, it is possible to sort to a finer degree when lumber is made into packages and piled by forklift than by hand-built piles. In addition, piles of packages do not necessarily have to be composed of a single item. For example, three packages of a pile may all contain the same species and thickness but different grades.

Stacking Lumber in Packages

Packages are sometimes stacked by hand, using a crew of one or two people (Fig. 36). Packages are made up beside

Figure 34—Hardwood lumber is graded on a conventional green chain and sorted on trucks before being stacked or sent to the automated stacker.

Figure 35—Sling sorter for holding lumber prior to being sent to the stacker.

Figure 36—Lumber is sometimes manually stacked.

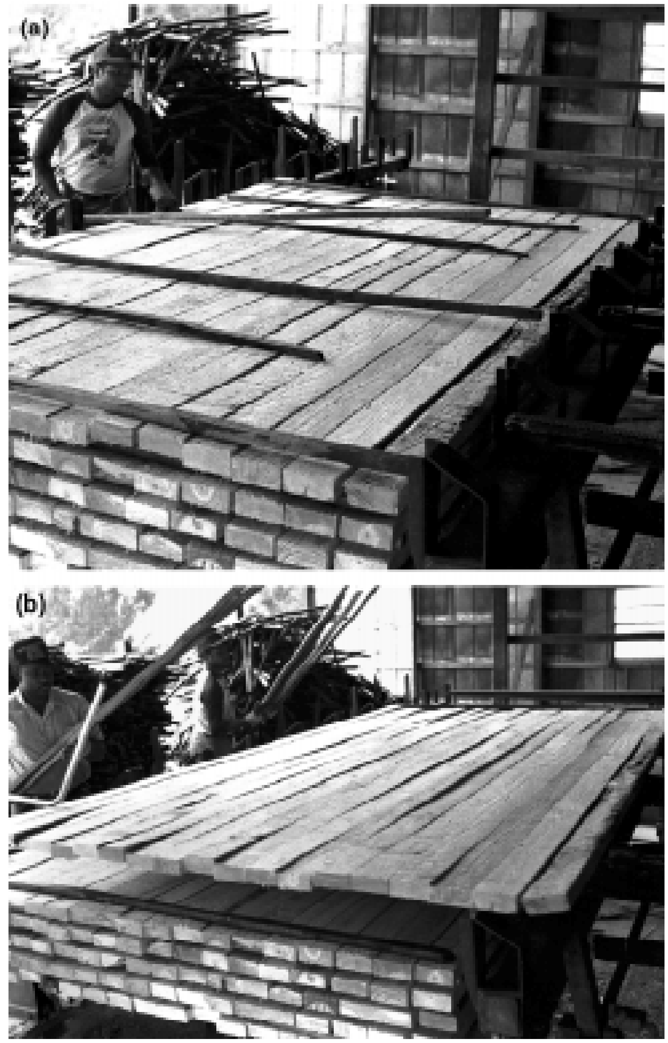

Figure 37—Semiautomatic stacker; (a) crews lay the stickers in place (b) at which time the stacker places a layer of lumber on the stickers.

the sorter or at a special stacking location to which the sorted lumber is delivered. Because the stacking of packages can be done at one place, in contrast to stacking lumber onto hand-built piles in the yard, a stacker building is often constructed to shelter the workers. The stacker operators stand on the ground or on a platform that is approximately at the same level as the bottom of the package of lumber. Because the stickered packages are seldom more than 1.2 m (4 ft) high, the whole package can be constructed without much lifting of the boards. The packages are usually built up on a stacking rack or jig equipped with sticker guides. The sorted lumber is delivered to the stackers in bulk units, which are placed alongside the stacker frame. The completed stickered package is lifted out of the sticker guide framework by forklift truck, transported to the yard, and placed on a designated pile.

When the volume of lumber being stacked for air drying is sufficient to justify their operation, automatic or semiautomatic stackers are sometimes installed. An automatic stacker is identified by the magazines that hold the stickers. The stickers are mechanically fed out the bottom of the magazine onto the lumber layers. A sticker magazine is located at each sticker tier, and the magazines are manually kept filled. The semiautomatic stacker lays up the courses of lumber onto the package, but the stickers are laid manually into sticker guides on both sides of the stacker frame (Fig. 37).

The lumber is transferred from the sorter as bulk units that are set on a conveyor, either roller or chain, which moves the unit to a breakdown hoist. The boards move from the breakdown hoist to an "unscrambler" where they are separated into a single layer and moved by conveyor to the stacker lay-up table. A grading and tally station might be located between the breakdown hoist and the stacker lay-up table.

When a course of lumber has been laid on the package by the stacker arms and the stickers laid automatically or manually, the package is lowered mechanically so that it is in a position to receive the next course. When the package is completely stacked, it is removed from the stacker and conveyed on rollers or chains to a station where a forklift truck can pick it up for transport to the air-drying yard.

Stacking Method

The stickered packages can be built up from length-sorted lumber, box piled (Fig. 38), or stacked with both ends ragged. Sorted length stacking is rapid, and with close sticker spacing and good sticker alignment, warp is restrained. Sticker tiers are at the ends of trimmed stock and uniformly spaced in between. In stacking untrimmed sorted lumber, one end of the package is made square at the bumper board end of the stacking stall or by the "even ender" on the automatic stacker. The sticker tier is at or very near the end. The other end of the package is ragged to the extent that the board

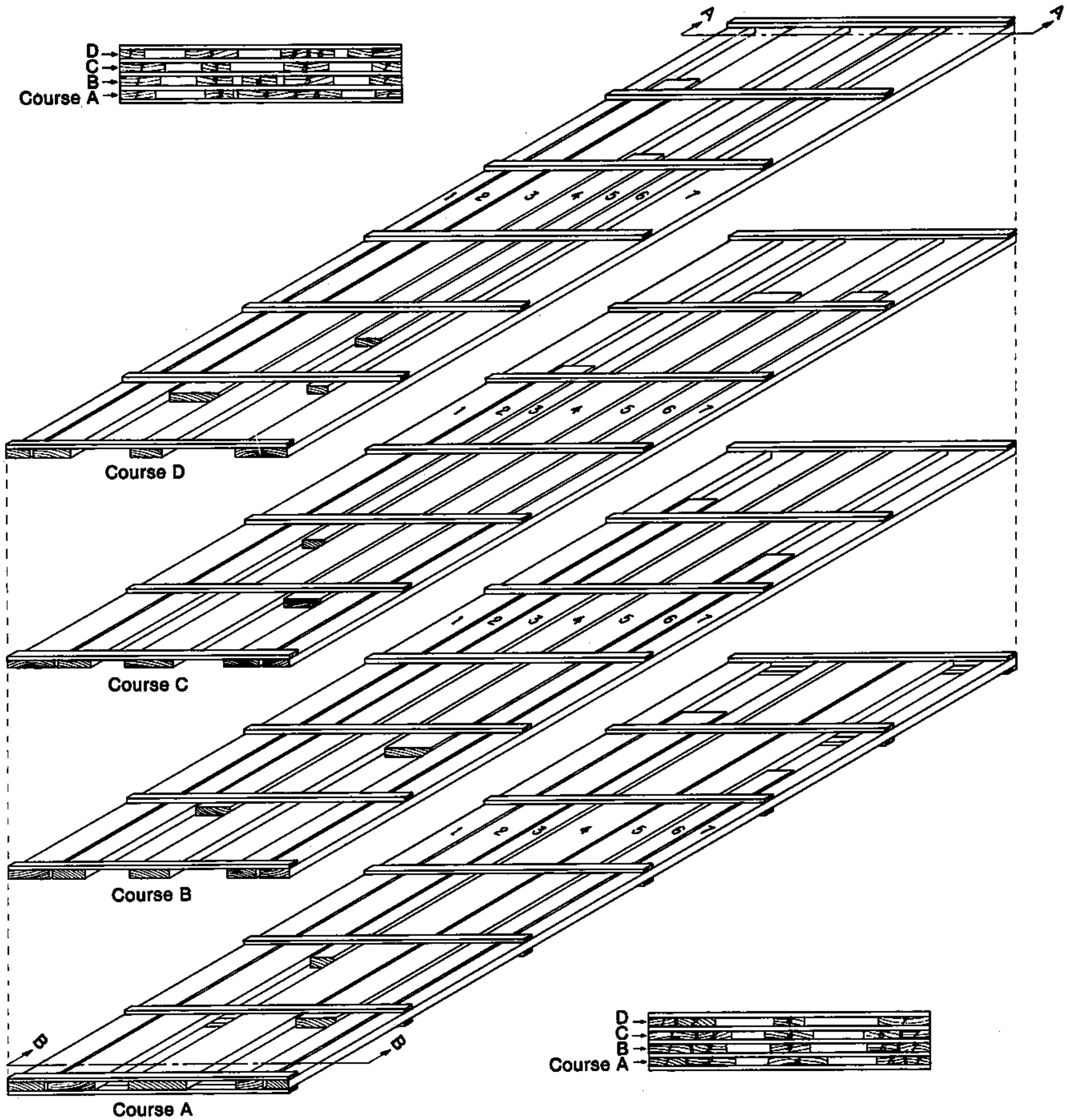

Figure 38—To improve the air flow through the stack of box-piled random length lumber, short boards are staggered in the center and full-length boards are placed on the edges.

length varies from the nominal length. The sticker tier is back far enough from this end to support most of the boards.

In box piling random length lumber, the long pieces are placed at the edges of the package and the shorter lengths are placed in between. By alternating the shorter boards from one end to the other, both ends of the package can be made square. Sticker tiers can be located so that most of the ends of the shorter boards are supported. Random length lumber can be box piled to produce unit packages with both ends square (Fig. 38) or with one end square and the other end ragged. Box-piled packages with a ragged end are difficult to transport without stickers being jolted out of alignment at the ragged end; therefore, the package should be built up with both ends square if possible. Bumper boards at both ends of the stacking stall can be used to produce square ends for both trimmed and untrimmed lumber. It is desirable to have long boards at the edges of each lumber layer. This may require manual replacement of boards on the lay-up table as the lumber moves toward the stacker.

Package Width and Board Spacing

The width of the stacked package is determined by the subsequent drying process and the load capacity of the forklift truck. Packages for yard drying only are likely to vary between 1.0 and 1.8 m (3 and 6 ft), with 1.2 m (4 ft) the most common width. When the lumber is ready to go from the yard to the dry kiln, the packages vary from 1.0 to 2.4 m (3-1/2 to 8 ft) wide, depending on the width of the kiln truckloads and whether the loads are to be one or two packages wide. The packages are usually 1.2 m (4 ft) wide for air drying when subsequent drying in package-loaded kilns is anticipated. Forklift trucks can handle packages up to 2.4 m (8 ft) wide, but package height is controlled to keep the total weight within the safe loading capacity of the machine.

The boards making up a course in a package may be stacked with or without spaces between them. Boards in packages that are 1.2 m (4 ft) or less in width are usually stacked edge to edge. There is generally one space in each course, because the sum of the board widths does not equal the exact width of the package. If the packages are to be placed later on kiln trucks or loaded into a package-loaded dry kiln, it is desirable that both sides of the package be square and plumb and that all courses have boards extending to the sides. This means that the space in the course should be within the course and not at the side. In mechanical stacking, this space is usually developed between the first two boards of a course that is laid down by the stacker arms. The people stickering or the stacker operator makes sure the first board is against the sticker guide frame.

If the packages are wider than 1.2 m (4 ft) and the species being stacked is relatively slow drying or inclined to blue stain, the boards on each course may be spaced to promote downward movement of air. The board spacing is generally about 25 mm (1 in.) but can be increased if the package needs to be “opened” up. In hand-stacking packages, the board spacing is done manually, but stackers acquire a skill in placing boards on the stickers as they lay up the course so that getting reasonably good board spacing is not a problem (Fig. 39). Some mechanical stackers can lay down the boards of a course with uniform spacing between boards. The equipment can be adjusted to make the board spacing larger or smaller. Wide unit packages for forklift yards are sometimes stacked with flues or chimneys.

Package Height

The height of the package or the number of layers in the package is determined by the thickness of the lumber being stacked, the thickness of the stickers being used, the loading or carrying capacity of the forklift truck or carrier, and the height of the kiln door. A standard height is 1.2 m (4 ft), and most forklift trucks can transport two packages, one above the other. Packages that are 1.8 to 2.4 m (6 to 8 ft) wide, when carried two packages high, may require lift truck equipment designed to carry the heavier loads.

Figure 39—Sticker guides are used to improve sticker alignment.

Pile Width and Height

Pile widths in a forklift yard are determined by the width of the package. Sometimes the air-drying pile of packages of softwoods is made two units wide with a relatively small space between the two tiers on the pile foundation. Pile height in a forklift yard depends upon the equipment used for placing packages in the pile. Piles of packages built up with forklift trucks are generally not more than about 4.6 m (15 ft) high and consist of four packages.

Use of Bolsters

Bolsters separate the packages to permit ready entrance and exit of the lift truck forks. The bolsters are usually 100- by 100-mm (4- by 4-in.) wood members and as long as the stickers. Bolster placement is critical as out-of-line bolsters between packages can cause warp (Fig. 40). The bolsters should be placed immediately above the tier of stickers of the bottom package in the pile. The packages on top should also be lined up so that the sticker tiers and all bolsters between packages are in vertical alignment. Thus, distortion or warp is restrained.

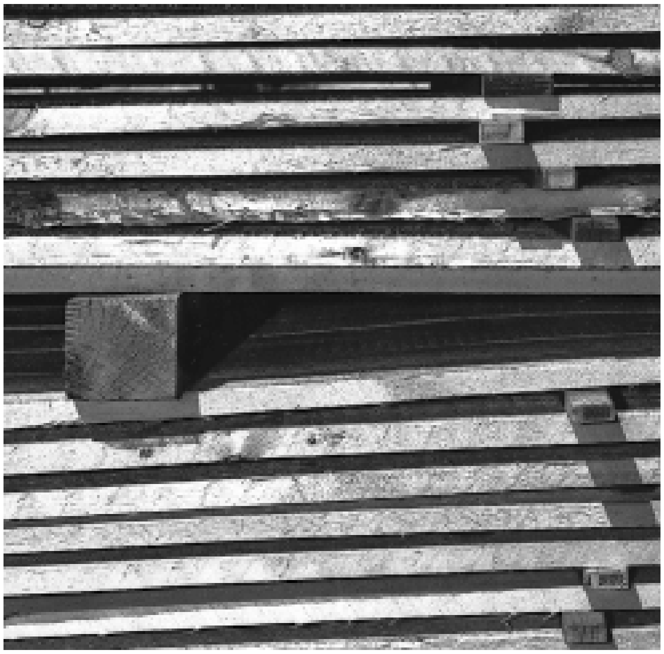

Figure 40—Improper bolster-sticker alignment will increase the defect of bow or warp.

A “side shifter” carriage on the forks of the lift truck aids in placing the packages so stickers are aligned with the bolster. Bolsters must still be carefully placed, and the lift truck operator must avoid jolting the bolsters out of place as the upper packages in the pile are moved into position. The bolsters are placed on the packages when the package is at ground level. Although bolsters between packages at every sticker tier would produce maximum influence of superimposed loading to restrain warp, it is not considered practical, and five bolsters are usually used on 4.9-m- (16-ft-) long lumber.

Both softwood and hardwood species are used for bolsters. Because they are generally used over and over again, bolsters should be a durable hardwood species that is being processed at the sawmill. Bolsters are generally rough sawn and are dried the first time out. When not in use, bolsters should be stored under cover and kept dry. Bolsters are usually not treated to prevent deterioration caused by stain, decay, and insects, yet should not infect or infest the green lumber on which they will be used.

Piling Modifications

The yarding arrangement of main alleys, cross alleys, rows, lines, and pile foundations within a row or line is generally well fixed. In completely paved yards with portable foundations, however, areas of the yard can be rearranged to either hasten or retard the drying rate. Even in line-type yards having fixed foundations, lumber might be piled in every other line when drying conditions are poor. An alternate practice would be to stagger the piles between the two foundations in the line. Yards with long rows between main alleys may have a foundation system that will permit changing pile spacing, increasing the spacing when drying weather is expected to be poor and reducing the pile spacing when the anticipated drying potential is good.

The makeup of the package is usually fixed as to size and method of course lay-up. But within a course, edge- to-edge stacking can be changed to spaced board stacking. Also, the spaces between boards can be increased or decreased as air-drying conditions warrant.

Stacking Random Length Lumber

Sloped and pitched hand-built piles of lumber are usually constructed of lumber sorted for length. If random length lumber is stacked, box piles are made with the boards flush with the front or pitched end of the pile. The other end of the pile is ragged, and good sticker support for the various lengths is lacking. Lumber is sometimes grouped according to length; for example, 1.8, 3.0, and 3.7 m (6, 10, and 12 ft) and 2.4, 4.3, and 4.9 m (8, 14, and 16 ft). The shortest boards are half as long as the longest boards; therefore, the scheme aids stacking and provides a good means for supporting ragged ends with a sticker tier.

Level, hand-built piles can be box piled with both ends square to incorporate good sticker restraint to warp. Grouping 1.8-, 3.0-, and 3.7-m (6-, 10-, and 12-ft) lengths and 2.4-, 4.3-, and 4.9-m (8-, 14-, and 16-ft) lengths into separate piles will result in less void space and better stickering. Level, hand-built piles are usually provided with pile roofs to keep rain entry to a minimum.

Special Piling Methods

The packages piled for air drying or the hand-built piles are usually considered flat piles. Other methods developed previously that have more or less limited use are crib piling, end racking, and end piling. These are methods of stacking lumber for air drying without stickers. These methods enable one person to stack lumber and require more area in the drying yard. These methods are not generally recommended and are not currently common in the United States, but are used sometimes in other countries, especially in the tropics.

Crib piling may be single, double, or triple (Fig. 41a). The first plank rests on a block at each end. One end of the second plank crosses the first plank with the other end resting on a third block. The third plank closes the triangle. Successive courses are built similar and on top of the first course. Crib piles are not provided with roofs.

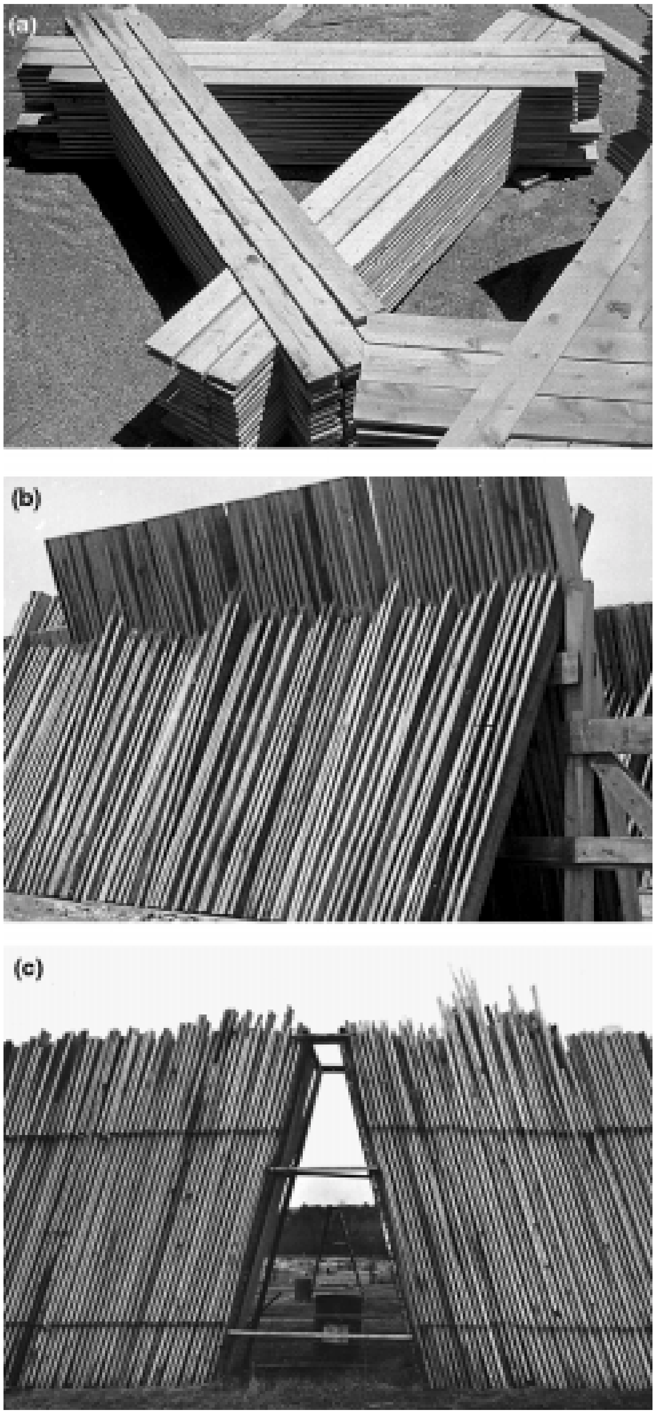

Figure 41—Alternative manual stacking arrangements that have been used in the past: (a) crib pile, (b) end racking, (c) end piling.

In end racking, the boards are placed upright and cross each other to form an “X” or an inverted “V” (Fig. 41b). End piling is approximately equivalent to tilting a flat pile on end until the boards are nearly vertical (Fig. 41c). In both end racking and end piling, the rows of boards are supported by frameworks. Neither of these types of pile is roofed. With end piling and end racking, it is important to support the lower ends of the boards above the ground surface. The lower ends of end-piled boards may rest on a spaced board platform or on boards laid directly on the ground. In end racking, the lower ends of the boards usually rest on timbers or planks placed directly on the ground.

All these piling methods have disadvantages and advantages compared with flat piling. All three methods can be done easily by one person; flat piling methods are more difficult for one person to do efficiently. These methods are also more susceptible to end and surface checking and warping than are flat piled. The ends of the boards in crib piling are likely to stain because of the retarded drying where they come in contact with each other. End piling and end racking promote rapid surface drying and consequently reduce the likelihood of staining. But treating lumber with a fungicide is common today, so this piling method is rarely used as the primary method of stain control. The boards are often wetter at the bottom than at the top ends.

Stickering Lumber

Stickers perform several important functions in air drying. They separate the courses or layers of lumber, permitting air to circulate over the broad faces of the boards (Fig. 42). Each sticker carries its proportionate share of the weight of the pile above it. Stickers, in combination with the loads that are imposed on them, tend to keep the boards flat, thus restraining warp. Finally, the position of the stickers at the two ends of a pile may reduce end checking, splitting, and warping near the board ends. In carrying out these roles, stickers must contact wet boards and the contact area that is somewhat retarded from drying may develop stain (Fig. 43).

Sticker Manufacture

Stickers are often made from lumber that is available at the plant where the air drying is performed, but sometimes they are purchased. In any case, stickers should be straight grained, durable, and strong so they can be used over and over again. The oaks, beech, and hickory make good stickers for hardwood operations. Douglas-fir and larch are used for stickers in the Pacific Northwest. Southern Pine and cypress heartwood stickers are used on softwoods in the South. It is preferable to make stickers from heartwood rather than sapwood. Stickers made from sapwood can become infected with stain or decay fungi, thus infecting freshly cut lumber on which they are laid. Green edgings from lumber have been used for stickers but do not perform as well as stickers made from thoroughly air-dried or kiln-dried lumber.

Figure 42—So that air can circulate over the board surfaces, wood stickers separate the layers or courses of lumber.

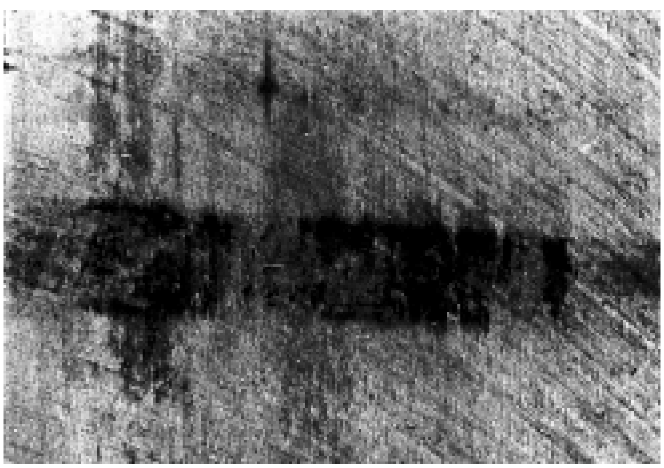

Figure 43—The area under the sticker is retarded from drying and stain sometimes results.

Sticker Size

For piling hardwoods, the stickers are usually made from 25-mm- (1-in.-) thick lumber, either rough or dressed to about 19 mm (0.75 in.), and from 25 to 50 mm (1 to 2 in.) wide, usually 32 mm (1.25 in.) wide. For piling softwoods, the 25-mm- (1-in.-) thick stickers are generally wider, as much as 100 mm (4 in.).

Sticker length is determined by the width of the package or pile being constructed. Four 1.2-m (4-ft) packages being stacked by hand in a framework of sticker guides or on an automatic stacker will use stickers about 1.3 m (50 in.) long. Hand-built piles in the yard will use stickers that are 1.8 m (6 ft) long on a 1.8-m (6-ft) pile. The pile is usually a few millimeters (inches) narrower than 1.8 mm (6 ft) so that the stickers project enough for the stacker to see the sticker tier location as the pile is constructed.

All stickers should be of uniform thickness to minimize warping. Miscut lumber from which stickers are being ripped should be surfaced on one or both sides prior to ripping in order to produce stickers of uniform thickness.

Rough Compared With Dressed Stickers

Whether the sticker surface contacting the lumber is rough or dressed probably does not greatly influence the drying rate of the wood under the sticker, although some yard supervisors prefer to use stickers with rough-sawn surfaces. In contrast, the operation of automatic stackers seems to be less troublesome when stickers are made from surfaced lumber.

Sticker Alignment

Stickers should be in good vertical alignment in both packages and hand-built piles (Fig. 44). If the stickers are not aligned, the superimposed weight will not be transmitted downward from one sticker, through the lumber, and directly down to the next sticker by direct compression, but will act on the span of the boards to cause warp (Fig 40). Sticker guides not only ensure good sticker alignment within a package, but they regulate the sticker spacing so that it will be the same from package to package. Uniform spacing is necessary if good alignment of stickers, bolsters, and foundation cross beams is to be obtained in a pile consisting of several packages. In stacking hand-built piles, sticker guides are seldom used and sticker alignment depends on the care and skill of the lumber stacker.

Sticker Spacing

The space between stickers in a course of lumber depends on the thickness of the lumber. Standard 19-mm (nominal 1-in.) lumber requires closer sticker spacing to control warp than does standard 38-mm (nominal 2-in.) material. Stickers

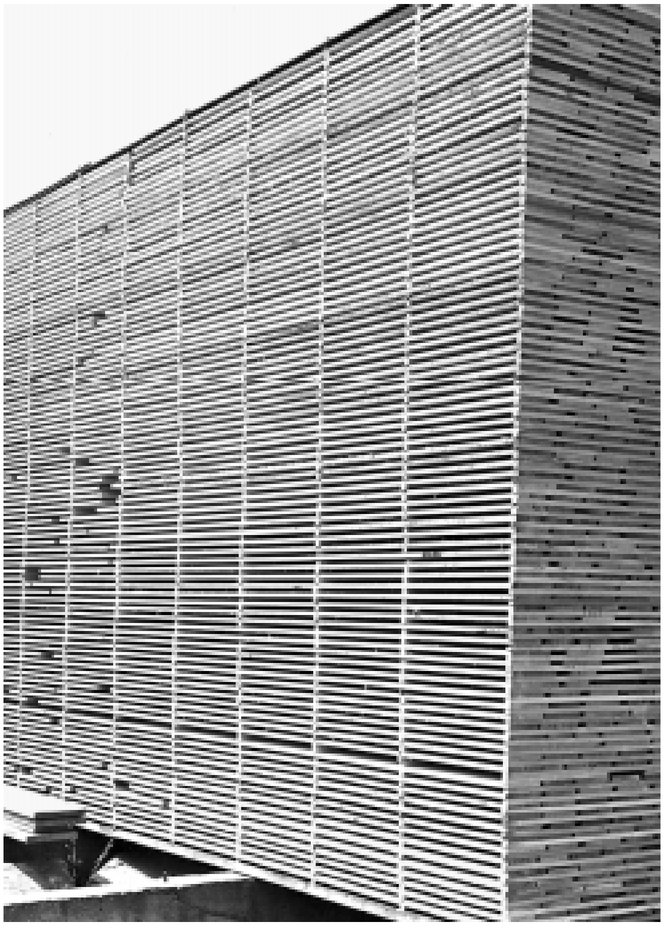

Figure 44—Good sticker alignment.

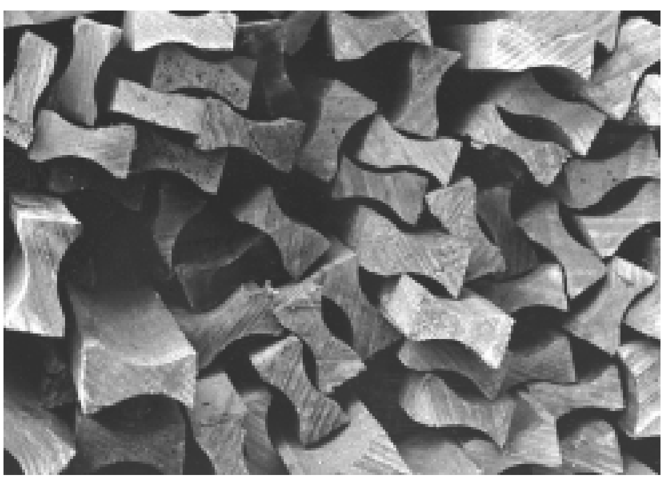

Figure 45—To avoid sticker stain, grooved stickers sometimes replace rectangular sticker.

retard drying to some extent at the areas where they contact the boards, so the fewest number of stickers that will produce the desired warp control is best. Fewer stickers are used with softwoods than with hardwoods, so softwood stickers are wider to provide sufficient bearing surface and avoid crushing the sticker or the lumber. Five stickers are generally used on 25-mm by 5-m (1-in. by 16-ft) softwoods. From five to nine stickers are used on 25-mm by 5-m (1 in. by 16 ft) hardwood lumber. Spacing stickers 400 to 600 mm (16 in. to 2 ft) apart is common for hardwood lumber, particularly for packages where sticker guides keep them in place when the courses of lumber are laid down.

Special Sticker Designs

Stickers used in stacking lumber for air drying are usually rectangular in shape. The broad faces of the sticker contact the stacked lumber. Where sticker marking is associated with chemical brown stain, grooved stickers have lessened the problem (Fig. 45). Here, 50-mm- (2-in.-) wide by 22-mm- (7/8-in.-) thick hardwood stickers have a groove approximately 35 mm (1-3/8 in.) wide machined out on the two sides to provide 8-mm (5/16-in.) bearing areas at each edge of the sticker. The grooved sticker presumably allows some air circulation under the stickers, reducing the likelihood of chemical reaction causing the stain.

Sticker Requirements

Automatic stackers eject stickers from the bottom of the sticker magazine. If the stickers are not straight and uniform in cross sectional dimension and length, the stacker will not function properly. Warped and end-battered stickers create problems in automatic stacker operation, so poor stickers must be replaced.

In semiautomatic stacking, the stickers are laid on the courses of lumber by hand. Sticker guides on both sides of the package are usually provided. Sometimes the sticker guide slots are considerably wider than necessary, resulting in some offset stickers in the tiers. As the stickers are hand laid, some sticker warpage can be tolerated, but very crooked stickers should be discarded. Stickers that are extremely bowed may require quite a few lumber layers on top to flatten them. Twisted stickers should be rejected because they cause the same problems as do excessively thick stickers mixed in with others of uniform thickness. Thin stickers should be rejected because they restrict the volume of air flow through the sticker openings.

Handling and Storage of Stickers

Stickers used in air drying lumber last longer than those used in kiln drying. In air drying, stickers are not subjected to repeated high temperatures and are not handled so frequently. However, sticker life can be shortened by rough handling. Stickers that have dropped out of the package may be run over by transport machines and broken.

Wetting may cause the moisture content of the stickers to increase to the point where stain or decay fungi can grow. This can shorten the life of the stickers, and fresh lumber piled with them may become infected. Poor sticker storage and handling and exposure to wetting and redrying may also cause the stickers to warp, which contributes to their breakage when they are used.

Forklift yards usually develop a sticker handling system. The packages are generally built at some central location. This requires that the stickers be returned from where the packages are taken down to the place where the stacking is done. If the packages of lumber are kiln dried after air drying, the stickers are returned to the stacker after breakdown of the kiln-dried package in the planer mill, the rough mill in a factory. At the package breakdown location, the stickers are often loaded into racks or bins that can be carried to the stacker by the lift truck or carrier (Fig. 46). In a forklift yard, it is possible to provide protection for the stickers from the weather by keeping the carrier racks or bins under cover.

Sticker Salvage

Stickers represent a considerable investment. Although the cost of each individual sticker is not great, the piles on the yard and in the kiln contain a considerable number of stickers. To what extent stickers are salvaged depends on their value. Today, some plants salvage broken stickers by trimming long stickers to the shorter lengths used in package operation. When only short or long stickers are used, the broken stickers with some salvage value are trimmed, scarfed or finger jointed, glued, and cut to length. Used stickers have re-sale value.

Figure 46—The handling of stickers is facilitated if they are racked for transport by forklift.

Chapter 6

Air-Drying Defects—Causes and Remedies

Losses in value and volume resulting from defects that develop in lumber during air drying increase the cost of air drying. If known, such losses should be assessed directly against the air-drying process. Air-drying defects may be caused by chemical reaction, fungal infection, insect infestation, or shrinkage. Chemical reactions cause chemical brown and gray stain, and sticker marking is one form of this discoloration. Fungal infection causes blue stain in the sapwood as well as decay and mold. Insect infestation results in pith flecks, pinholes, and grub holes. Shrinkage causes end checks and end splitting, surface checks, honeycomb, and warp. Exposure of lumber directly to weathering conditions aggravates these shrinkage defects, and extended yarding after the lumber is air dried accelerates the rate of grade deterioration or volume losses. Drying defects that do not degrade rough lumber may cause volume losses during machining. Warp may cause skips or splits in the dressing operation. Knots that are loosened in softwoods during drying may be knocked out during planing, and knots that are checked may be broken.

Chemical Reaction

Certain stains or discolorations can develop in lumber during air drying in addition to those caused by fungi or by general weathering. These stains result from chemical changes that occur in the wood. Called chemical stains, they darken the wood to colors ranging from gray to buff to dark brown. Species that are subject to objectionable chemical stains are ponderosa pine, the true white pines, western hemlock, noble fir, redwood, and several hardwoods including ash, maple, birch, hickory, and magnolia.

In pine, chemical brown stain develops in either sapwood or heartwood. It is more prevalent in lumber sawn from old logs that have been cut for some time than in lumber from newly cut logs. It is also more prevalent in boards that have been solid piled for 2 or more days immediately after sawing than in boards stacked for drying immediately after sawing. The stain develops during hot, humid months and usually is observed on the surfaces of the boards, but it can penetrate deeply into the wood. In some cases, it occurs inside a board and does not show on the surface. The stain results from a concentration of extractives that are transported by the water and deposited at the point where the water is vaporized or absorbed as bound water. These extractives are believed to be sugars and amino acids, which are present within the free water or are formed through enzymatic action immediately after felling or during solid piling of the lumber. The enzymatic action can be slowed down by dipping the green lumber in enzyme-inhibiting chemicals.

Deep grayish-brown chemical stains may occur in the sapwood of lumber in air-drying yards and predryers. These stains can be a problem in oak, hickory, ash, maple, tupelo gum, magnolia, persimmon, birch, basswood, and Douglas-fir. Stains develop during very slow drying. In this situation, enzymes are produced by slowly dying parenchyma cells, which darken when oxidized. To minimize these stains, green lumber should be stickered immediately after sawing, with good air circulation provided, and preferably at temperatures greater than 21°C (70°F).

Sticker marking, a form of chemical stain, develops in woods such as maple, white ash, and magnolia during the warm, humid summer months. The discoloration, which often does not surface out of the rough, dry boards, can be significantly reduced by using dry stickers and subjecting the lumber to good drying conditions immediately after stacking. Fan shed drying and forced air drying, or low temperature kiln drying, are very effective in preventing sticker marking in these woods during the warm months of the year.

Chemical stains can be reduced by conditions that encourage rapid drying. Rapid air drying can be promoted by keeping the yard surface well drained, free from vegetation and debris, using high and open-pile foundations, increasing the spacing between piles in the rows, and opening the unit packages by increasing board spacing and constructing more chimneys in hand-built piles.

Fungal Infection

Stain

Stains in wood can be caused by fungi that grow in the wood and use parts of it for food. These stains are confined largely to sapwood of both softwoods and hardwoods and are of various colors. The so-called "blue" stains, which vary in color from gray to bluish to bluish black, are most common. The blue color is caused by the thread-like hyphae of the fungus that invade the wood. Except for toughness, blue stain has little effect on the strength properties of wood, although it does cause degrade where color is important.

Blue stain is likely to develop where air drying is retarded. It is most likely to occur during the warm, damp seasons of the year. It occurs in flat piles of self-stickered lumber, where green boards are used for stickers, and in end racking and crib piling, where the boards themselves come in contact. The likelihood of blue staining can be reduced by using narrow, dry stickers and by opening up the yard and the piles to encourage rapid air drying.

Fungal growth can be prevented in lumber by quickly drying it to a moisture content of 20% or less and keeping it dry. Air-drying conditions may not always be favorable to prevent the growth of staining fungi; therefore, chemical treatment of the freshly cut lumber may be necessary. The chemical treatment is usually accomplished by dipping the lumber or spraying it with a suitable fungicide. However, if the lumber has already become infected, the fungus may have penetrated so far below the surface that the organism is not completely killed by dipping. When such lumber is air dried slowly, the interior portions may blue stain, although the surfaces may remain bright. The effectiveness of the antistain chemicals may also be reduced by leaching if the lumber is exposed to wetting while in the yard.

Successful stain control with chemicals not only depends upon immediate and adequate treatment but also upon proper handling of the lumber in the air-drying yard. The yard and lumber storage areas must be kept as well drained and sanitary as possible to reduce the chance of infection. The fungus is propagated by spores when the fungus has reached a certain stage. These spores are airborne, are practically always present, and infect freshly sawn lumber by coming to rest on the surfaces. If the conditions of air, moisture, and temperature are favorable, spores develop quickly into the fungus. Sap stain fungi can grow at temperatures from 1.7°C to 38°C (35°F to 100°F). Spores, although generally carried by the wind, are also carried by insects, and when the insect burrows into the sapwood, the spores are carried into the burrows.

Mold

Mold is also propagated by airborne spores. During warm, moist weather, mold grows on wood surfaces and penetrates the wood. In contrast to blue stain, the hyphae of molds are colorless and do not stain the wood. The discolorations of wood surfaces are caused by the fruiting bodies. Under exceptional conditions, mold may develop to a point where it restricts air circulation in certain portions of a pile, thereby retarding drying. The measures used to reduce or control blue stain apply also to mold.

Decay

Decay or rot is caused by fungi that not only discolor wood but actually destroy it. Decay, blue stain, and mold organisms all thrive under similar conditions of moisture content, air, and temperature, but decay requires somewhat longer time to develop. Freshly sawn lumber may be infected by airborne spores or contact with decayed foundation timbers or stickers. The best way to combat decay is to dry the lumber to a moisture content of 20% or less as quickly as possible. In some cases, it may be necessary to treat decay with a suitable fungicide. Decay is frequently present in the living tree, and lumber sawn from the logs will contain the organisms. Some decay fungi may continue to develop in the lumber as it dries.

Insect Infestation

In all stages of drying—from the green condition to completely dry—wood can be subject to attack by insects. Piles of lumber in an air-drying yard are sometimes infested. Debris, in the form of broken timbers or stickers, provides breeding places for insects that may spread to the lumber.

Powder post beetles attack hardwoods and softwoods, freshly cut and air-dried lumber. The sapwood of hickory, ash, and oak are particularly susceptible to attack. Damage is indicated by holes left in the surface of the lumber by the winged adults as they emerge and the fine powder that may fall from the wood. This is evidence that the insect has departed and that subsequent treatments to sterilize may serve no purpose. Sterilization of green lumber in saturated steam at 54°C (130°F) or at a lower relative humidity at 82°C (180°F) for 2°h is effective for 25-mm (1-in.) lumber. Thicker lumber requires a longer time to sterilize. Heat sterilized wood will not prevent subsequent infestation; therefore, good yard sanitation is essential to check infestation by these insects.

Shrinkage

When a log is sawn into lumber, the drying process starts and soon after stacking in the air-drying yard, shrinkage of the board begins. The stresses set up in the surface zones of the lumber by shrinkage may cause deformation or failure. Because the amount of shrinkage varies with the species of wood and the grain patterns of the lumber, a change in shape usually results. If the drying stresses exceed the strength of the wood, failures can develop, such as various types of splits and cracks.

Checks

Checks are failures of the wood that develop along the grain because of drying stresses. Checks are of three types: end, surface, and honeycomb. Some woods are inclined to check more readily than others (Table 10).

Table 10—Checking tendency of various woods

Low	Intermediate	High
Hardwoods		
Alder	Ash	Beech
Aspen	Birch, yellow	Oaks
Basswood	Butternut	Sycamore
Birch, paper, sweet	Elm, rock	Tanoak
Cherry	Hackberry	
Cottonwood	Hickory	
Elm, American	Maple, sugar, bigleaf	
Magnolia, southern	Pecan	
Maple, red, silver	Sweetgum	
Tupelo	Walnut	
Yellow-poplar	Willow	
Softwoods		
Baldcypress	Firs, true	Douglas-fir
Cedar	Hemlocks	Larch, western
Pine, sugar	Pine, jack	
Pine, loblolly	Pine, lodgepole	
Pine, shortleaf	Pine, longleaf	
Redwood	Pine, ponderosa	
Spruce	Pine, red	
	Pine, slash	
	Pine, white	

End checks originate on end-grain surfaces and appear as radiating lines pointing toward the pith or heart center of the tree (Fig. 47). They occur at the junction of the wood rays and the remainder of the wood cells, or within the wood rays. When started, end checks become wider and, by extending radially and longitudinally, develop into splits. Surface checks are similar separations of the wood under stress, but they occur on tangential or flatgrain faces (Fig. 48). End checks become longer by extending in the longitudinal direction of the grain of the wood and deeper by extending in the radial direction. As drying progresses, the surface checks may close up on the surface but widen and deepen internally. These are called bottleneck checks (Fig. 49).

Exposure to the sun and breeze during sawing and hot, dry weather immediately after piling is likely to cause checking. End and surface checks will probably be more severe in those parts of the pile that are fully exposed, that is, the ends, sides, and top parts of the pile. Checks will be particularly severe in the upper surfaces of the boards in the top course if the pile is not roofed.

Figure 47—End checks in lumber can extend to develop splits.

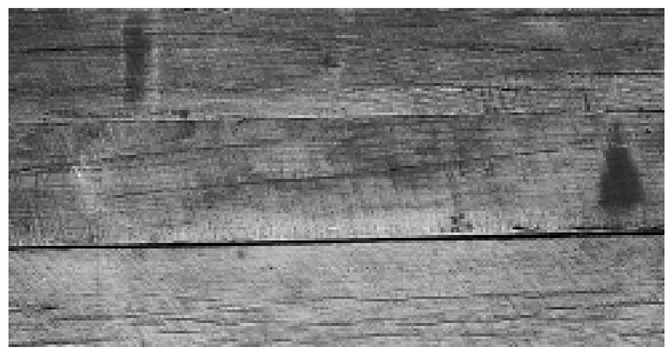

Figure 48—These oak boards surface checked in the early stages of air drying. These surface checks can penetrate deep into the wood, and when they close at the surface, the internal failure appears to be honeycomb.

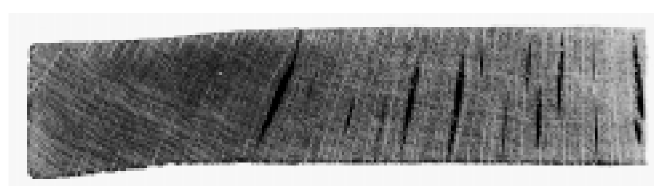

Figure 49—Bottleneck checks, which develop from closed surface checks, can look like honeycomb.

Volume losses as a result of end checking and end splitting can be serious. End coating the freshly sawn lumber immediately after trimming to length retards the end drying that causes these failures. Several proprietary end coatings are available. The emulsified waxes that can be applied by either brushing or spraying are effective for use on lumber being air dried.

End checking frequently begins in the log yard. It may pay to end coat both ends with emulsified wax to minimize end checking. An alternative method would be to sprinkle the dry log deck with water.

Honeycomb

Although not so common in air drying as end and surface checks, honeycomb or internal checking can occur (Fig. 50). This results from tensile failures entirely within the interior of the piece and usually occurs during kiln drying caused by too high a temperature too early in the schedule. Sometimes, surface depressions and grooves are indicated by the presence of honeycomb, but sometimes it cannot be detected until a piece is planed or sawn.

Honeycomb and bottleneck checks look similar but result from different causes; therefore, it is beneficial to distinguish between the two. In doing so, elimination of the problem may be possible. Honeycomb begins internally and usually does not extend to the surface, thus is rarely exposed to the air. In contrast, bottleneck checks begin on the surface, and at one time were exposed to the air. With the surface open, sometimes dirt collects in the check. If the defect in question extends to the surface or contains dirt, it is considered a bottleneck check.

After determining which type of defect is present, measures can be taken to avoid the defect in the future. Honeycomb is generally a kiln-drying problem caused by too high a temperature too early in the drying schedule. By waiting to increase the dry-bulb temperature or using a different drying schedule, this risk is reduced. Bottleneck checks can be an air- or a kiln-drying problem. If the check contains dirt, it most likely was initiated before entering the kiln and uncontrolled air drying was probably the cause. By reducing the air flow and/or providing more protection, the risk of checking is reduced. This is accomplished by using a protective cloth (Fig. 30), closer stacking of piles, or converting to shed drying. If there is no debris in the check, severe conditions early in the kiln schedule could have caused the checks. In which case, either reducing the initial wet-bulb depression or not advancing to the second kiln schedule step as quickly can help avoid the defect.

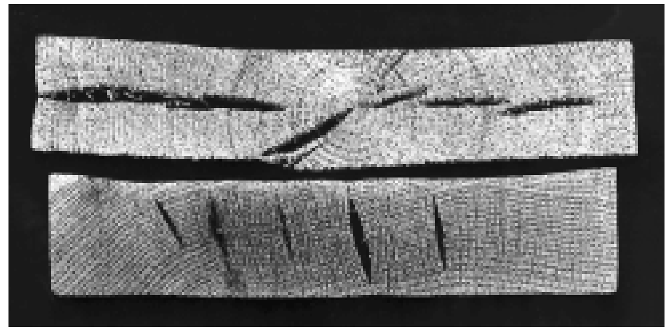

Figure 50—Honeycomb is failure initiated internally along the rays.

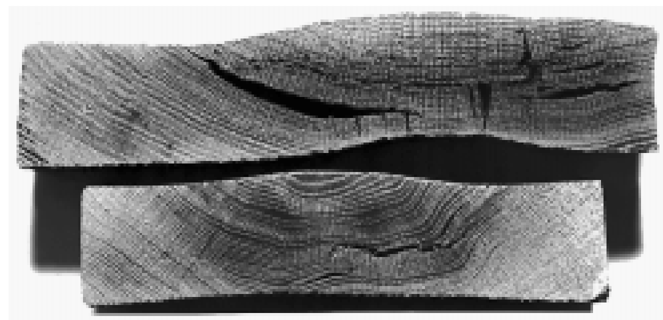

Figure 51—Shake is failure that follows the growth rings.

Shakes

Failures that do not conform with the usual definition of checks sometimes occur under shrinkage stresses. These failures are caused by abnormally weak wood and are called shakes. They are check-like openings located within or at the junction of the growth rings. Shakes may originate on end-grain surfaces and look like end checks, except that they follow the growth rings rather than the wood rays. These ring failures are not considered a drying defect and cannot be avoided by altering the drying method (Fig. 51).

Splits

Splits are longitudinal and radial separations of the wood. Usually they occur radially. Splits are generally located at a board end, but occasionally occur along the length of a board. A split along the length of the board may or may not extend completely through the thickness of the piece. End splits often result from extension of end checks further into a board. Splits are sometimes associated with longitudinal stresses that were in the log and the board when it was freshly sawn. When a split originates, the longitudinal stresses cause it to open wide and extend along the length of the piece.

Cracks

Cracks have the appearance of surface checks or splits but are formed differently. Cracks occur in pieces containing the pith or heart center of the tree. They generally develop from surface checks or end checks, but their characteristically large width is caused by the difference between tangential and radial shrinkage. Cracks are common in poles, posts, and boxed-heart timbers. On a transverse section, a crack appears as a wedge-shaped opening extending from a face to the pith.

Cross Breaks

Boards containing abnormal wood (e.g., compression wood) adjacent to normal wood, when dry, can develop checks crosswise of the board (Fig. 12). These checks result mainly because the abnormal wood shrinks more longitudinally than does the adjacent normal wood. The restraint by the normal wood results in tension stresses parallel to the grain in the abnormal wood; finally, the stress exceeds its strength and causes failure. What looks like small cross breaks in normal wood are sometimes observed and are generally identified as impact failures that may have developed in felling the tree.

Collapse

Some woods with a high green moisture content tend to take on a corrugated or washboard appearance when dry. The excessive shrinkage is termed collapse (Fig. 52). It is observed more in quartersawn lumber than in flatsawn lumber. Normal shrinkage of wood causes little change in the size of the cell cavity, whereas when wood is collapsed, the cell cavities are much smaller and often appear caved in. Collapse is not caused by shrinkage of the wood material but by the capillary forces in the free water in the cell lumen. Collapse is aggravated by kiln-drying temperatures. Air drying green lumber cut from butt or sinker logs of redwood and western red cedar and the heartwood of sweetgum and swamp oaks reduces the amount of collapse compared with what would be found if the material were kiln dried. Collapsed eucalyptus lumber that is air dried or predried can be reconditioned with steam to restore normal thickness prior to kiln drying the lumber to lower moisture content values. This process has not been adapted for woods of the United States, probably because the volume of collapsed lumber involved does not justify the added costs.

Casehardening

In air drying green lumber, the fibers in the outer zones of a board dry below the fiber saturation point, but their shrinkage is restrained by the core. A tension set, that is, a permanently stretched condition, develops in the outer zones. Some compression set—a permanently compressed condition—can develop in the core. Later when the board is uniformly dry through its cross section, the drying stresses have reversed. The outer zones are in compression, and the inner fibers are in tension. This is a condition known as casehardening. It is the normal behavior of lumber to undergo stresses as it dries and to develop tension set. In air drying, a considerable amount of tension set can be developed in the outer zones of a board. In air drying, the development of casehardening is normal and is not considered a defect because it is normally relieved after kiln drying.

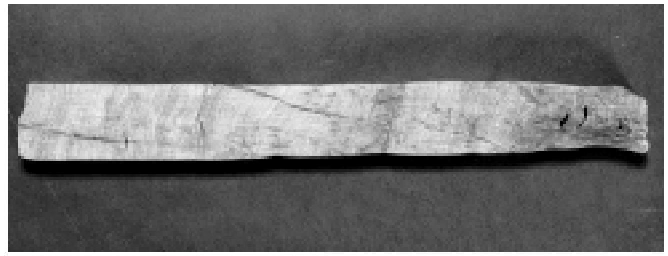

Figure 52—The irregular surface is evidence of collapse in this section from an air-dried western redcedar board.

Knots

Knots that are not intergrown with surrounding wood generally loosen during air drying. Both the shrinkage of the wood surrounding the knot and the shrinkage of the knot contribute to the loosening. A knot does not shrink as much lengthwise as the board shrinks in thickness, and as a result, the knot tends to project above the surfaces of the dried board. Encased knots, formed when a branch becomes embedded in a tree trunk when the branch dies, are surrounded by bark or pitch that may become hard and brittle when dry, loosening the bond between the knot and the wood. This, combined with shrinkage, tends to cause encased knots to be knocked out during machining.

Warp

The differences in longitudinal, tangential, and radial shrinkage characteristics of wood result in distortions of the cross section of a board. These distortions are termed warp and in lumber items, are classified as cup, bow, crook, twist (Fig. 53), and kink. Normal longitudinal shrinkage of wood does not greatly influence lengthwise distortions, but if juvenile and reaction wood are present, the resulting changes can cause degrade. A classification of the warping tendencies of some woods is given in Table 11. The general kinds of warp are defined as follows:

Cup: Deviation of the face from being a straight line across the width of the board

Bow: Deviation of the face from being a straight line along the length of the board

Crook: Deviation of the edge from being a straight line along the length of the board

Twist: A distortion caused by a turning or winding of the edges of a board so that the four corners of either face are no longer in the same plane

Kink: An edgewise deviation, similar to crook, caused by a knot or severe localized grain distortion to develop two straight portions in the piece at a large obtuse angle; also, a flatwise deviation, similar to bow, caused by physical bending and restraint such as out-of-line stickers or bolsters

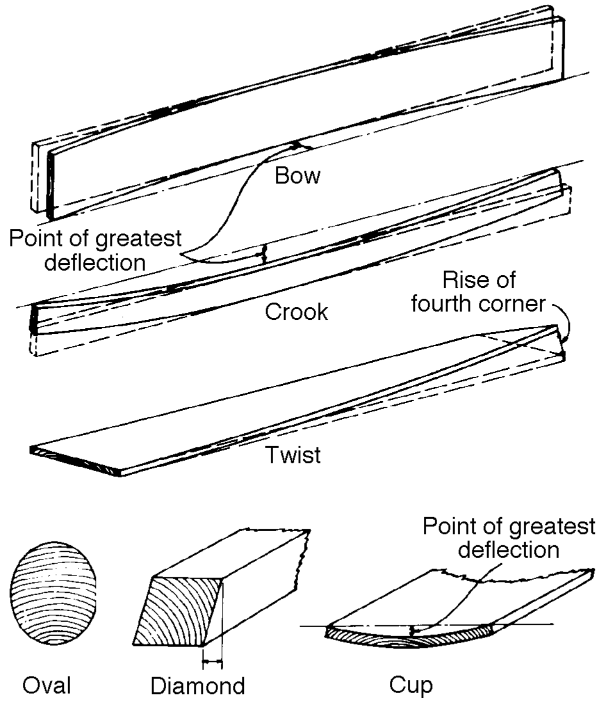

Figure 53—Various types of warp in lumber.

Cup is common in flatsawn boards, and all such boards tend to cup if permitted to dry and shrink without restraint. In a flatsawn board, because of the position of the growth rings, the face toward the bark of the tree has a greater shrinkage potential than does the face toward the pith. Consequently, when the board shrinks, the face toward the bark tends to become concave and the face towards the pith tends to become convex.

For a given species, the tendency to cup varies inversely with the distance the annual rings in the board are from the pith of the tree. The other forms of warp, bow, crook, and twist may be caused by spiral or diagonal grain, or localized distortions of grain, as around knots, for example. Spiral grain is present in the log, and diagonal grain is developed by sawing crooked logs or sawing parallel to the pith rather than to the bark.

The amount and character of warp depends on the slope of the grain and the location and size of the areas of cross grain. Bow, crook, or twist may also be caused by the presence of bands of compression, tension, or juvenile wood that has abnormal longitudinal shrinkage. Wood near the pith, which may contain juvenile or compression wood, often has abnormal longitudinal shrinkage. This is a good reason for boxing the heart in sawing so that the pith does not fall on one edge or face. Juvenile wood in the inner portions of mature trees is lighter in weight than the more mature wood nearer the bark and shrinks more along the grain. Consequently, boards containing both types of wood tend to warp during drying.

Table 11—Warping tendency of various woods

Low	Intermediate	High
Hardwoods		
Alder	Ash	Beech
Aspen	Basswood	Cottonwood
Birch, paper, sweet	Birch, yellow	Elm, American
Butternut	Elm, rock	Sweetgum
Cherry	Hackberry	Sycamore
Walnut	Hickory	Tanoak
Yellow-poplar	Locust	Tupelo
	Magnolia, southern	
	Maples	
	Oaks	
	Pecan	
	Willow	
Softwoods		
Cedars	Baldcypress	
Pine, ponderosa	Douglas-fir	
Pine, Sugar	Firs, true	
Pine, white	Hemlocks	
Redwood	Larch, western	
Spruce	Pine, jack	
	Pine, lodgepole	
	Pine, red	
	Pine, Southern	

Kink is observed in softwood dimension lumber where a knot or the grain distortion that surrounds a knot is located on one edge near the middle of the piece. The two portions of the piece are essentially flat and straight. Sometimes the sharp bend in the faces of a board caused by an offset sticker and considerable superimposed loading is also called a kink.

Warp Reduction

Warping is caused by the differences in shrinkage in the three grain directions and because of irregular and distorted grain. Warping can be minimized by following good stacking and piling practices. The tiers of stickers and other supporting members, such as foundation cross beams and bolsters, should be in good vertical alignment. Protecting the boards in the top course of a pile with a roof reduces exposure to the weather with its alternate wetting and drying cycles. Good sawing practices produce boards of uniform thickness, which is a desirable quality for stacking and drying uniformity.

The more refractory (that is, difficult to dry) woods like oak and beech are very difficult to air dry during periods of good drying weather without surface checking. These failures result when the tension forces across the grain tend to localize at the small fractures created by the sawing process. Surfacing the green wood removes the sawing fractures, and the likelihood of surface checking in air drying is reduced. By presurfacing lumber to a uniform thickness, not only is the usable volume of a unit package increased, but the amount of warp present is reduced.

Stacking, Package Piling, and Pile Protection

The volume and grade reduction as a result of poor stacking, improper piling practices, and inadequate pile protection can be appreciable. Warp is aggravated, and volume losses as a result of end checks, end splits, and surface checking are increased.

Stacking Effects

Lumber of uniform thickness and trimmed for length can be stacked in such a way that warp is restrained. As a result of poor sorting, stacking, and piling practices, however, good grade and volume recovery might not be attained. In stacking, even dry stickers may vary in thickness. When associated with poor sticker tier alignment, the introduced warp may be significantly increased. Perhaps length sorting cannot be justified, requiring that the packages be box piled. Insufficient sticker tiers and carelessly locating them may further fail to provide adequate board end support. Along with careless board placement, this further invites warp (Fig. 54). When long boards for the edges of the box piled courses are not readily available, shorter boards are often laid down, causing sticker overhang. If the space is not blocked, sag can be created in the courses of lumber above. This is a problem of greater concern in stacking the narrower unit packages.

When stickered packages of lumber, particularly 25-mm (1-in.) softwoods of the less dense species, are transported by forklift trucks, two extra tiers of stickers are often included. Such tiers, located so they will be above the pickup points of the fork, are often installed six to eight layers from the bottom. The package is usually stiffened enough so that the end stickers will not fall out during transport. Carrier bunks should be spotted at these extra sticker tiers to minimize the sag in the bottom lumber layers of the package when the package is transported or temporarily stored (Fig. 55).

Package Piling Effects

Packages are usually piled one above the other two, three or four packages high, depending on the height of the packages.

Figure 54—Example of poor sticker alignment.

Thus, the lower packages are weighted by the upper ones. Any failure of the pile foundation, or the bolsters between the packages, to adequately support the load will warp the lumber. Green lumber can be bent and, if it dried while bent, the bends become fixed and are permanent. Where the number of cross beams in the foundation does not adequately support the pile at the sticker tiers, the lower courses are likely to sag. This introduced bow can result in appreciable grade reduction.

Weathering Effects

When piles are not covered, the upper layers are exposed and defects can develop that cause value losses as a result of grade reduction and volume losses in ripping and trimming to maintain grade. The economic effect is particularly notable in the upper grades of hardwoods and finish grades of softwoods. A rain tight roof with overhang on sides and ends will prevent excessive moisture regain and reduce the overall drying time in the yard. Where the output of air-dried lumber per square meter of yard area must be fairly high and production fairly constant, prevention of moisture regain during rainy seasons of the year is a necessity. In this case, good prefabricated pile covers are economical. The prevention of alternate wetting and drying also reduces grade losses caused by general weathering, mainly surface checking and warp. The cost of the pile roof construction, placement, tiedown, storage when not in use, and maintenance may justify designing and installing drying sheds, particularly for high value lumber.

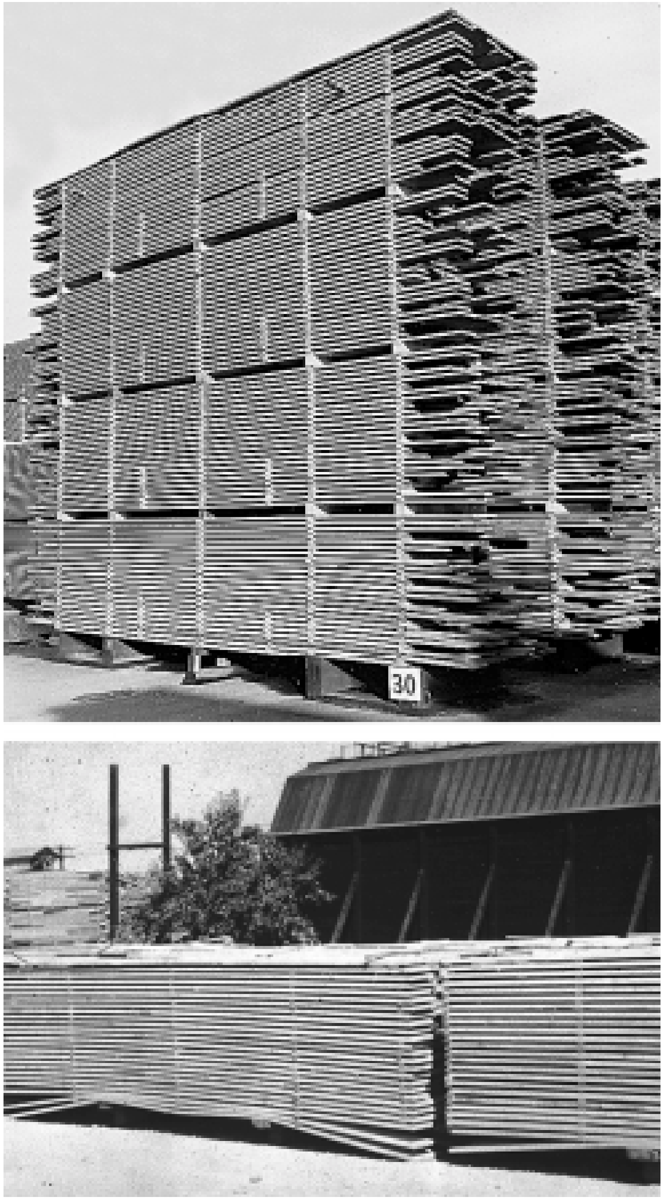

Figure 55—Forklift stickers in the lower layers of each package avoid damaging the lower layers when picked up by a forklift.

Chapter 7

Protection of Air-Dried Lumber

When lumber is as dry as can be expected in the air-drying yard, it should be stored where it is no longer exposed to wind, sun, and rain. The deteriorating effect of weathering continues as long as the lumber is left outdoors. When stickered lumber is taken down and solid stacked, it takes up less space and a shed can provide the needed protection. When yard space is needed for air drying lumber, less favorable drying areas are often set aside for bulk storage of lumber that has already been air dried.

The seasonal changes that influence the air-drying potential of an area also affect the conditions of dry lumber storage. However, significant moisture changes in air-dried lumber result mainly from rains that rewet the lumber. If good, raintight pile roofs with adequate projections were used during drying or if the lumber were shed dried, the needed protection from adverse weather was provided.

Lumber that has reached 20% moisture content or less is usually no longer threatened by the development of stains or fungus and insect attack. Consider storing and protecting this lumber without additional drying.

Outdoors

The air-drying process is, in effect, outdoor lumber storage. The inventory is handled in such a way that drying takes place during the storage period. But the inventory period in the air-drying yard should be no longer than that required to reduce the moisture content to a level suitable for use, kiln drying, or shipment. Then, it becomes a matter of protecting the air-dried lumber against rewetting. This protection is especially important if the lumber is of high grade and the storage period is likely to be lengthy. Roofs should now be provided if they were not when the pile was first erected. The lumber may be left on sticks, or piles, and packages may be taken down and the lumber bulk piled for more efficient use of space.

If the average moisture content of the lumber is greater than 20%, it should be protected in such a way that drying can be continued, as under a roof or in a shed. It should not be bulk piled because of the hazards of stain and decay development. When the moisture content of the lumber is less than 20%, the piles or packages may be wrapped with plastic tarpaulins or enclosed in prefabricated waterproof wrappings for temporary outdoor storage.

Foundations in the storage area should provide good support and ground clearance just as in the original air-drying pile. Support is still essential to prevent pile sagging. Ground clearance is not only needed to provide room for forklift operations but for ventilation to keep moisture regain in the bottom layers to a minimum. If the water table in the ground is high, a ground cover to provide a barrier to moisture vapor movement out of the soil may be desirable, particularly if the storage period is extended. Precautions should be taken to protect the lumber against infestation by termites and other insects.

Indoors

Sheds can provide the indoor storage of air-dried lumber. The advantage of shed storage is the protection provided by the permanent roof. The air-dried lumber is stored in the shed either as stickered unit packages, as bulk-piled lumber in unit packages, or bulk piled in bins or bays. The sheds can be open, closed, or closed and heated; they may or may not be floored or paved. The design, size, and materials of shed construction will vary depending upon plant arrangement, storage volume requirements, and the cost of locally available building materials.

Open-Shed Storage

An open lumber storage shed is one that usually does not have sides or ends to block air movement through the building. Sheds with louvered walls are considered open sheds (Fig. 56). Wind-blown rain is baffled, a distinct feature of this type of shed. If the shed is not floored or paved, foundations for stickered or bulked packages of air-dried lumber will be necessary to provide ground clearance for ventilation.

When hand-built piles in the yard are taken down, the lumber is often bulk piled in bins or bays in the “rough dry shed.” In a forklift yard operation, the stickered unit packages or packages of bulked lumber are stored in the open shed. The height of the package pile is governed by the height of the shed. Lumber storage volume can be increased by having a forklift available to place carrier packages two, three, or more units high, depending upon the height and construction of the shed.

Figure 56—Open shed with louvered side wall helps protect lumber from wind-blown rain.

Figure 57—A closed, unheated lumber storage shed.

Closed, Unheated Storage

A closed, unheated shed for the storage of air-dried lumber differs from an open shed in that the sides and ends of the buildings are walled, blocking air movement through the structure (Fig. 57). Doorways and other access openings for the transport of lumber in and out of the shed are usually kept closed when activity is not great or the sawmill or factory is not in operation. Ventilators are sometimes installed on the roofs of these buildings, but the air circulation within the shed remains virtually stagnant. Partially dry, stickered units of lumber can be stored in a closed shed but, if further drying at a reasonable rate is wanted, the air movement through the stickered package must be stimulated by introducing forced air circulation with fans.

As air movement in and out of a closed shed is restricted by the solid walls, some heating of the air in the building results from solar radiation. If the roof and walls exposed to sunshine are dull black, these structural elements are heated when the sun shines and the air inside the building in contact with these heated elements is warmed. The air in the upper space of the building is warmer than the air at the ground level and, if warmed air is moved downward by fans, the EMC conditions of lumber storage are lowered. In a closed shed, air-dried lumber is more certain to remain dry and partially air-dried lumber in stickered unit packages will dry faster.

If the closed shed is not floored or paved, foundations must be provided for the unit packages or the lumber in the bins in order to create a space between the ground and the lumber. The walls of the building are often open near the ground level in a closed shed to create air drift or ventilation under the lumber. These ground-level wall openings can be screened or louvered to discourage entry of birds and small animals into the shed.

Closed, Heated Storage

A closed, heated shed is most often utilized to store lumber that was kiln dried to moisture content levels lower than can usually be attained in conventional air drying. However, such a shed might sometimes be used to dry stickered unit packages of air-dried lumber because the systems used to heat the closed shed involve forced air circulation with fans.

The closed, heated storage shed is usually floored or paved. The unit packages of lumber, or bulked lumber in bins, should not be in direct contact with a paved floor, however, because some moisture could migrate through the paving. The warmed air being circulated in the shed should be allowed to move under the stored lumber unit. In most instances, the bunks used in carrier or forklift operations provide adequate elevation of the lumber. The temperature maintained in a closed, heated lumber storage shed are not very high and insulated walls, roofs, or ceilings are seldom installed.

The wood equilibrium moisture content (EMC) conditions in a heated storage shed depend upon the outdoor temperature and relative humidity and the temperature of the circulated air within the shed. When outdoor air is heated, the absolute humidity remains the same but the relative humidity is reduced. Thus, the wood EMC of outdoor air is reduced when the air is heated. Figure 58 shows the effect on EMC of increasing inside temperature above outside temperature.

The values shown in Figure 58 apply to all outside temperatures from -1^{o}C to 32^{o}C (30^{o}F to 90^{o}F). For example, if outside EMC is 14%, Figure 58 indicates that a temperature increase of 36^{o}C (20^{o}F) reduces EMC in the heated shed from 14% to 7%. As another example, if during winter months the outdoor temperature averages 4^{o}C (40^{o}F) and 75% relative humidity, the wood EMC is about 15%

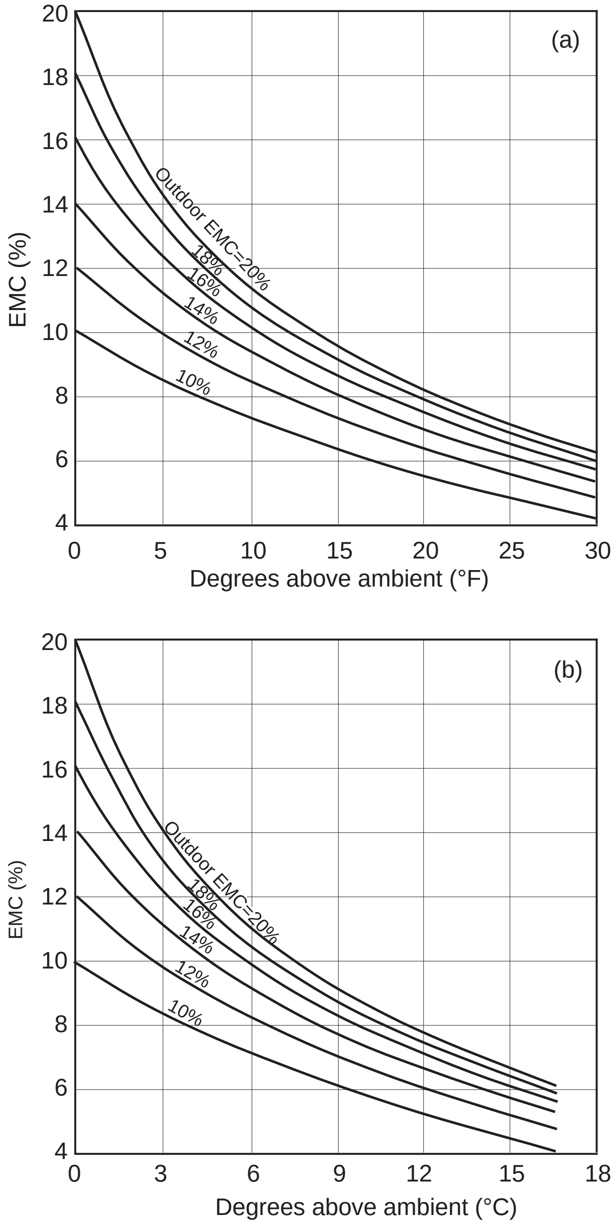

Figure 58—EMC of wood when air in an enclosed space is heated greater than the temperature of the outside air.

(Table 2). To what temperature should the shed be heated to reduce the EMC to 12%? By interpolating between the 14% and 16% outdoor EMC curves in Figure 58, we see a temperature increase of about 2.8^{o}C (5^{o}F), so the shed should be heated to 7^{o}C (45^{o}F) to maintain an EMC of 12%.

Air-dried lumber in storage does not require much heating of the ambient air to prevent moisture regain, and it is quite possible that in many areas of the country solar radiation will provide the needed heat energy. Circulation of the air within a closed, heated lumber storage shed by means of fans is necessary regardless of how heating is accomplished, particularly in a solar-heated system. The fans move the air across the warmed roof and walls and mix this warmed air with that being circulated around the dry, stored lumber.

Closed sheds at millwork and furniture plants are often equipped with unit heaters complete with fans. Usually these unit heaters are supplied with steam from a central plant, but individual gas burning units are sometimes used. The heaters are located in such a way that the warmed air is directed toward the stored lumber. The conventional temperature control of a unit heater is a thermostatic control of the fan motor. When the thermostat calls for heat, the unit heater fan motor is started and air is forced through the finned coils of the heater. Forced air circulation in the shed is desirable at all times; therefore, the unit heater fan motor can be kept in full-time operation and the temperature controlled by installing a motor valve on the steam or gas supply for “on and off” operation. This control mechanism is more expensive to install than a thermostatically controlled fan but it does ensure full-time fan operation to keep the warmed air in the heated shed from stagnating and stratifying.

Temperature control in a closed, heated shed for dry lumber is mainly a problem of controlling wood EMC conditions at a predetermined value; therefore, the most simple control system is a humidistat that controls the shed temperature. By controlling the relative humidity in a heated shed, the wood EMC condition is controlled closely enough for most practical purposes. For example, from Table 2, the relative humidity that establishes a 12% EMC condition is about 65% over a fairly wide range of temperatures. By setting the humidistat at 65% relative humidity, the indoor air will be heated to decrease the indoor relative humidity to this level. The advantage of a humidistat control installation on the unit heater is that, with changing outdoor temperature and relative humidity, the wood EMC in the heated shed remains substantially constant. With humidistat control, the fans on the unit heaters should operate continuously and the humidistat should control the steam or gas input into the heater.

The hazards of stain and decay developing in air-dried lumber stored in a heated shed are significantly reduced. However, partially air-dried lumber should be left on stickers so that drying can continue in storage.

In Transit

Air-dried lumber is shipped from the producing sawmills by railroad and truck to the factories where it may be kiln dried to a lower moisture content for final processing. However, the air-dried rough lumber may be kiln dried and processed to some extent at custom kiln-drying companies who carry out these services on an “in transit” basis. When the producer ships air-dried lumber, either by railroad or by truck, protection from the weather must be provided.

Railroad

High value, air-dried lumber is sometimes shipped to wood-using factories in boxcars. The lumber is thus protected from the weather and deterioration is not likely to occur. The labor costs of loading and unloading have affected the volume of shipments transported this way. To facilitate loading and unloading, boxcars are available with wide doors so that unitized packages of bulk-piled lumber can be moved in and out of the boxcar with lift trucks. Air-dried lumber is also shipped in gondola cars. The bulk-piled lumber may be loaded onto the gondola cars by hand, or unit packages can be loaded onto the car by crane or by a lift truck equipped with special slings. The unit packages of bulk-piled lumber are individually strapped, and the completed gondola load is strapped or chained in such a manner that the lumber cannot shift during rail transit. Protection from the weather is seldom provided.

Flatcars are becoming widely used for the transport of air-dried lumber because these cars can be quickly loaded and unloaded by a forklift (Fig. 59). When the carload is in place, it is anchored or bound to the car by numerous cables that are thrown over the load and tightened with ratchet load binders. Metal corner protectors may be used to prevent cable damage to the edges of the boards in the top layer of the top packages in the load. Flatcars with A-frames in the longitudinal center are also available, and the advantage is increased sidewise stability of the flatcar load.

Figure 59—Flatcar loaded with lumber and held in place with cables.

Truck

Considerable quantities of air-dried lumber are shipped by truck from the producing sawmills to the using factories or custom kiln-drying plants. Tractor trailer units are usually used for this purpose, and in most instances, the trailer is a flatbed unit that can be loaded and unloaded by a lift truck. The load of lumber is anchored to the trailer by chains tightened with load binders. Air-dried lumber should be protected by covering the load with canvas tarpaulins (Fig. 60).

Figure 60—Tarpaulin protection on a trailer load of air-dried lumber.

Appendix

Summarized Guide for Air-Drying Practices

Air-Drying Yard

Site

High, well-drained ground with no obstructions to prevailing winds provides the greatest drying potential. Transportation is facilitated if the yard is located close to the sawmill or woodworking factory.

Yard Layout

Roadways of main and cross alleys divide the yard into rectangular blocks or areas for the lumber piles. The row-type forklift yard has main alleys at least 7.3 m (24 ft) wide with cross alleys that may be 18 m (60 ft) wide. In a line-type forklift yard, an 18-m (60-ft) cross alley might be the principal roadway from the sawmill or woodworking factory. The lines of piles and the main alleys are placed at right angles to the cross alley. Yard boundaries or the need for cross alleys for insurance or fire fighting purposes determines the length of the lines. The hand-built pile yard is usually laid out in blocks of main alleys with a rear alley between each two rows of piles. The main alleys can be relatively narrow, but the blocks are often separated by wide cross alleys that could also be fire lanes.

Yard Orientation

Main alleys often run north and south to obtain faster roadway drying after rains or faster snow and ice melt. In forklift yards, the main alleys are sometimes laid out parallel to the prevailing wind to improve air movement in the unit packages.

Row Spacing

In a row-type yard, the row space needs to be wide enough to enable the forklift operator to maneuver and place the packages on the pile. A 1-m (3-ft) spacing between rows is recommended. A closer spacing might be practical in a paved yard. A “side shifter” on the forklift truck will make unit package placement much easier for the forklift driver.

Line Spacing

The space between the two lines in a line-type yard varies, but 0.6 m (2 ft) is considered a minimum. The two lines of permanent foundations need to be separated by this much space or more to ensure unobstructed air drift between the lines.

Pile Width

Narrow packages of lumber tend to tip, often requiring long tie bolsters between piles. Wider unit packages minimize the possibility of tipping, and some hardwood operations are piling 2.4-m (8-ft) packages successfully. Hand-built piles of hardwoods are usually 2.4 m (8 ft) wide. Self-stickered softwood piles vary from 2.4 to 5 m (8 to 16 ft) wide, depending upon the sorted length of the lumber being stacked.

Pile Height

Although the pile height in a forklift yard is limited mainly by safety issues, a standard practice is to pile four unit packages on a foundation, making a pile height of about 6 m (20 ft). Higher piles of unit packages are not recommended. The hand-built pile, if built up from the ground, is usually about 5 m (15 ft) high, but those erected alongside an elevated dock can be as much as 9 m (30 ft) high. Compression of stickers and the indentation of the lumber in the lower courses because of superimposed loading may require using wider stickers in building these high piles.

Pile Spacing

The recommended minimum pile spacing in a row-type forklift yard is 0.6 m (2 ft). The pile spacing in the row can be varied to open up the yard when necessary. The space between ends of piles in a line-type forklift yard can be 0.3 m (1 ft) or less, depending upon whether the forklift truck is equipped with a side shifter. The recommended space between piles in a hand-built yard is about 1 m (3 ft).

Pile Placement

In a row-type forklift yard, the rows are placed perpendicular to the main alley. The length of the row is determined by the inventory. In a line-type forklift yard, the lines are parallel to the main alleys. Hand-built piles are placed perpendicular to the main alley.

Yard Transportation

For easy and rapid handling, motorized transport equipment is used to move lumber from the sorter to the yard or from the stacker to the yard.

Pile Foundation

Wood foundation members are generally used for row-type forklift yards and hand-built pile yards. Preservative treatment of mudsills, posts, and piers is justified. When concrete piers are used to support stringers or cross beams, their footings should be below frostline. Concrete piers supporting railroad rails are frequently used in line-type forklift yards. The minimum foundation height for forklift yards is 200 mm (8 in.), and the preferred design allows free air movement in any direction under the pile.

Pile Protection

Sun and rain-tight pile roofs protect high value lumber from weathering. Sun shields or end coatings reduce footage losses caused by end checking and end splitting in thicker lumber items. Wind barrier tarpaulins can minimize surface checking when they are used to cover piles on the windward side of a forklift yard during periods of hot, dry winds.

Stacking and Piling Lumber

Sorting

Drying time varies with lumber thickness, and yard output is greater if thickness segregations are made for stacking and selected yard placement. Sorting by length is also recommended. Stacking of lumber sorted for length reduces grade losses caused by warp. Sorting by species is generally essential.

Sorting Equipment

Smaller sawmills and woodworking plants will set up a conventional green chain or other mechanical or semimechanical means to sort lumber for stacking. At larger sawmills, mechanical sorting equipment such as edge, drop, or tray sorters can reduce lumber handling costs.

Stacking of Lumber Into Unit Packages

Sticker guides on stacking stalls or mechanical stackers ensure good sticker alignment. Mechanical stackers provided with an “even-ender” produce square ends on the packages. When random-length lumber is stacked, box piling is recommended.

Board Spacing

Edge-to-edge stacking of both softwoods and hardwoods is practical for unit packages 1.2 m (4 ft) or less in width. For wider packages of random-width hardwoods, board spacing may be necessary to minimize blue stain. Flues or chimneys are built into wide unit packages of stain-prone softwoods to promote better air circulation and minimize stain..

Package Height

The load-carrying capacity of the lift truck often determines the height of a unit package. A package height of about 1.2 m (4 ft) is recommended as a general standard for most yarding operations.

Bolster Size

Small wood timbers 100 by 100 mm (4 by 4 in.) in cross section and as long as the unit package width support the entire package and allows for entry of the forks of the lift truck.

Stacking Lumber in Hand-Built Pile Yards

Random-width hardwood boards should be spaced. Very wide piles may require flues or a chimney in addition. Random-length hardwood boards will warp less if they are box piled. Chimneys or several flues are recommended in building sloped and pitched piles of softwood lumber. Board spacing between flues is usually not essential. Board spacing in addition to a large central chimney is recommended for self-stickered piles of softwood lumber.

Stacking Stickers

Stickers processed from high grade dry and surfaced heartwood lumber give longer and satisfactory service. Stickers should be uniform in thickness and stored under cover when not in use.

Control of Drying Defects

Chemical Brown Stain

Treating green white pines with enzyme inhibitors is effective for preventing chemical brown stain. Sawn white pine lumber needs to be stacked promptly and subjected to good air-drying conditions as soon as possible after stacking.

Sticker Marking

Use dry stickers. The sawn lumber should be stacked and promptly subjected to good air-drying conditions.

Blue Stain, Mold, and Decay

Treatment of the green lumber with a suitable fungicide is recommended. Tight pile roofs prevent rain from wetting the lumber. Good yard sanitation practices are essential to keep sources of infection to a minimum. Good air movement and rapid drying helps reduce stain and mold.

Insect Infestation

Logs and lumber may require spray treatment with a suitable insecticide. Insect-breeding places need to be cleaned up or destroyed.

End Checks and Splits

Freshly trimmed ends of high value lumber thicker than 32 mm (1-1/4in.) should be end coated to minimize end checks and splits. Sun shields may be more practical in some situations.

Surface Checks

Presurfacing check-prone species like oak and beech can be considered if grade losses as a result of surface checking are serious. Package and pile buildup can be modified to retard air movement. Pile spacing can be smaller during periods when the drying potential is severe. Wind baffles may be necessary at times.

Honeycomb

Precautions to prevent the development of end checks and surface checks are recommended. Honeycomb in air-dried hardwoods is generally caused by the extension of end checks and the penetration and extension of surface checks.

Warp

To prevent warp, good stickering and piling practices are recommended. Uniform-sized stickers, close sticker spacing, and good alignment are essential. Firm and straight foundations with supporting members at all sticker tiers are necessary. Improved thickness control in sawing or presurfacing may be required if miscut lumber significantly contributes to warp development. Clamping or superimposed loading may be a practical remedy for warp-prone species.

Cost Reduction

Degrade Studies

Investigations to evaluate losses in grade and footage caused by drying defects can point out where improvements are needed. Changes in stacking and piling practices may be justified to reduce defects such as surface checking and warp. The treatment of green lumber with a fungicide to control blue stain may be profitable.

Drying Time Reduction

As overall air-drying costs increase with extended yard time, ways and means should be explored to decrease the time that a unit of lumber spends on the yard. A lower inventory being air dried may be warranted to reduce the average drying time.

Labor Cost Reduction

The switch from hand-built pile yarding methods to forklift yarding operations results from a need to reduce labor costs. Package handling methods allow increased use of mechanical equipment for stacking, transport, and piling.

Protection of Air-Dried Lumber

Outdoor Storage

If air-dried lumber is at a moisture content of 20% or less, it can be bulk piled. However, protection from rain is essential and rain-tight roofs or tarpaulins can be used. Unit packages of bulk-piled lumber can be wrapped with waterproof paper for temporary storage. If lumber is at a moisture content of more than 20%, air drying in place can be continued.

Indoor Storage

If air-dried lumber is at a moisture content of 20% or less, bulk piling indoors in unit packages or bins is satisfactory. If the lumber is at a high moisture content, the stickered unit packages are stored without dismantling and lumber coming from hand-built piles is stickered. If the shed is not floored, unit package and bin foundations are required to provide ground clearance. Stickering lumber of high moisture content stored in bins would be a good precaution. Circulating air in closed sheds by fans is recommended. Humidistat control is recommended for closed, heated sheds.

Truck Transit

Tarpaulin protection from rain is often used for tractor-trailer transport of air-dried lumber.

Railroad Transit

Cars of bulk-piled strapped packages of air-dried lumber are not protected from the weather. If rains during shipment wet the lumber, prompt stickering for air or kiln drying is recommended.

Glossary

Active drying period. A time or season of the year when weather conditions are such that yarded lumber loses moisture rapidly.

Air dried. The dried condition of lumber, usually 12% to 20% moisture content, reached by exposing the lumber for a sufficient period to the prevailing outdoor weather conditions.

Air drying. *Syn.* Air seasoning. The process of drying green lumber by exposure to prevailing atmospheric conditions outdoors.

Alleys, cross. The passage ways that connect main alleys in an air-drying yard.

Alleys, main. *Syn.* Runways. The roads in an air-drying yard for the transport of lumber.

Alleys, rear. The space between the backs of rows of hand-built piles in an air-drying yard.

Annual growth ring. The growth layer put on a tree each year in temperate climates, or each growing season in other climates. Each ring includes earlywood and latewood.

Anti-stain chemical. A chemical applied to lumber to prevent or retard chemical or fungus stain development.

Blue stain. *See* Stain, blue.

Board. (1) Yard lumber that is less than 51 mm (2 in.) thick and 25 mm (1 in.) or more wide. (2) A term usually applied to 25- mm- (l-in.-) thick lumber of all widths and lengths.

Board foot. A unit of measurement equal to a board 305 mm (1 ft) long, 305 mm (1 ft) wide, and 25 mm (1 in.) thick. In finished or surfaced lumber, the board foot measure is based on the measurement before surfacing or other finishing. In the lumber industry, the working unit is 1,000 board feet = 2.4 m^3.

Bolster. *Syn.* Spacer. A square piece of wood usually 102 by 102 mm (4 by 4 in.) in cross section, placed between stickered packages of lumber to provide space for the entry and exit of the forks of a lift truck. Bolsters need to be aligned with the stickers in the lumber packages.

Box piling. Method of stacking random length lumber so that the length of the outside boards in each course is equal to the full length of the stack.

Bound water. *Syn.* Adsorbed moisture, hygroscopic moisture. Moisture that is intimately associated, by weak chemical bonds, with the finer wood elements of the cell wall.

Bow. *Syn.* Camber. A form of warp in which a board deviates from flatness lengthwise but not across the faces.

Boxed heart. *Syn.* Boxed pith. When the pith falls entirely within the outer faces of a piece of lumber anywhere in its length, it is said to contain boxed heart.

Bright. *Syn.* Unstained. The term is applied to lumber that is free from discolorations. The term bright sapwood is sometimes used to describe sapwood of natural color or in which the stain or discoloration can be removed by surfacing to standard thickness.

Brown stain. *See* Stain, chemical brown.

Bulk pile. *Syn.* Solid pile. The stacking of lumber into unit packages or into bins without vertical spaces or stickers between the layers.

Bunk, carrier. Specially designed wood beams on which lumber is placed, enabling the straddle truck or carrier to pick up the unit for transport.

Cambium. The one-cell-thick layer of tissue between the bark and wood that repeatedly subdivides to form new wood and bark cells.

Canal, resin. *Syn.* Resin duct. Intercellular passages that contain and transmit materials, extending vertically or radially in a tree.

Case hardening. A condition of stress and set in dry lumber in which the outer fibers are under compressive stress and the inner fibers under tensile stress.

Cell. A general term for the minute units of wood structure having distinct cell walls and cell cavities including wood fibers, vessel segments, and other elements of diverse structure and function.

Check. *Syn.* Drying check, checking. A separation of the wood fibers on any surface of a log, timber, or lumber resulting from tension stresses set up during drying, usually the early stages of drying.

Check end. A failure usually in the plane of the wood rays on the end grain surface of a log, timber, or board resulting from stresses caused by too rapid or excessive end drying.

Check internal. *See* Honeycombing.

Check, surface. A check occurring on the tangential surface of a board and extending across the annual growth rings into the interior.

Chemical brown stain. *See* Stain, chemical brown.

Chimney. *See* Flue. A vertical space, more than 152 (6 in.) wide, in the center of a hand-built pile extending the length and depth of the pile, intended to facilitate air circulation in the pile.

Collapse. *Syn*. Washboarding, crimping. A corrugated appearance of the surface of a piece of wood caused by an irregular drawing together of the cell walls as free water leaves the cavities; occurs only in the early stages of drying green heartwood of low permeability, especially quartersawn stock.

Common lumber. A broad grade of lumber usually including several subgrades, applied to both hardwoods and softwoods.

Compression failure. Deformation of the wood resulting from excessive pushing together of the fibers along the grain. It may develop in standing trees as a result of bending by wind or snow or as a result of internal longitudinal stresses imposed during felling. In surfaced lumber, compression failures appear as fine wrinkles across the face of the piece.

Compression wood. *See* Reaction wood. Abnormal wood formed on the lower side of branches and inclined trunks of softwood trees. As seen on the cross-section surfaces of a branch or stem, it appears as relatively wide, eccentric growth rings with little or no demarcation between earlywood and latewood and more than normal amounts of latewood. Compression wood shrinks more longitudinally than does normal wood.

Correction, temperature. An adjustment of the readings of the resistance-type electrical moisture meter to compensate for changes in the temperature of the wood.

Course. *Syn.* Layer. A single layer of lumber of the same thickness in a stickered pile or package.

Crib pile. Stacking lumber to usually form a hollow triangle. The boards lap at the corners.

Crook. A form of warp in which a board deviates edgewise from a straight line from end to end.

Cross break. A separation of the wood cells across the grain caused by internal strains resulting from the unequal longitudinal shrinkage commonly associated with reaction wood.

Cross section. *See* Section, cross.

Cup. A form of warp in which there is a deviation from flatness across the width of a board.

Decay. *Syn.* Rot. The decomposition of wood substance by fungi.

Defects. Any irregularity or imperfection in a tree, log, bolt, or lumber that reduces its volume or quality or lowers its durability, strength, or utility value. Defects may result from knots and other growth conditions and abnormalities; from insect or fungus attack; from milling, drying, machining, or other processing procedures.

Diagonal grain. *See* Grain, diagonal.

Dipping. Process of submerging lumber in a dipping vat containing fungicides or other chemicals to prevent stain or decay.

Discoloration. Change in the color of lumber as a result of a fungus, chemical stain, or weathering.

Drying. *Syn.* Seasoning. The process of removing moisture from lumber to improve its serviceability in use.

Earlywood. *Syn.* Springwood. Wood formed during the early period of annual growth; usually less dense than wood formed later.

Edge piling. Stacking of wood products on edge so that the broad face of the item is vertical; usually done to restrain crook.

Edge-to-edge stacking. *Syn.* Close piling. In stacking stickered unit packages for air drying, placing the edges of each item in the layer against the adjacent pieces.

Electrodes. In testing wood for moisture content, devices made of electrically conducting material, usually steel pins, for connecting wood into the electric circuit of an electric moisture meter.

Electrodes, insulated. In testing wood for moisture content, special electrodes for use with resistance-type electric moisture meters that are coated with an insulating material to limit or control the point of contact between the electrode and the wood.

End coating. A coating of moisture-resistant material applied to the end grain surfaces of green lumber to retard end drying and consequently checking and splitting.

End pile. Stacking of green lumber on end, and inclined in a long, fairly narrow row; the layers are separated by stickers.

End racking. Placing of boards on end against a support to form a pile in the shape of an "X" or an inverted "V."

End splitting. *See* Split, end.

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

Extractives. Substances in wood, not an integral part of the cellular structure, that can be removed by hot or cold water, ether, benzene, or other solvents that do not react chemically with a wood substance.

Fiber. A general term for a long narrow cell.

Fiber saturation point. *Abbr.* fsp. The stage in the drying of wood at which the cell walls are saturated with water and the cell cavities are free of water. It is usually considered to be approximately 30% moisture content, based on the weight of the wood when ovendry.

Flat pile. Stacking of lumber so that the broad face of the item is horizontal.

Flat pile, sloped. A pile of stacked lumber on foundations that are not level, but deviate from the horizontal. The slope is usually lengthwise of the board and may be 25 mm or more per 0.30 m (1 in. or more per foot) of length.

Flatsawn. *See* Grain, flat.

Flue. *See* Chimney. Vertical spaces, 152 mm (6 in.) or less in width in the pile and extending the length and depth of the pile, intended to facilitate circulation of air within the pile.

Foundation, open. Structural supports for the air-drying pile designed to facilitate air circulation under the pile.

Free water. *Syn.* Capillary water. Water that is held in the cell cavities of wood.

Fungi. Low forms of plants consisting mostly of microscopic threads that traverse wood in all directions, dissolving out of the cell wall materials they use for their own growth.

Grade. A classification or designation of the quality of logs or manufactured lumber.

Grain. The direction, size, arrangement, appearance, or quality of the fibers in lumber.

Grain, cross. Lumber in which the fibers deviate from a line parallel to the sides of the piece. Cross grain may be either diagonal or spiral grain or a combination of the two.

Grain, diagonal. Lumber in which the annual rings are at an angle with the axis of a piece as a result of sawing at an angle with the bark of the log. A form of cross grain.

Grain, edge. *Syn*. Comb grain, edge sawn, quarter grain, quartersawn, rift grain, rift sawn, stripe grain, vertical grain. Lumber that has been sawn or split so that the wide surfaces extend approximately at right angles to the annual growth rings exposing the radial surface. Lumber is considered edge grained when the rings form an angle of 45^{o} to 90^{o} with the wide surface of the piece.

Grain, end. The ends of logs or timbers, dimension, and boards that are cut perpendicular to the fiber direction.

Grain, flat. *Syn.* Flatsawn, plain grain, plainsawn, slash grain, tangential cut. Lumber that is sawn or split in a plane approximately perpendicular to the radius of the log. Lumber is considered flat grained when the annual growth rings make an angle of less than 45^{o} with the surface of the piece.

Grain, spiral. A form of cross grain in lumber in which the fibers take a spiral course about the trunk of a tree instead of the normal vertical course. The spiral may extend in a right-handed or left-handed direction around the tree trunk.

Grain, straight. Lumber in which the fibers and other longitudinal elements run parallel to the axis of a piece.

Grained, close. Lumber with narrow, inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine textured" is more often used.

Grained, coarse. Lumber with wide, conspicuous annual rings in which there is considerable difference between earlywood and latewood. The term is sometimes used to designate wood with large pores, such as oak, ash, chestnut, and walnut, but in this sense "coarse textured" is more often used.

Hardwoods. Generally one botanical group of trees that has broad leaves, e.g., oak, elm, and basswood. Also, the wood produced from such trees. The term has no reference to the actual hardness of the wood.

Heartwood. The inner layers of wood which, in the growing tree, have ceased to contain living cells and in which the reserve materials, e.g., starch, have been removed or converted into heartwood substances. It is generally darker in color than sapwood although not always clearly differentiated.

High temperature drying. In kiln-drying wood, use of dry-bulb temperatures of 100^{o}C (212^{o}F) or more.

Honeycombing. *Syn.* Hollow horning, internal checking, interior checking, inner checking. In lumber, separation of the fibers in the interior of the piece, usually along the wood rays. The failures are often not visible on the surfaces, although they can be extensions of surface and end checks.

Humidity, relative. The ratio of the vapor pressure of water in a given space compared with the vapor pressure at saturation for the same dry-bulb temperature. Under ordinary temperatures and pressures, it is the ratio of the weight of water vapor in a given space compared with the weight that the same space is capable of containing when fully saturated at the same temperature.

Hygrometer. An instrument for measuring the dry- and wet-bulb temperatures of the air, usually consisting of two thermometers.

Infection. The invasion of lumber by fungi or other microorganisms.

Infestation. The establishment of insects or other animals in lumber.

Juvenile wood. Growth rings formed near the pith of the tree.

Kiln drying. The process of drying lumber in a closed chamber in which the temperature and relative humidity of the circulated air can be controlled.

Kink. A form of warp in which there are sharp deviations from flatness or straightness as a result of exceptionally abrupt grain distortions, such as around knots, or the piece is sharply bent by misplaced stickers.

Knot. That portion of a branch or limb that has been surrounded by subsequent growth of the tree.

Latewood. *Syn*. Summerwood. The portion of the annual growth ring that is formed after the earlywood formation has ceased. Latewood is usually denser and stronger than earlywood.

Lumber. The product of the sawmill and planing mill that is not further manufactured other than by sawing, resawing, passing lengthwise through a standard planing machine, cross cutting to length, and matching.

Lumber, nominal size. As applied to lumber, the rough sawn commercial size by which it is known and sold in the market.

Meter, electric moisture. An instrument used for rapid determination of the moisture content in wood by electrical means.

Moisture content. The amount of water contained in the wood, usually expressed as a percentage of the weight of the ovendry wood.

Moisture content section. A cross section approximately 25 mm (1-in.) in length along the grain, cut from a board and used to determine moisture content by the oven-drying method.

Mold. A fungus growth on lumber at or near the surface and, therefore, not typically resulting in deep discolorations.

Ovendry. A term used to describe wood that has been dried in a ventilated oven at approximately 104^{o}C (220^{o}F) until there is no additional loss in weight.

Pile. *Syn.* Stack, rack. Stacking lumber layer by layer, separated by stickers or self-stickering, on a supporting foundation (hand stacking) or placing stickered unit packages by lift truck or crane, one above the other on a foundation and separated by bolsters.

Pile pitch. The forward lean of the front face of a hand-built sloped pile of lumber. The pitch is usually approximately 25 mm in 305 mm (1 in. in 12 in.) of pile height.

Pile roof. *Syn.* Pile cover, cover boards, stack cover. A cover on top of the pile to protect the upper layers from exposure to the degrading influences of sun, rain, and snow. The sides and ends of the roof may project beyond the pile to provide added protection.

Pile, roof. A method of flat stacking random-length lumber for air drying. Full-length boards are placed in the outer edges of each layer, and shorter boards are alternated lengthwise in between to produce square end piles or unit packages.

Pitch pocket. *Syn.* Gum check. An opening extending parallel to the annual growth rings containing, or that has contained, resins, either solid or liquid.

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

Rays. A ribbon-like grouping of cells extending radially across the grain, so oriented that the face of the ribbon is exposed as a fleck on the quartersawn surface.

Reaction wood. Wood with more or less distinctive anatomical characteristics, formed in parts of leaning or crooked stems and branches. In hardwoods, this consists of tension wood and in softwoods, compression wood.

Refractory. Implies difficulty in processing or manufacturing by ordinary methods; resistance to the penetration of preservatives; difficulty in drying or difficulty in working.

Resins. A class of amorphous vegetable substances secreted by certain plants or trees.

Ring failure. *Syn.* Ring shake. A separation of wood along the grain and parallel to the annual rings, either within or between the rings.

Rot. *See* Decay.

Sap. The moisture in green wood and all that is held in solution.

Sapstain. *See* Stain, blue.

Sapwood. The outer layers of the stem that in the living tree contain living cells and reserve materials, e.g. starch. The sapwood is generally lighter in color than the heartwood.

Section, cross. *Syn.* Transverse section. A section of a board or log taken at right angles to its longitudinal axis.

Shake. *See* Ring failure.

Shrinkage. The contraction of wood fibers caused by drying below the fiber saturation point. Shrinkage—radial, tangential, and longitudinal—is usually expressed as a percentage of the dimension of the wood when green.

Softwoods. In general, one of the botanical groups of trees that, in most cases, has needlelike or scalelike leaves; the conifers; also, the wood produced by such trees. The term has no reference to the actual softness of the wood.

Sorting. Segregation of rough sawn wood items into lots having similar drying characteristics, such as thickness, species, grades, sapwood, heartwood, grain patterns, and into classes for stacking, such as width and length.

Specific gravity. The ratio of the ovendry weight of a piece of wood to the weight of an equal volume of water at 4^{o}C (39^{o}F). Specific gravity of wood is usually based on the green volume.

Split. A separation of the fibers along the grain forming a crack or fissure that often extends through the piece from one surface to another.

Split, end. A split at the end of a log or board. Often an extension of end checks.

Springwood. *See* Earlywood.

Stack. To make a pile on a suitable foundation by placing layers of lumber on stickers or similar stock (self stickered). To construct by hand or with mechanical equipment, unit packages of the item to be dried, by separating layers of the stock with stickers.

Stacking rack. *Syn.* Stacking jig, stacking stall. In hand building stickered unit packages of lumber, guides are provided to produce good sticker alignment and square sides.

Stain. A discoloration in wood that may be caused by microorganisms, metal, or chemicals.

Stain, blue. *Syn*. Sapstain. A bluish or grayish discoloration in the sapwood caused by the growth of certain dark-colored fungi.

Stain, chemical brown. *Syn.* Brown oxidation stain, kiln brown stain, yard brown stain, kiln burn. A brownish discoloration of chemical origin in wood that sometimes occurs during the air drying of several softwood species, apparently caused by the concentration and oxidation of extractives.

Sticker. *Syn.* Crosser, strip, piling strip, stick. A wood strip placed between courses of lumber in a pile or unit package and at right angles to the long axis of the stock to permit air to circulate between the layers.

Sticker marking. *Syn.* Crosser stain. Indentation or compression of the lumber by the sticker when the superimposed load is too great for the sticker-bearing area. Sometimes identified as the discoloration caused by blue stain or chemical stain in the wood at the location of the sticker.

Summerwood. *See* Latewood.

Surface checking. *See* Check, surface.

Swelling. Increase in the dimensions of wood caused by increased moisture content. Swelling occurs tangentially, radially, and, to a lesser extent, longitudinally.

Temperature, dry-bulb. Temperature of air as indicated by a standard thermometer.

Temperature, wet-bulb. Temperature indicated by any temperature-measuring device; the sensitive element of which is covered by a smooth, clean, soft, water saturated cloth (wet-bulb wick).

Temperature, wet-bulb depression. The difference in the readings of wet- and dry-bulb thermometers.

Texture. The size, distribution, and proportional volume of the cellular elements of which wood is composed; often used interchangeably with grain. Depending on the relative size and distribution of the cellular elements, texture may be coarse (open grain) or fine, even, or uneven.

Tier. Stacking lumber or other wood products in vertical alignment; usually refers to sticker alignment.

Tracheid. *See* Vessels. The elongated cells that constitute the greater part of the structure of the softwoods (fibers); also present in some hardwoods.

Tramways, elevated. An elevated roadway, often constructed of wood, between rows of piles and well above the pile foundations to facilitate hand stacking.

Twist. *Syn.* Winding, spiral distortion. A form of warp; a distortion caused by the turning or winding of the edges of a board, so that the four corners of any face are no longer in the same plane.

Vessels. *Syn.* Tracheid. Tube-like structure of indeterminate length in porous woods; namely, hardwoods.

Wane. Bark, or the lack of wood from any cause, on any edge of a piece of square-edged lumber.

Warp. Distortion in lumber causing departure from its original plane, usually developed during drying. Warp includes cup, bow, crook, twist, and kinks, or any combination thereof.

Weathering. The mechanical or chemical disintegration and discoloration of the surface of lumber that is caused by exposure to light, the action of dust and sand carried by winds, and the alternate shrinking and swelling of the surface fibers with continual variation in moisture content brought by changes in the weather. Weathering does not include decay.

Weight of wood. The weight of wood depends on its specific gravity and moisture content. Weight equals the oven-dry wood and the moisture it holds. It is expressed as pounds per cubic foot at a certain moisture content or weight per 2.4 m^3 (1,000 board feet) at a specified moisture content.

Wetwood. *Syn.* Glassy, sinker, water core, water soak. Wood with abnormally high water content and a translucent or watersoaked appearance. This condition develops only in living trees and does not originate through soaking logs or lumber in water.

Wood. *Syn.* Xylem. The tissues of the stem, branches, and roots of a woody plant lying between the pith and cambium, serving for water conduction, mechanical strength, and food storage, and characterized by the presence of tracheids or vessels.