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MARKETING AND UTILIZATION

Drying Small Quantities of Hardwood Lumber—Understanding The Effects of Moisture on Wood

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Up to one-half the weight of most freshly cut hardwood lumber is water or sap. Nearly all of this water must be removed before the lumber can be used for many purposes. Simple air drying of lumber does not make it suitable for indoor use. If the wood is not dried prior to its use, it will dry while in service, shrinking and leaving gaps between boards which were originally tight together. Some warping and checking can also result. To minimize these problems, lumber produced commercially is dried in kilns to the average moisture content consistent with that found where the wood will finally be used. Kilns are large, enclosed compartments where the temperature can be elevated, sometimes as high as 240°F, and the humidity can be controlled. Commercial companies will usually not dry small quantities of lumber on a custom basis. As a result, many small woodworking companies and hobbyists frequently have problems locating economical sources of well-dried hardwood lumber.

Other individuals want to use lumber cut from their own supply of trees or logs. In this case, high quality trees suitable for veneer should not be cut for lumber. It may be more economical to harvest lower grade trees or even buy the lumber and then sell the veneer quality trees. This publication will explain the effects that the removal of moisture has on wood and will outline proper air drying procedures. A method for drying small quantities of lumber for indoor use is also given. Commercial companies and individuals who desire further information should consult the references given at the end of this publication.

Moisture Content of Lumber

The moisture content of lumber is a critical factor. Green lumber is heavy and can stain, mold, and even rot if not properly handled. As the moisture content of wood drops below 30 percent, shrinkage begins and can be accompanied by serious defects such as end splitting, surface checking, cupping, bowing, and twisting. Dry wood can also pick up moisture and swell. Therefore, knowing the moisture content of lumber is paramount in understanding how to handle and work with the material.

Table 1 shows the moisture content of freshly cut lumber for some common Indiana species. As can be seen, the moisture varies from a low of 44 percent in the sapwood of white ash to a high of 160 percent in the heartwood of cottonwood. Moisture content can also vary with location in the tree. However, the moisture content does not seem to vary substantially between seasons of the year.

A moisture content of 28 to 30 percent in North American woods is a critical point in lumber drying. This point is called the *fiber saturation point* (FSP). Comparatively large changes result in the physical and mechanical properties of wood as the moisture content drops below this point. Any moisture removed below the FSP is called "bound water" and comes from the cell wall. Therefore, the FSP is the moisture content level at which shrinkage, and thus the potential for warping, checking, and splitting of lumber, begins. Moisture above the FSP is held as "free water" in the cell cavities. Its removal will not affect the shrinkage of wood. The term FSP pertains to the moisture content of individual cell walls and not to the whole piece of wood. Therefore, when freshly cut lumber begins to check, it does not necessarily mean that the FSP has been reached throughout the piece but rather just for some cells.

The standard method of determining moisture content is called oven-drying, and the moisture content of wood is expressed as a precentage of the oven-dry weight. The oven-dry weight is determined by heating wood at 105°C until a constant weight is reached. The formula used to figure moisture content is:

$$MC = \frac{IW - OD}{OD} \times 100$$

where

MC = moisture content in percent
IW = initial weight of the wood
OD = oven-dry weight of the wood.

Electric moisture meters can also be used to determine the moisture content of wood. Although not as accurate as oven-drying, these devices can give reasonable readings within the range of seven to 25 percent moisture content; however, electric moisture meters are subject to error if not used properly. Less expensive models start at about $150.

Table 1. Moisture content in percent of oven-dry weight for freshly cut wood.

	Moisture Content (%)	
Species	Heartwood	Sapwood
Ash (White)	46	44
Basswood	81	133
Beech	55	72
Cherry	58	---
Cottonwood	160	145
Elm (American)	95	92
Hackberry	61	65
Hickory	71	49
Maple (Silver)	58	97
Maple (Sugar)	65	72
Oak (Red)	80	69
Oak (White)	64	78
Sweetgum	79	137
Sycamore	114	130
Blackgum (Tupelo)	87	115
Walnut	90	73
Yellow-Poplar	83	106

Shrinkage of Wood

Changes in the moisture content of wood below the FSP result in the shrinking and swelling of wood. The species and grain pattern will also have an effect on the amount of shrinkage that occurs. The importance of this dimensional change in wood cannot be overemphasized. As wood dries and shrinks, stresses are set up and then relieved by development of defects such as warping, surface checking, and end splitting. Common problems associated with the shrinking and swelling of wood already in service are evidenced by squeaking wood flooring and sticking doors and windows.

Figure 1 illustrates the grain pattern of lumber as it relates to shrinkage. The reduction in size parallel to the growth rings, or circumferentially, is called *tangential shrinkage*. The reduction in size parallel to the wood rays, or radially, is called *radial shrinkage*. A plain or flatsawed board shrinks tangentially in width or radially in thickness. A quartersawed board shrinks radially in width and tangentially in thickness. Lumber is seldom cut as a perfect plainsawed or quartersawed board. As a result, the expected shrinkage in the width of a board is usually some percentage between those given for radial and tangential shrinkage.

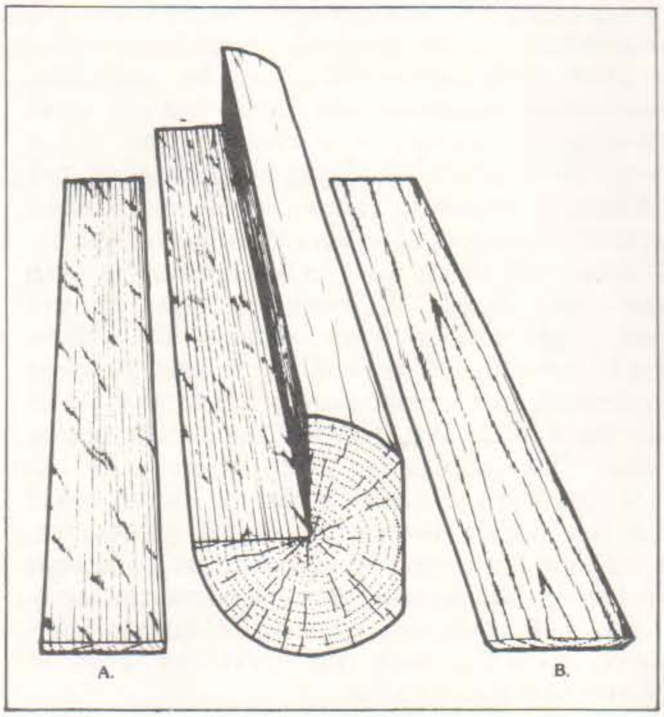


Figure 1. Quartersawed (A) and plainsawed (B) boards cut from a log.

Table 2. Total shrinkage values of common Indiana woods expressed as a percentage of green dimensions.

Species	Shrinkage to 0 percent moisture content		Shrinkage to 6 percent moisture content	
	Radial (%)	Tangential (%)	Radial (%)	Tangential (%)
Ash (White)	4.9	7.8	3.8	6.2
Basswood	6.6	9.3	5.3	7.4
Beech	5.5	11.9	4.1	8.8
Cherry	3.7	7.1	3.0	5.7
Cottonwood	3.9	9.2	3.1	7.4
Elm (American)	4.2	9.5	3.4	7.6
Hackberry	4.8	8.9	3.8	7.1
Hickory	7.4	11.4	5.9	9.1
Maple (Silver)	3.0	7.2	2.4	5.8
Maple (Sugar)	4.8	9.9	3.9	7.6
Oak (Red)	4.0	8.6	3.2	6.6
Oak (White)	5.6	10.5	4.2	7.2
Sweetgum	5.3	10.2	4.2	7.9
Sycamore	5.0	8.4	4.1	6.1
Blackgum (Tupelo)	5.1	8.7	3.5	6.2
Walnut	5.5	7.8	4.4	6.2
Yellow-Poplar	4.6	8.2	3.2	5.7

The longitudinal shrinkage of wood is generally 0.1 to 0.2 percent of the green dimension and is considered insignificant.

Wood species also affects the amount of shrinkage which will occur as wood dries below the FSP. Heavy, hard woods such as hickory or beech generally shrink and swell more than the lightweight woods such as yellow poplar and silver maple. Table 2 gives shrinkage values in the radial and tangential directions for some common hardwoods in drying from green (44-160 percent moisture) to six and zero percent moisture content. Wood with a moisture content of six to eight percent is suitable for indoor use.

The shrinkage values in Table 2 can be converted into useful units of measurement. Each three percent of shrinkage, either radially or tangentially, is roughly equivalent to a decrease in width or thickness of 1/32 inch per inch. For example, the tangential (plainsawed board) shrinkage of white oak from green to six percent moisture content is 7.2 percent (Table 2). Therefore, the shrinkage per inch in width is:

$$\frac{7.2}{3} \times \frac{1}{32} = .08 \text{ inch}$$

Equilibrium Moisture Content

Wood is generally dried to a specific moisture content depending upon its end use. However, wood is a hygroscopic material. Therefore, it constantly picks up or gives off moisture to maintain an equilibrium with the environment. Thus, wood is constantly shrinking or swelling. The amount of moisture which wood will gain or lose depends upon the temperature of the air and the relative humidity. At a constantly maintained temperature and relative humidity, wood will reach an equilibrium where it neither loses nor gains moisture. At this point, wood is said to have reached its *equilibrium moisture content* (EMC). Figure 2 shows the EMC of wood in relation to temperature and relative humidity.

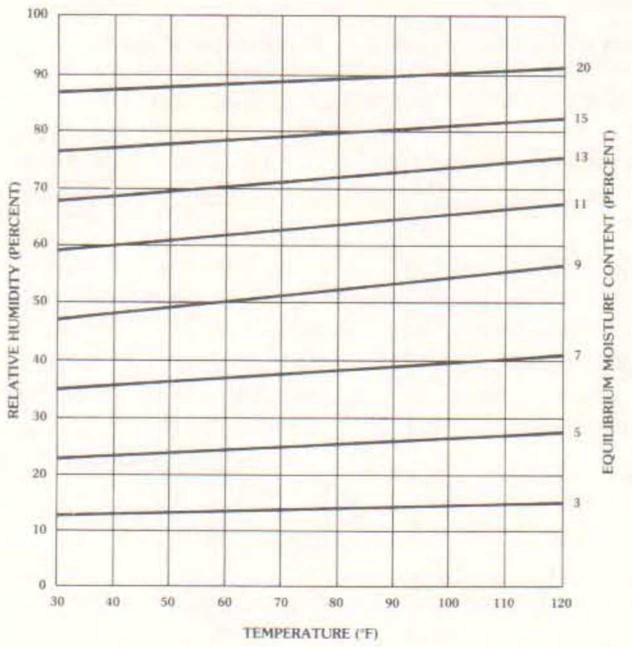


Figure 2. Equilibrium moisture content of wood as related to air temperature and relative humidity.

Under normal conditions, the EMC and thus the shrinking and swelling of wood varies between seasons of the year. Figure 2 shows that at a temperature of 70°F and a relative humidity of 30 percent, the resulting EMC of wood is about six percent. These conditions would be typical for a heated home without humidification during winter months in Indiana. During summer months, at 70°F the relative humidity would be closer to 70 percent and the resulting EMC would be slightly less than 13 percent. A change of seven percentage points in the EMC of wood will result in substantial dimensional change.

The EMC of wood and thus shrinking and swelling cannot be completely controlled under most situations. However, to prevent unnecessary problems with dimensional change, such as cracks developing in furniture or flooring, wood is dried to a moisture content which is an average EMC for the area in which it will be used. Table 3 shows these average moisture content values for different uses and locations in the United States.

How Wood Dries

Lumber dries because moisture in wood will move from zones of high concentrations to zones of low concentrations. Thus, wood will dry first on the surface. Moisture from inside the board then moves toward the surface and eventually evaporates.

During the drying process, several forces may be acting simultaneously to move water. These forces include:

1. Capillary action, which causes free water to flow, for the most part, through cell cavities and small openings in the cell wall (pits).
2. Differences in relative humidity in the wood which causes water vapor to move through various passageways by diffusion.
3. Differences in moisture content which move the bound water through the small passageways in the cell wall by diffusion.

When green wood starts to dry, evaporation of water from the surface sets up capillary forces which exert a pull on the free water in the zones of wood beneath the surface, resulting in a flow. This process is similar to the movement of water in a wick. Much of the free water in sapwood moves in this manner.

Movement of moisture by diffusion results from differences in the relative humidity and moisture content between the surface and the interior or between any two zones of the wood. Moisture in wood moves to the surface by simultaneous diffusion of vapor and bound water. In comparison with capillary movement, diffusion is a slow process.

Table 3. Recommended moisture content values for various wood items at time of installation.

	Moisture content for					
	Most areas of United States		Dry southwestern areas		Damp, warm coastal areas	
	Average	Individual pieces	Average	Individual pieces	Average	Individual pieces
	%	%	%	%	%	%
Interior:						
Woodwork, flooring, furniture, wood trim, laminated timbers, cold-press plywood	8	6-10	6	4-9	11	8-13
Exterior:						
Siding, wood trim, framing, sheathing, laminated timbers	12	9-14	9	7-12	12	9-14

The rate at which moisture moves through wood depends upon the permeability of the species being dried. Generally lighter woods will dry faster than heavy ones. Sapwood will dry faster than heartwood since its pits are "open," and it does not contain extractives or other obstructions as heartwood often does.

Moisture moves through wood in the longitudinal direction as well as laterally. Although diffusion is about 10 to 15 times faster longitudinally, drying in this direction (except for end checking and splitting) is not of practical importance except for short items. Because of rapid longitudinal diffusion, large stresses can develop at the ends of boards. These stresses can lead to end checking and deep splits on wide stock. End coatings are sometimes used to control longitudinal diffusion and thus reduce defects at the ends of the piece.

Since the surface or "shell" of a board dries first and begins to shrink, stress can build up. Stress can result in surface checking, and sometimes when it is severe, as in improper kiln drying or very rapid air-drying, stress can even cause collapse or checking in the interior of the board or "core."

As the shell of the board dries, it will begin to shrink, but the core will try to retain its original dimensions. Therefore, the shell of the board is stressed in tension, and surface checks will open up. These surface checks are common in oak as it begins to dry. Then, as the core eventually dries, it will shrink and relieve some of the tension in the shell, and the checks may close up. However, sometimes the shell of the board may become "set" and prevent the checks from closing completely. Or as the core begins to dry, it will be restrained by the shell, and internal checking will develop. Under proper conditions, most drying defects can be prevented. However, if drying becomes too rapid, serious damage to the wood can result.

Air-Drying Lumber

A great deal of the moisture in freshly cut hardwood lumber can be removed by air seasoning. Properly stacked lumber will dry to about 15 to 20 percent moisture content. The time it takes lumber to air-dry depends upon climatic conditions (temperature, relative humiditiy, and air movement or wind), wood species, lumber thickness, and piling method. Air seasoning times for green one-inch thick lumber for some common hardwood species are given in Table 4. The minimum times apply to lumber piled during good drying weather such as occurs in the spring and summer. Lumber piled late in the summer, or lumber that is piled during the fall or winter, will usually not reach a moisture content of 20 percent until the following spring. This accounts for the maximum periods given in the table.

The wood species also affects the drying rate. In general, the relatively lightweight species such as yellow poplar, silver maple, and basswood will air season at a faster rate than the relatively heavy woods such as oak, walnut, cherry, and beech. Oak is noted as a slow and difficult wood to dry, and some serious checking and splitting can even occur during air-drying.

Lumber cut two inches thick will require three to five times longer to air season than the times given in Table 4. Lumber cut thicker than two inches, particularly of the hard-to-dry woods such as oak, is even more difficult to air season and will require substantially longer time periods.

Table 4. Approximate time to air-dry green 1-inch lumber to 20 percent moisture content.

Species	Time (days)
Ash (White)	60-200
Basswood	40-150
Beech	70-200
Cherry	70-200
Cottonwood	50-150
Elm (American)	50-150
Hackberry	30-150
Hickory	60-200
Maple (Silver)	30-120
Maple (Sugar)	50-200
Oak (Red)	70-200
Oak (White)	80-250
Sweetgum	
Heartwood	70-300
Sapwood	60-200
Sycamore	30-150
Blackgum (Tupelo)	70-200
Walnut	70-200
Yellow-Poplar	40-150

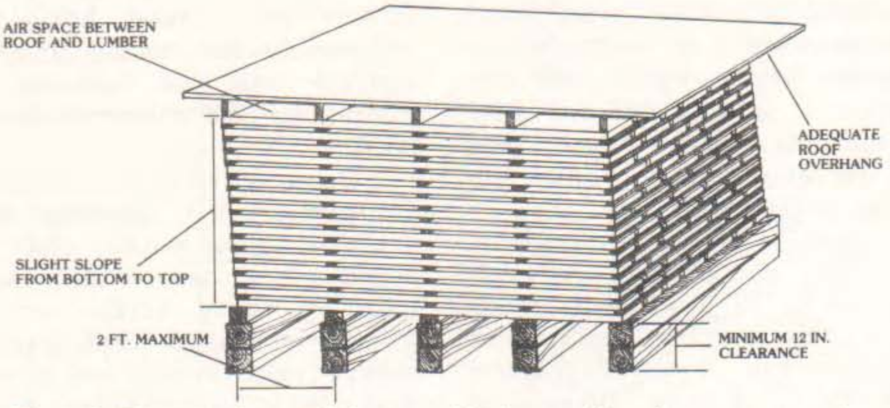


Figure 3. Diagram of essential features of lumber stacking for proper seasoning.

To air-dry lumber in a reasonable time period and to prevent excessive amounts of degrade, certain steps should be followed. Figure 3 illustrates the essential features of a well constructed lumber pile.

Start with a good foundation. In commercial situations, air-drying yards are often paved or at least built up with road rock and are graded so that all water will run off rapidly. Lumber foundations are sometimes made with concrete footings and iron- or pressure-treated crossbeams or stringers bolted directly to the concrete. The foundation should be constructed in such a way that air is allowed to circulate freely under the pile. Weeds, grass, and other vegetation must be eliminated around the pile. The foundations are sometimes sloped to allow rain water to run off the lumber pile.

The lumber pile should be oriented so that the prevailing winds will blow across the boards. Commercial lumber piles are often eight feet wide, but more rapid drying is likely with narrower piles. However, some care must be exercised when green lumber of the difficult-to-dry species is exposed to persistent hot, dry winds. In these cases, the lumber can suffer serious degrade unless the pile is protected

However, lumber can be dried without such elaborate foundations. Railroad crossties, heavy timbers, or cement blocks can be used as a foundation. Regardless of how the foundation is erected, it is important that it slopes from front to back about one inch for every foot of length to insure water run-off. The lowest point of the pile should be at least 12 inches above ground level. Make certain that the cross members are in perfect alignment since any low or high spot or a twist from opposite corners of the pile will result in lumber with about the same amount of warp. Cross members should be arranged so that one is present at the very front of the pile, at the very back of the pile, and at about two foot intervals in between. Wood strips called stickers are placed directly above each crossbeam to space the lumber. It may also be helpful to cover the soil beneath and around the lumber pile with black polyethylene to keep the moisture from moving from the soil to the wood and to keep weeds and grass down which could restrict natural air movement.

The quantity of lumber to be piled will likely affect the method used. Ideally, the lumber should be sorted for length and thickness. Lumber of the same length should be put in one pile. If this practice is not feasible, the lumber should be "box piled" (Figure 4). For each tier of lumber, the long boards should be placed on the edges of the pile. Shorter boards should be on the inside and should alternate being flush with the front and back of the pile. Loose ends should not be allowed to overhang without support. It is also easier to put the thick lumber on the bottom of the pile. This positioning prevents some handling of the heavy stock, and the weight from the top of the pile will restrain this material as it dries, preventing excessive warping. Furthermore, the thick stock will take longer to air season. If you plan to use certain boards first, these should be near the top of the pile for easy access.

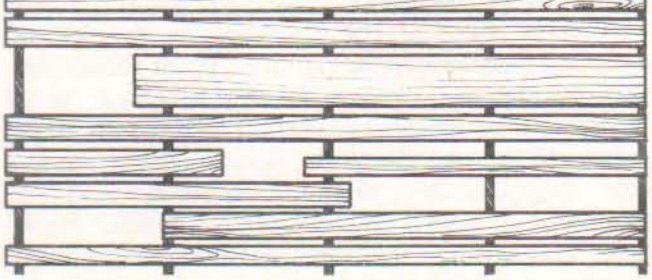


Figure 4. Plan view of a tier of boards, illustrating the system of alternating short lengths for box piling. Unsupported ends of boards placed on the inside will dry with less defect than if allowed to extend over the end of the pile.

Stickers are used to separate each tier of lumber so that the air can move between the boards. The stickers should be straight, of uniform thickness, free from bark, decay and stain, and thoroughly dry. Stickers are commonly 1-inch thick by 1-1/2 inches wide. The length of the stickers should be the width of the lumber pile. Thinner material can be used but it will likely result in slower drying. Building lathe doubled in thickness is sometimes appropriate if standard-size material is not available. Be certain that an adequate supply of stickers is available so that green lumber can be piled promptly.

The stickers must be placed directly over the foundaton crossbeams, with the ends in good vertical alignment, so that each vertical tier of sticker is supported by a crossbeam. Some short boards will be encountered. Do not allow these board ends to occur directly over each other in succeeding layers. Stickers can help bridge an occasional gap, but the pile will be weakened, and the boards will likely warp if too many gaps occur in one spot. Likewise, boards which overhang the end of the pile by more than a foot or two without support will warp severely during drying.

In sloped lumber piles, each course of boards should protrude slightly beyond the board ends in the previous layer so that the front of the pile is pitched slightly forward. To reduce severe end splits, it is helpful to place a sticker directly at the end of the board; even overlapping by about 1/4 to 1/2 inch is helpful. As the pile is built up, these stickers and boards are compressed, thus reducing end splits.

In properly piled lumber, the weight of the lumber helps prevent excessive warping in all but the top courses. Therefore, the low grade boards should be placed on top of the pile. Other weights such as concrete blocks will help restrain the top course of lumber.

The lumber pile should also be covered. In commercial operations, roofs are constructed of galvanized sheet metal or of lumber covered with roofing paper. Practically any device which sheds water can be used. The roof should extend two feet beyond the front and back of the pile. An air space of four to six inches should be left between the top of the pile and the bottom side of the roof.

End Coatings

Lumber dries several times faster from the ends of a board than from the surface or edges. As a result, wide boards often check severely. This checking can be reduced by end coating. Commercial end coatings are available, but it may be easier to use readily available materials when dealing with small quantities of lumber. Aluminum paint in a spar varnish base or asphalt roofing cement will work well. This end coating can be applied to the lumber or even to logs before they are cut.

Lumber Stain and Wood Borers

Both fungal type stain and wood borers can be a serious problem in green hardwood lumber and can be controlled by the use of chemicals. However, if your logs are sawed into lumber soon after the trees are felled and lumber is stacked to air-dry within a few days after being cut, few problems will be experienced. Also, substantially fewer problems are experienced from fungi (stain) and insects when logs and lumber are cut during cold weather rather than in the hot summer months. For additional information about stain and borers, consult the list of additional readings at the end of this publication.

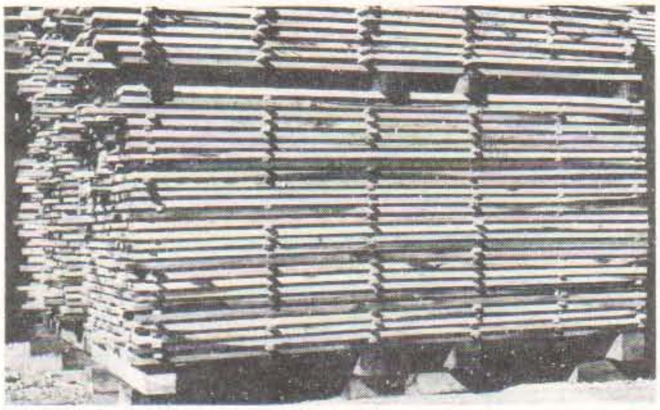
Additional Drying Procedures

Thoroughly air seasoned lumber is suitable for constructing unheated garages, barns, or other farm buildings. However, air-dried lumber *is not* suitable for indoor use. Well air seasoned lumber can dry to about 15 to 20 percent moisture content while lumber used inside should have a moisture content of only six to eight percent. Therefore, further drying is necessary.

Commercially, dry kilns are used to bring the moisture content of lumber down to the six to eight percent range. Unfortunately, most commercial kiln operations cannot economically handle and dry small quantities of lumber. However, if you should have access to a dry kiln, be certain that the kiln operator has set up a stress relief period at the end of the drying cycle. Failure to relieve stresses set in wood during kiln drying causes saw pinching and warping of boards when they are ripped.

If access to a dry kiln is not possible, some alternatives do exist. For example, small quantities of well air seasoned lumber can be further air-dried in areas subject to natural heating such as attics and the overhead space in garages during summer months. In houses without mechanical humidification, small pieces of well air-dried stock can usually be dried during the winter months in a few weeks to a suitable moisture content simply by bring them inside.

Limited experience with a small solar heated dryer in southern Wisconsin (43° North latitude) shows that solar heating can be used to dry



Well-constructed lumber pile under commercial conditions.

lumber suitable for high quality uses such as furniture. The dryer will reduce the moisture content of lumber to about eight percent. Additional information and construction plans are available by requesting Forest Products Utilization Technical Report No. 7, "Constructing and Operating a Small Solar-Heated Lumber Dryer" from the U.S. Forest Products Laboratory, Box 5130, Madison, Wisconsin 53705.

Regardless of what substitute method is used for kiln drying, extreme care must be exercised to see that the lumber finally reaches a moisture content of six to eight percent. Otherwise, shrinking, warping, and checking of the lumber after it is put into use is likely. One approximate method to determine if the wood is dry enough to use is to cut a section approximately one inch in length across the grain from each of several of the wider boards. To avoid the effects of earlier end drying, the section should be cut from the center portion of the boards and should be several inches from any knot or other defect. Measure the width of this board section to within 1/64 inch. Place the section near an operating radiator, hot air register, or stove for *at least* one day. If no checks appear on the ends and no measurable shrinkage in width occurs, the wood is uniformly dry to a moisture content of about six to eight percent.

Additional Readings

Air Drying of Lumber—A Guide to Industry Practices. 1971. Agr. Handbook No. 402, USDA Forest Service, 110 pp. (For sale by the Superintendent of Documents, Goverment Printing Office, Washington, D.C. 20402).

Storage of Lumber. 1978. Agr. Handbook No. 531, USDA Forest Service, 63 pp. (For sale by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402).

Dry Kiln Operator's Manual. 1961. Agr. Handbook No. 188, USDA Forest Service, 197 pp. (For sale by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402).

"Sap Stain in Hardwood Logs and Lumber," FNR 90, 6 pp. (Available from Agriculture Mailing Room, Agricultural Administration Building, Purdue University, West Lafayette, IN, 47907).*

"Powder Post Beetles," E-73, 2 pp. (Available from Agriculture Mailing Room, Agricultural Adminstration Building, Purdue University, West Lafayette, IN, 47907).*

Acknowledgement

Acknowledgement is given to the numerous technical wood drying publications of the U.S. Forest Products Laboratory, Forest Service, Madison, Wisconsin.

*Free of charge to Indiana residents. Out-of-state residents should request a price quotation from the Mailing Room.

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