Chapter 7
Kiln Schedules

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Chapter 7 was revised by William T. Simpson, Supervisory Research Forest Products Technologist, and R. Sidney Boone, Research Forest Products Technologist.

A kiln schedule is a carefully worked-out compromise between the need to dry lumber as fast as possible and, at the same time, to avoid severe drying conditions that will cause drying defects (ch. 8). It is a series of dry- and wet-bulb temperatures that establish the temperature and relative humidity in the kiln and are applied at various stages of the drying process. Temperatures are chosen to strike this compromise of a satisfactory drying rate and avoidance of objectionable drying defects. The stresses that develop during drying (ch. 1) constitute the limiting factor that determines the kiln schedule. The schedules must be developed so that the drying stresses do not exceed the strength of the wood at any given temperature and moisture content. Otherwise, the wood will crack either on the surface or internally, or be crushed by forces that collapse the wood cells. Wood generally becomes stronger as moisture content decreases, and, to a lesser extent, it becomes weaker as temperature increases. The net result is that as wood dries, it becomes stronger because of the decreasing moisture content and can tolerate higher drying temperatures and lower relative humidities without cracking. This is a fortunate circumstance because as wood dries, its drying rate decreases at any given temperature, and the ability to raise the drying temperature helps maintain a reasonably fast drying rate. Thus, rapid drying is achieved in kilns by the use of temperatures as high as possible and relative humidities as low as possible. For hardwoods, relative humidity can generally be reduced substantially before temperature can be raised substantially.

Drying stresses are related to the difference between the moisture content of the interior and surface of the lumber. The extent of this difference is related to the kiln temperature, relative humidity, and airflow as well as the characteristics of the species. The larger the difference in moisture content, the greater the drying stresses. If the drying stresses become too great, they can exceed the strength of the wood and cause surface and internal cracks. Many kiln schedules are based on average moisture content of the wood because it indicates the difference in moisture content between the interior and surface of the wood.

Kiln schedules can be classified as general or special. General schedules are intended for drying lumber intended for almost any product and will do a satisfactory job. Special schedules are those developed to attain certain drying objectives; for example, to reduce drying time, dry chemically treated lumber, or maintain maximum strength of the lumber for special uses. Because of the many variables in the character of wood, type and condition of kiln, quality of drying required, and cost considerations, no schedule presented in this chapter can be considered ideal. The schedules are presented as guides for kiln operators in developing schedules best suited for their own particular operation. In general, the schedules presented are conservative and can often be accelerated with care; this chapter also outlines procedures for systematically accelerating a schedule.

Commercial kilns use different methods for drying hardwoods and softwoods. In general, hardwood lumber is slower drying and more susceptible to defects than softwood lumber. Also, most end uses of kiln-dried hardwood lumber require uniformity of moisture content and permit few drying defects. Softwoods, on the other hand, generally dry faster and more uniformly than hardwoods, and are less susceptible to drying defects. Also, most structural lumber is made from softwoods, and the standards for such lumber are lower in regard to drying defects and tolerance of moisture content. The net result is that hardwoods are generally kiln dried by moisture content schedules; that is, dry- and wet-bulb temperatures are changed when the lumber reaches certain moisture contents. Softwoods, on the other hand, are generally kiln dried by time schedules—whether the wood is intended for structural lumber or for appearance uses, such as furniture or millwork. In time schedules, dry- and wet-bulb temperatures are changed after certain periods with no estimate of moisture content as a guide. Moisture content schedules can often be changed to time schedules after lumber of the same species, thickness, and source is repeatedly dried in the same kiln.

Satisfactory time schedules have been worked out for drying softwood lumber of a uniform character in the same type of kiln. An operator inexperienced in drying softwoods may want to consider a moisture content schedule as a safer way to get started and then switch over to a time schedule later. Even though moisture content schedules are rarely used for softwood lumber, they are included in this manual for the occasions when they might be useful.

The schedules listed in this chapter are designed for use in kilns where the air velocity is approximately 400 ft/min. The general schedules are conservative enough to produce lumber with a minimum of drying defects in a reasonably short time. The operator should not make the schedules more conservative unless there is some specific reason for doing so, such as abnormal lumber or poor kiln performance. With properly maintained kilns, the general schedules can usually be modified to shorten drying time.

The schedules presented in this manual are also presented in the report by Boone et al. (1988) referenced at the end of this chapter. In this report, the kiln schedules are completely written out rather than coded, and thus the report serves as a quick reference source for schedules.

Hardwood Schedules

General Hardwood Schedules

Pilot testing and considerable commercial experience have demonstrated that the general schedules developed by the Forest Products Laboratory for steam-heated kilns, which are presented in this chapter, are satisfactory for drying 2-in and thinner hardwood lumber. They form the base from which an operator can develop the most economical schedule for a specific type of kiln. Related information on application and modification of the schedules is also presented together with suggestions for drying thick hardwoods.

Moisture Content Basis

Both drying rate and susceptibility to drying defects are related to the moisture content of lumber, so kiln schedules are usually based on moisture content. The successful control of drying defects as well as the maintenance of the fastest possible drying rate in hardwood lumber depends on the proper selection and control of temperature and relative humidity in the kiln.

At the start of drying, a fairly low temperature is required to maintain maximum strength in the fibers near the surface to help prevent surface checks (ch. 8). The relative humidity should be kept high early in drying to minimize the surface checking caused by the tension stresses that develop in the outer shell of lumber (ch. 1). Even at these mild initial kiln conditions, the lumber will lose moisture rapidly. Therefore, each combination of species and thickness (and in some cases, end product) has been classified into a schedule code of "T" number for temperature and "C" number for wet-bulb depression settings. To maintain a fast drying rate, relative humidity must be lowered gradually as soon as the moisture content and stress condition of the wood will permit. Wood becomes stronger as moisture content decreases and can withstand higher drying stresses. As a general rule, relative humidity can be safely lowered gradually after the green wood has lost about one-third of its moisture content. The temperature generally cannot be raised, even gradually, until the average moisture content reaches about 30 percent. These first temperature changes must be gradual because at about this moisture content the stresses begin to reverse; that is, the core of the lumber goes into tension (ch. 1), and the danger of internal honeycomb becomes a concern. When the moisture content at midthickness is below 25 to 30 percent moisture content (which means the average moisture content for l-in-thick lumber is about 20 percent), it is generally safe to make a large increase in dry-bulb temperature in order to maintain a fast drying rate. In thicker lumber of some dense species, it is necessary to bring average moisture content down to 15 percent to get midthickness moisture content down to 25 to 30 percent. If the temperature is raised too soon while the core is still wet and weak, the danger of honeycomb is great in some species such as oak. An ample number of kiln samples should be used to make good estimates of these critical moisture contents. The recommended operating procedure is to take the average moisture content of the wetter half of the kiln samples—called the controlling samples-as the factor that determines when to change drying conditions (ch. 6).

Material Considerations

The general schedules are for hardwoods that are to be dried from the green condition. They can be modified to apply to previously air-dried lumber. The schedules are for the more difficult to dry types of lumber in a species-for example, flatsawn heartwood. Because of the difference in the moisture content of sapwood and heartwood in many species, most of the kiln samples should be taken from the wettest heartwood and their moisture content used in applying the kiln schedule. Modifications are suggested later in this chapter for lumber that is all or predominately sapwood.

Recommended Schedules for Steam-Heated Kilns

Schedules for dry-bulb temperatures and wet-bulb depressions are given in tables 7-1 and 7-2. Together, the dry-bulb temperature and the wet-bulb depression determine the relative humidity and the wood equilibrium moisture content (EMC) (ch. 1, table 1-6).

Table 7-1 lists 14 temperature schedules ranging from a very mild schedule, T1, to a severe schedule, T14. In all cases, initial temperatures are maintained until the average moisture content of the controlling samples reaches 30 percent.

Table 7-2 lists the wet-bulb depression schedules for six moisture content classes. These classes are related to the green moisture content of the species (table 7-3). Another moisture content class, H, will be discussed later. There are eight numbered wet-bulb depression schedules; number 1 is the mildest and number 8, the most severe. The wet-bulb temperature to be set on the recorder-controller is obtained by subtracting the wet-bulb depression from the dry-bulb temperature.

Table 7-4 is an index of recommended schedules for 4/4 to 8/4 hardwood lumber and other products. While the same schedule is listed for 4/4, 5/4, and 6/4 lumber, these thicknesses obviously will have different drying times and should be dried separately. For drying 6/4 lumber of refractory species such as oak, the 8/4 schedule may be desirable.

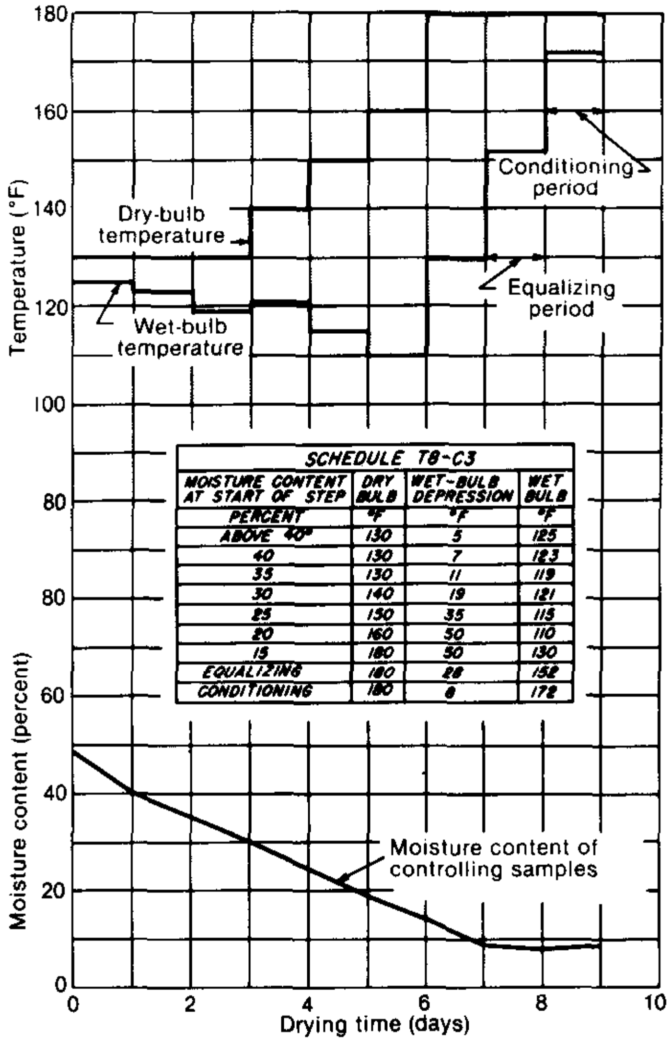
There are 672 possible schedules in tables 7-1 and 7-2. There is no demonstrated need for so many schedules, nor have they all been tested. They merely represent a systematic way to develop the whole range of degrees of severity in kiln schedules. The combination of experience and judgment then allows one to estimate an appropriate schedule.

Kiln-drying hardwoods thicker than 8/4 from the green condition is often impractical because of the long kiln time. A common practice is to either air dry the lumber before kiln drying or use a predryer before kiln drying. Table 7-5 is an index of suggested schedules for 10/4 and thicker hardwood lumber. These schedules are not as well established as the schedules for thinner lumber and should be used with caution.

Assembly of a Drying Schedule

A form such as the one in table 7-6 can be used to assemble a drying schedule as follows:

1. From table 7-4, find the schedule code number for the lumber to be dried. In table 7-6 the code numbers are T8-C3 for 4/4 sugar maple. Place the code numbers at the top of the form.
2. Since the first change in drying conditions involves the wet-bulb depression, write the wet-bulb depression step numbers 1 through 6 in column 2.
3. In column 3, write the moisture content values corresponding to these steps from the appropriate moisture content class of table 7-2. In this example, the class is C, so the values are >40, 40, 35, 30, 25, and 20.
4. In column 5, write the wet-bulb depression values corresponding to the steps from the appropriate wet-bulb depression schedule number from table 7-2. In this example, the number is 3, so the wet-bulb depression values are 5, 7, 11, 19, 35, and 50.
5. In column 1, write the temperature step numbers. Since dry-bulb temperature changes are not made until the average moisture content of the controlling samples reaches 30 percent, repeat temperature step number 1 as often as necessary. In this example, it is repeated three times. The moisture content at the start of temperature step 5 is 15 percent (table 7-1). Therefore, in filling out the schedule form it is necessary to repeat wet-bulb depression step 6, as shown in table 7-6. Experienced kiln operators usually omit columns 1 and 2.



SCHEDULE T8-C3			
MOISTURE CONTENT AT START OF STEP	DRY BULB	WET-BULB DEPRESSION	WET BULB
PERCENT	°F	°F	°F
ABOVE 40°	130	5	125
40	130	7	123
35	130	11	119
30	140	19	121
25	150	35	115
20	160	50	110
15	180	50	130
EQUALIZING	180	28	152
CONDITIONING	180	8	172

Figure 7-1—Kiln schedule and drying curve for 4/4 sugar maple. (ML88 5608)

6. In column 4, write the dry-bulb temperature that corresponds to the temperature step number in table 7-1. If step 1 is repeated, the initial dry-bulb temperature must be repeated, as shown in table 7-6.
7. Subtract the wet-bulb depression from the dry-bulb temperature in each step to obtain the corresponding wet-bulb temperature. These values are entered in column 6.

Columns for relative humidity and EMC, which are helpful in understanding drying, can be added at the right of the table if desired. These values can be obtained from table 1-6 in chapter 1. The T8-C3 schedule for 4/4 sugar maple and a drying curve obtained in a kiln run are illustrated in figure 7-1.

Uniformity of moisture content and relief of drying stresses are achieved by equalizing and conditioning treatments near the end of drying, as described later in this chapter.

Examples of Assembled Schedules

Some schedules for hardwoods, assembled from tables 7-1 and 7-2, are illustrated in table 7-7. A study of these will be helpful when assembling schedules for other species.

The schedules listed in tables 7-1 and 7-2 may be conservative for some types of dry kilns and for some drying requirements. With experience, an operator should be alert to the possibility of modifying schedules to reduce drying time. Schedule modifications are discussed later in this chapter.

Use of Schedules for Air-Dried or Predried Lumber

The general schedules for green hardwoods are also recommended for kiln drying lumber that has previously been air dried or dried in a predryer. Most kiln samples should be prepared from the wettest and slowest drying boards, but should include at least one sample from the driest and fastest drying boards (ch. 6).

For 4/4, 5/4, and 6/4 (except oak) lumber that has been dried to 20 to 30 percent moisture content, the following procedure applies:

1. Bring the dry-bulb temperature up to the value prescribed by the schedule for the average moisture content of the controlling kiln samples, keeping the vents closed and the steam spray turned off.
2. After the kiln has reached the dry-bulb temperature, set the wet-bulb temperature.
   a. If the air-dried or predried lumber has not been wetted on the surface or exposed to a long period of high humidity just before entering the kiln, set the wet-bulb temperature as specified by the schedule.
   b. If there has been surface wetting or moisture regain, set the wet-bulb controller for a 10 °F wet-bulb depression and turn on the steam spray. Let the kiln run 12 to 18 h at this wet-bulb setting, and then change to the wet-bulb setting specified by the schedule.

For 6/4 and 8/4 oak that has been dried to 20 to 30 percent moisture content, the following procedure applies:

1. Bring the dry-bulb temperature up to the value prescribed by the schedule for the average moisture content of the controlling kiln samples, keeping the vents closed. Use steam spray (manually) only as needed to keep the wet-bulb depression from exceeding 12 °F.
2. After the kiln has reached the dry-bulb temperature, set the wet-bulb temperature.
   a. If there has been no surface moisture regain, set the wet-bulb temperature at the level specified by the schedule.
   b. If there has been surface moisture regain, set the wet-bulb controller for an 8 °F wet-bulb depression and turn on the steam spray. Let the kiln run for 18 to 24 h at this setting. Then set a 12 °F depression for 18 to 24 h before changing to the conditions specified in the schedule.

If the moisture content of lumber going into the kiln is much above about 30 percent, the procedure for lumber that has been only partially air dried or predried is slightly different. For 4/4, 5/4, and 6/4 (except oak) lumber, the following procedure applies:

1. Bring the dry-bulb temperature up to the value prescribed by the schedule for the average moisture content of the controlling kiln samples. Keep the vents closed and use steam spray only as needed to keep the wet-bulb depression from exceeding 10 °F. Do not allow the depression to become less than 5 °F or moisture may condense on the lumber.
2. After reaching the prescribed dry-bulb temperature, run each of the first three wet-bulb depression steps of the whole schedule a minimum of 12 h, but still observe the 5 °F minimum wet-bulb depression. Then change to the conditions prescribed for the moisture content of the controlling samples.

For partially dried 6/4 and 8/4 oak, the following procedure applies:

1. Bring the dry-bulb temperature up to the value prescribed by the schedule for the average moisture content of the controlling kiln samples. Keep the vents closed and use steam spray only as needed to keep the wet-bulb depression from exceeding 8 °F. Do not allow the depression to become less than 5 °F.
2. After the prescribed dry-bulb temperature has been reached, run each of the first three wet-bulb depression steps of the schedule a minimum of 18 h while still observing the 5 °F minimum wet-bulb depression. When the kiln conditions coincide with those prescribed by the schedule for the average moisture content of the controlling samples, change to the moisture content basis of operation.

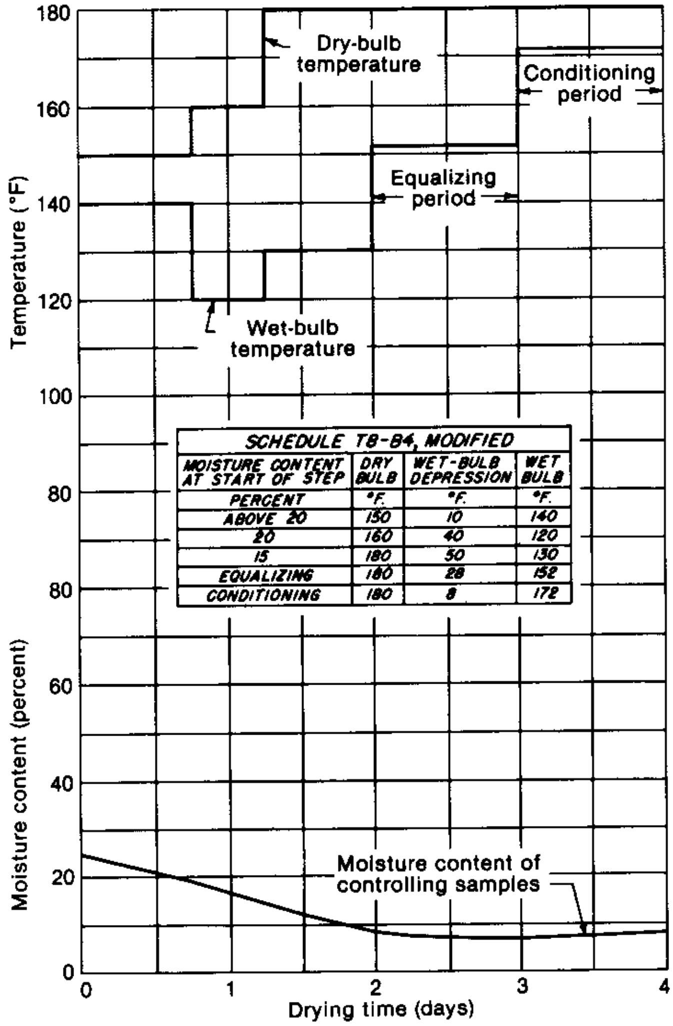


Figure 7-2—Kiln schedule and drying curve for air-dried 4/4 black cherry that has regained surface moisture before entering the kiln. (ML88 5607)

The kiln-drying conditions for 4/4 air-dried black cherry that has regained surface moisture before entering the kiln are shown in figure 7-2.

Air-dried lumber should not be subjected to high humidity at the start of kiln drying. This may cause surface checks to open during subsequent drying and thereafter remain open. It may also increase warping.

Modifications to General Hardwood Schedules

Once a kiln operator has dried a certain species and item by one of the general kiln schedules without causing defects or excessive degrade, modification of the schedule should be considered to reduce drying time. Perhaps the lumber can stand a more severe schedule without developing serious defects, or the dried product does not need to be free of defects. The operator should try to develop the fastest drying schedules consistent with acceptable amounts and types of defects. Schedules should be modified in a systematic way, for which good records will be helpful. It must be recognized, however, that schedule modification satisfactory for lumber from one source and dried in one kiln may not be satisfactory for lumber from another source and dried in a different kiln.

Kiln schedule modifications required by factors of kiln operation or performance are dealt with in chapter 9. Drying charges of mixed species are also discussed in chapter 9.

The first move in systematic schedule modification is to shift from one wet-bulb depression schedule to another, the second is to shift temperature schedules, and the third is to modify certain steps within the schedule.

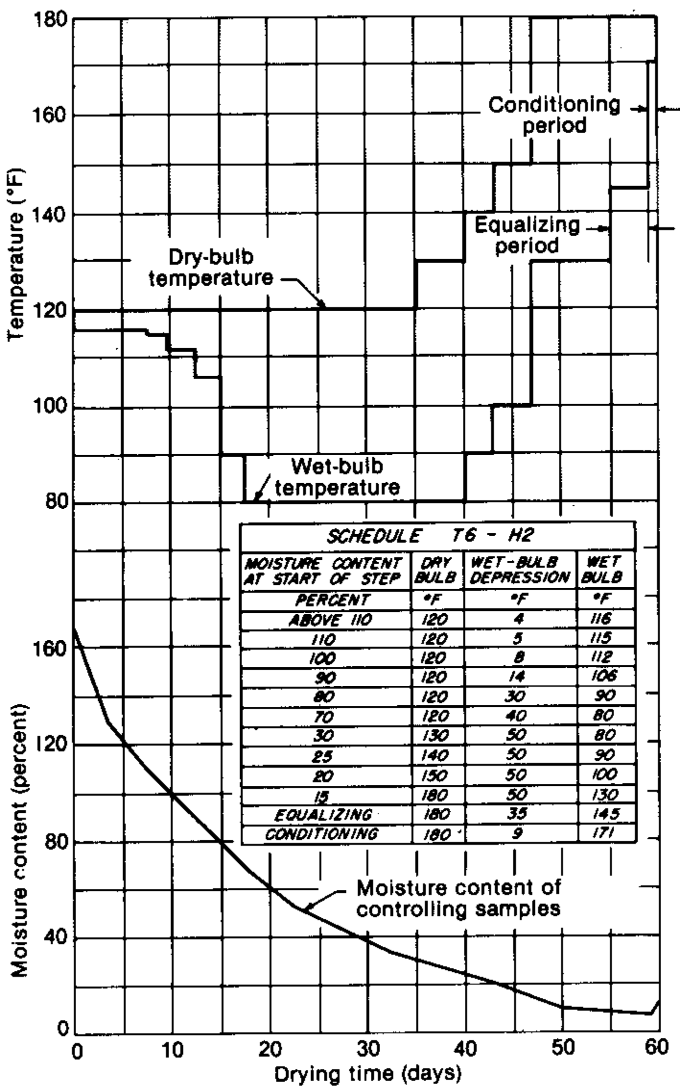
Shifting Wet-Bulb Depression Schedules

The moisture content classes (table 7-3) are set up so that a species of wood can be classified in accordance with the green moisture content of its heartwood. The moisture content limits of the classes were chosen on a conservative basis. Thus, the first modification that a kiln operator should consider is to shift to a higher moisture class, particularly if the green moisture content is near the upper end of the values in the class. For example, 4/4 northern red oak at 95 percent moisture content has been successfully dried in pilot tests on the E2 instead of the D2 schedule, with a saving of 4 or 5 days in drying time. By going to the E2 schedule, the first increase in wet-bulb depression is made at 60 percent moisture content rather than at 50 percent. This modification is especially useful when the lumber to be dried is mostly sapwood.

The next modification that should be considered is to shift to the next higher wet-bulb depression schedule number. This modification results in an increased wet-bulb depression at each moisture content level. It may cause minor surface and end checks that are generally of little concern for many uses. A drastic change in wet-bulb depression may cause severe surface and end checks.

Using H-Type Wet-Bulb Depression Schedules

A special moisture content class, designated as H, has been devised to permit more use of the principles that the first change in wet-bulb depression can be made when one-third of the green moisture content is gone and that additional increases in wet-bulb depression can be made soon after. This is particularly useful in drying species with a green moisture content of greater than 140 percent, but may also be applied with some advantage to lumber with a green moisture content of 100 percent or more. The H schedules are given in table 7-8. The wet-bulb depression schedule numbers are the same as those in table 7-2.



SCHEDULE T6 - H2			
MOISTURE CONTENT AT START OF STEP	DRY BULB	WET-BULB DEPRESSION	WET BULB
PERCENT	°F	°F	°F
ABOVE 110	120	4	116
110	120	5	115
100	120	8	112
90	120	14	106
80	120	30	90
70	120	40	80
30	130	50	80
25	140	50	90
20	150	50	100
15	180	50	130
EQUALIZING	180	35	145
CONDITIONING	180	9	171

Figure 7-3—Kiln conditions and drying curve for 1-1/2-in-thick water tupelo heartwood, based on H schedule T6-H2. (ML88 5606)

To set up a specific H schedule, find the moisture content for the first change in wet-bulb depression by taking two-thirds of the average green moisture content of the controlling samples. If, for example, their average green moisture content is 168 percent, the first change point is 112 percent. For convenience, this is rounded to 110. Subsequent changes in wet-bulb depression are made after each 10 percent loss in moisture. An H schedule developed for 6/4 water tupelo heartwood is shown in figure 7-3. In view of the long drying time in this particular case, preliminary air drying or predrying should be considered. However, H schedules are applicable to other, faster drying species.

Shifting Temperature Schedules

Temperature is critical in preventing collapse and honeycomb, two defects that may not appear until later in the drying process. Until the kiln operator has gained experience in drying a particular species and thickness, the recommended temperature schedule number should be followed. The general temperature schedules will safely dry most lumber used in commercial drying. If the lumber being dried is almost all sapwood or is relatively free of natural characteristics that contribute to drying defects, increasing the temperature (T) number by 1 or 2 to obtain a 10 °F greater initial temperature generally is permissible. For example, 9/4 all-sapwood sugar maple free of pathological heartwood and mineral streak has been dried on a T7 temperature schedule instead of the recommended T5 schedule. The milder T5 schedule would be used for drying a charge of sugar maple that had a considerable amount of heartwood or mineral streak.

Changes Within the Schedule

The only significant change that can be made within a wet-bulb depression schedule is a more rapid reduction of wet-bulb temperature during the intermediate stages of drying. The logical approach is to increase the wet-bulb depression in steps 3 and 4 of table 7-2. This modification should be approached with caution, and several charges should be dried before making further modification. If any objectionable amount of checking occurs, ease back the wet-bulb depression to the previously satisfactory schedule.

Three types of temperature changes within the T schedules (table 7-1) can be considered. One is to use a temperature in the initial stage of drying that is between that of steps 1 and 2 of the recommended schedule. For some slow-drying species, such as 4/4 red oak, using an initial temperature of 115 °F instead of 110 °F until the lumber reaches 30 percent moisture content may be satisfactory if experience has shown no surface checking at 110 °F. Another type of change is to increase the dry-bulb temperature during the intermediate stages of drying. This is the most dangerous change because of the possibility of honeycomb in some species and should be approached with caution. A third type of change is to increase the temperature during the last stages of drying. After the average moisture content of the controlling samples has reached 15 to 20 percent, temperatures of 200 °F or greater can be used without damaging the wood. Research and experience are beginning to show that many hardwood species that have been dried to below 15 to 20 percent can be safely dried the rest of the way at temperatures as high as 230 °F.

Special Hardwood Schedules

Although the general hardwood schedules, with minor modifications, will do a good job of drying most species for most end uses, special purpose schedules are advantageous in some cases. Some examples follow.

Maximum Strength Schedules

Exposure of wood to temperatures above 150 °F can cause some permanent reduction in strength. At kiln temperatures of 200 °F or less, only long exposure would cause excessive strength reduction. Thus, the general drying schedules and proper operating procedues do not significantly reduce the strength of the lumber; lumber strength is sufficient for most end uses. However, when the wood is to be used for products requiring high strength per unit weight, such as aircraft, ladders, and sporting goods, somewhat lower temperatures should be used in drying. Table 7-9 lists temperature schedule code numbers for various softwood and hardwood species, and table 7-10 lists the actual maximum drying temperatures at various moisture contents recommended for these schedules. For example, from table 7-9, 1-in-thick Sitka spruce has a temperature schedule number of 2. Then, from table 7-10, the maximum drying temperature at 40 percent moisture content is 145 °F. Any general schedule used should thus be modified to stay below these maximum temperatures. Wet-bulb depressions should remain the same as listed in the general schedules.

Alternative Schedules for Some Species

Some species have peculiar drying characteristics or there is some other reason for a special drying schedule. Some of the more useful schedules are mentioned in the following paragraphs; these and other special schedules are described in table 7-11.

Hickory.—Upper grades of hickory are sometimes used for high-quality specialty products, such as tool handle stock, and require a slightly more conservative schedule than that listed in table 7-4.

Swamp and water tupelo.—The heartwood and sapwood of swamp and water tupelo have quite different drying characteristics. When the heartwood and sapwood can be separated, it is advantageous to dry them separately by different schedules.

Aspen.—Aspen trees sometimes develop a darkened area of wet-pocket wood in the center of the tree. This wood is slow drying and susceptible to collapse; it is usually present in the lower grade boards sawn from the center of the log. The upper grades of lumber sawn from the outside of larger logs can ***still*** be dried by the recommended general schedule.

Sugar maple.—Some end uses of sugar maple put a premium on the whitest color possible for sapwood, and the special schedule in table 7-11 will accomplish this. Also sugar maple sometimes has mineral streaks that are impermeable and subject to collapse and honeycomb during drying.

Red oak.—The red oaks are subject to a bacterial infection that invades the living tree and subsequently causes the lumber to be more susceptible to drying defects. There is little if any visual difference between bacterially infected and noninfected lumber. Often, however, infected oak has a characteristic rancid odor. With care, bacterially infected oak can be dried with a minimum of surface checks and honeycomb by using schedules listed in table 7-11.

Red and white oak—In sawing lumber from logs, the saw usually leaves small tears and fractures in the surface fibers of a board. These tears are points of weakness where drying stresses can cause surface checks to occur. If these boards are lightly surfaced, the tears are removed and the boards are less likely to surface check. As a result. the kiln schedule can be accelerated.

Time Schedules

Hardwood time schedules have been developed for some of the western hardwoods and are listed in table 7-12.

High-Temperature Schedules

High-temperature kiln drying is usually defined as the use of dry-bulb temperatures above 212 °F, usually in the range of 230 to 250 °F. Research and limited experience have shown that many of the low-density hardwoods can be dried at high temperatures while still maintaining quality. Schedules for these species are shown in table 7-13.

Schedules for Imported Species

The same principles that govern the selection of schedules for domestic species also apply to imported species. The schedules recommended in table 7-14 were gathered largely from the world literature on lumber drying. Table 7-14 is arranged by common name, and the scientific names can be found in chapter 1, table 1-2.

Schedule for Presurfaced Northern Red Oak

Presurfacing of lumber before kiln drying can result in reduced degrade from warping and practically eliminate surface checking. The technique, when combined with an accelerated schedule, can lead to 16 to 30 percent savings in drying time for 4/4 red oak. Other benefits of presurfacing include increased volume per kiln load and reduction of planer jams in the rough mill. Successful use of this technique depends on uniform air velocity of about 400 ft/min, well-baffled loads, accurate temperature and humidity control, adequate moisture content sampling, and a knowledgeable kiln operator. The cost to initiate and use the system is minimal.

The procedure is simple and only requires that the rough lumber be surfaced on two sides prior to stacking for drying. A double surfacer can be placed near the lumber grading station and ahead of the automatic stacker. Conveyors can feed the lumber and take it away from the planer. An alternative to using a knife planer in the line is to install an abrasive planer using 24- or 36-grit belts.

Whichever way the planing is done, the machine should be set to remove equal amounts from each side of the boards. For example, lumber sawed 1-1/8 in thick in the rough can be planed to 1-1/32 in by taking 3/64 in from each face; if the boards are sawn to reasonably uniform thickness, 80 percent of the pieces will have clean faces for their full length.

No change is required in the stacking operation, assuming the usual good practices are followed, including uniform sticker thickness and spacing, good vertical alignment, box piling, and support for ends of boards. One or two extra courses can generally be stacked in a unit package of surfaced lumber compared to a package of rough lumber of the same height. No change is required in kiln loading procedures when using surfaced lumber, again assuming good pile support, good alignment, and proper baffling are already practiced.

One major reason for presurfacing lumber before drying is to be able to accelerate the drying and thereby reduce costs. Existing schedules can be used, and it is possible to save about 10 percent in drying time as compared with drying rough lumber. Part of this saving is due to reducing or eliminating the thickness variation between boards and to the fact that the lumber is slightly thinner than rough stock.

Research work on oak drying has shown that because surfacing reduces the potential for checking and splitting, higher temperatures can be used earlier in the kiln run. McMillen (1969) developed a schedule for accelerated drying of presurfaced 1-in-thick northern red oak (table 7-13). Tests of this schedule on various loads of red oak in a variety of kilns have shown that 16 to 30 percent drying time can be saved in commercial kilns, if the schedule is followed as designed. In terms of kiln days, this means 4/4 oak can be safely dried green from the saw to 7 percent moisture content in 18 days instead of 21 to 28 days.

Successful use of this schedule depends on the following:

1. The kiln equipment must be in good repair—accurate calibration of the recorder-controller; good adjustment of vents, automatic valves, and traps; and proper operation of fan and baffle system.
2. The kiln load must be well stacked and baffled so the air velocity through the load is at least 400 ft/min.
3. Drying must be controlled with well-selected kiln samples. A minimum of six samples are recommended; eight are preferred for better knowledge of moisture content distribution.
4. The kiln operator must be confident that the drying information is accurate and must make schedule changes promptly.

There are two disadvantages to presurfacing lumber prior to drying: (1) since hardwood lumber is graded in the rough form, surfacing the boards may change the grade and make any dispute about the original grade difficult to settle and (2) if a planer is not readily available for presurfacing, the added cost of the machine may not be justifiable. This could especially be true if the rough lumber was very accurately sawn.

Softwood Schedules

Softwood Moisture Content Schedules

The softwood moisture content schedules presented in this chapter can be used with the kiln sample procedure of chapter 6 to dry softwood lumber with a minimum of drying defects. These schedules are described for the sake of the few instances where they might be used and for the sake of maintaining knowledge about them. Because softwoods are generally easy to dry, industry practice has gone to almost exclusive use of time schedules. Time schedules will be discussed in the next section.

Moisture Content Basis

As in the drying of hardwoods, there is a relationship between the moisture content of the lumber and the drying conditions the lumber can withstand. Although the stress patterns that develop in softwood lumber during drying differ from those in hardwood lumber, the surface zones do become stressed in tension (so that surface checking is a danger) during the early stages of drying and ultimately become stressed in compression. However, stress reversal generally does not occur until the lumber reaches a moisture content somewhere between 20 and 15 percent-a little lower than in hardwoods. Therefore, wet-bulb depressions should not be drastically increased until the lumber reaches this moisure content level. Gradual changes in wet-bulb depression can be made early in drying, however, in accordance with the moisture content of the lumber. The temperature and moisture content relationships that cause collapse and honeycombing in hardwoods affect softwoods similarly.

Material Considerations

The difference between sapwood and heartwood moisture content is considerable in many softwoods (ch. 1, table 1-5). Generally, the heartwood is more susceptible to drying defects, so most of the schedules are based on the moisture of the heartwood. In some situations, however, the heartwood dries to a safe moisture content level before the sapwood is dry enough to stand a drastic increase in wet-bulb depression. In these cases, the schedules are based on the moisture content of the sapwood or of a mixture of sapwood and heartwood.

Wetwood or sinker stock can be a problem when drying some softwood species such as redwood, hemlock, sugar pine, eastern and western white pine, and the true firs. This is wood that contains so much water and so little air in the cell cavities that it sometimes sinks in water. Wetwood dries slowly and is subject to collapse if too high a temperature is used during the initial stages of drying. If practical, it is desirable to sort the green softwoods of species prone to wetwood into different weight or moisture content classes and dry each separately.

The softwood moisture content schedules are intended for drying green lumber, but they can be applied to partially air-dried lumber as well.

Moisture Content Schedules

The softwood moisture content schedules are given in tables 7-15 and 7-16. These schedules are similar ***to*** the general schedules for hardwoods, except for a few important differences. Wet-bulb depressions of 40 °F or more are avoided until the controlling moisture content reaches 15 percent. Changes in wet-bulb depression between 15 and 35 °F are made gradually, 5 °F at a time. For drying lower grades, final wet-bulb depressions generally do not exceed 20 °F. The main features of moisture content schedules of this type were discussed in the Hardwood Schedules section in this chapter. In the moisture content method of operation, the initial temperature is maintained until the controlling kiln samples have an average moisture content of 30 percent.

Table 7-17 is an index of recommended schedules for 4/4, 6/4, and 8/4 softwood lumber, of both upper and lower grades. The schedules for lower grade lumber generally call for lower final temperatures and smaller final wet-bulb depressions to reduce loosening of knots and to hold planer splitting to a minimum.

Table 7-18 is an index of suggested schedules for 10/4 and thicker softwoods. The drying time may be too long for ordinary commercial operations, but the schedules are suitable for special cases where thick lumber of upper grades is to be dried.

Instructions for assembling a softwood moisture content schedule are the same as those given for hardwoods.

Kiln Drying Air-Dried Lumber

Since preliminary air drying is uncommon for softwoods that are to be kiln dried (except for redwood, incense cedar, and western redcedar), recommended schedules for kiln drying air-dried lumber have not been developed. The following steps are suggested for the assembly of such a schedule.

1. Determine the moisture content of representative samples of slow- and fast-drying boards (ch. 6) and use the average moisture content of the wettest half of the samples as the controlling moisture content.
2. Use the temperature step of the recommended schedule corresponding to that moisture content (table 7-15).
3. If the controlling moisture content is above 40 percent, dry the lumber as green.
4. If the controlling moisture content is 40 percent or less, change the wet-bulb depression as follows:
   a. Use a depression of 10 to 15 °F for the initial 8 to 16 h.
   b. After this period, if the controlling moisture content is between 15 and 25 percent, change the wet-bulb depression to 20 °F.
   c. Use a wet-bulb depression of 30 °F or more after the lumber reaches 15 percent moisture content.

Modifying Softwood Moisture Content Schedules

The principles described for hardwood schedule modification generally can be applied to softwoods.

Commercial Softwood Time Schedules

Most western and southern softwood mills use time schedules to dry both upper and lower grade lumber. The drying conditions are changed at convenient intervals, such as every 12 or 24 h or multiples thereof. A wide range of schedules has been developed at individual mills or by individual researchers, and these schedules are often modified. The schedules given here represent schedules that should serve as a satisfactory starting point for kiln operators. They are intended as a guide from which an operator can develop the best schedule for the particular drying requirements and type of kiln at the mill. Time schedules are dependent on the rate of air circulation and kiln performance because these affect drying rate. The conventional-temperature schedules in this chapter are based on the performance of single-track or double-track kilns that are equipped with booster coils and for a minimum air velocity of 400 ft/min. The high- temperature schedules are intended for kilns with 800 to 1,000 ft/min air velocity.

Conventional-Temperature Kiln Schedules

The recommended schedules aye indexed in table 7-19, and the schedules themselves are written out in table 7-20. Because the schedules were developed from a wide diversity of actual schedules, the times given in the last step are for guidance only. The actual time required for individual kiln charges may vary from the times given. If at the end of a kiln run the moisture content level and the degree of moisture content uniformity do not meet requirements, modify the schedule or the equalizing time, or both, on subsequent charges. The length of time of the last step in the schedule is often modified to attain the desired target final moisture content. The most common procedure used to adjust drying time for variations in initial moisture content is to use the same initial and intermediate drying steps and then to lengthen or shorten the final step to reach the desired final moisture content. In winter when lumber is sometimes quite wet when placed in the kiln, the initial step is prolonged or is preceded by a milder step.

Lumber from trees that have been dead for some time, such as insect-killed trees, is likely to be lower in moisture content and therefore require less drying time than lumber from trees that were alive at the time of harvesting. Lumber from dead trees may be more susceptible to surface checking.

High-Temperature Kiln Schedules

The usual range of temperatures for high-temperature drying of softwoods is from 230 to 250 °F, although the current trend is for even higher temperatures. High-temperature drying of some softwood species has become common in the last 15 to 20 years. Although tests have shown that significant strength loss occurs in some western species, southern pine apparently is much less affected than other species and shows little or no strength loss. The effect of strength loss should be considered when selecting a kiln schedule for a product where loss of bending or tension strength is important.

Since the mid-1970's the majority of new kilns built for drying southern pine dimension lumber have been high-temperature kilns, and most of these have been direct-fired rather than steam-heated kilns. Wet-bulb control is not as precise in direct-fired kilns, and conditioning is generally not possible because steam spray is lacking. However, direct-fired kilns are usually less costly to build than steam-heated kilns and generally perform satisfactorily for southern pine lumber.

The species index of schedules is given in table 7-21, and the actual schedules are written out in tables 7-22 and 7-23.

Softwood Schedules for Special Purposes

Some softwood lumber and items require or benefit from special precautions or schedules, and the following sections discuss some of these special needs.

Brown-Stain Control

Brown stain is a discoloration of wood that can occur during kiln drying as a result of a change in the color of substances normally present in some softwoods. It can be a significant problem in drying sugar pine, eastern and western white pine, ponderosa pine, sinker hemlock heartwood, and the southern pines. Brown stain is most prevalent during hot and humid months. It occurs in logs that have been stored in water or on sprinkled log decks for long periods. The storage time between when lumber is sawed and dried should be kept to a minimum, especially if the lumber is solid piled.

Brown stain can be severe when high dry- and wet-bulb temperatures are used at the start of the schedule. If it is a problem, the initial dry-bulb temperature should be dropped so as not to exceed 120 °F. Use as large a wet-bulb depression as the lumber will tolerate without excessive surface and end checking. A suggested schedule based on moisture content for eastern and western white pine and sugar pine is given in table 7-24, and schedules based on time are provided in table 7-25. (See following section if setting the pitch is necessary.)

Setting Pitch and Retaining Cedar Oil

Kiln schedules can be modified either to retain oil in wood, as in drying eastern redcedar used for cedar chests, or to set pitch that might exude later from pine and cause paint and finishing problems by bleeding through. High temperature in the presence of moisture and steam causes volatile oils and resins to vaporize. Therefore, when drying eastern redcedar, avoid high temperatures and do not condition the lumber unless it is absolutely necessary because it will be resawed or surfaced unequally.

On the other hand, to set pitch it is desirable to drive off the volatile turpentine and other solvents normally present. This can be done most easily at the start of drying by using a high temperature. However, if brown stain is a problem, the best compromise is to use the anti-brown-stain schedule at the start of drying and finish with a dry-bulb temperature of at least 160 °F. A temperature of 160 °F is usually satisfactory for 4/4 lumber, but the final temperature for thicker lumber should be at least 170 °F.

Lumber Treated With Waterborne Preservatives or Fire Retardants

Some softwood species, particularly southern pine and Douglas-fir lumber and plywood, are often treated with fire retardants and preservatives. Preliminary drying is required before either treatment; the lumber can be predried in the same way as lumber that is not treated. During treatment, however, the lumber or timbers reabsorb considerable water, and they are often redried after treatment. The chemicals used in treatment usually accelerate the strength-reducing effects of prolonged exposure of moist wood to high temperatures. Research is in progress to help set maximum recommended drying temperatures for treated wood products where strength is critical, but until those temperatures are better defined the usual recommendation is to not exceed 190 °F for wood treated with waterborne preservatives and 160 °F for wood treated with fire retardants (Winandy 1988). Table 7-26 shows several satisfactory schedules for treated Douglas-fir plywood.

Maximum Strength Schedules

Maximum drying temperatures for maintaining maximum strength were discussed earlier in this chapter. The maximum temperatures for softwoods for each moisture level are shown in table 7-10, and the species code numbers for finding these temperatures are shown in table 7-9.

Bevel Siding, Venetian Blinds, and Other Resawed Products

Softwood lumber that is to be resawed into bevel siding, venetian blinds, or other products should be properly equalized and conditioned (see section on equalizing and conditioning treatments) to obtain a uniform moisture content over the cross section and to relieve drying stresses. Otherwise, the resawed halves of the boards will quite likely cup (ch. 8). Before equalizing, use the final wet-bulb depression given in the schedules to achieve a low average moisture content as soon as possible.

Bundled Short-Length Items

Most drying of bundled short-length items takes place from the end-grain surfaces. Because some of these items do not end or surface check readily, kiln schedules for them can be rather severe. Other items, however, still require low dry-bulb temperatures to avoid collapse.

Because western redcedar shingles produced from wet stock that is logged in low areas may collapse, the shingles are dried with an initial dry-bulb temperature of about 95 °F. This temperature is gradually increased over a 10- to 14-day period to 150 °F or higher. Shingles produced from stock at a relatively low moisture content can be started at 150 °F or higher and finished at 180 °F. In both cases, wet-bulb temperature is not controlled, and the vents are kept open.

Incense cedar pencil stock is usually dried from a green to partially dry condition in the form of 3-in planks or squares and then cut into thin slats and graded. These slats are treated with a small amount of wax, bundled, and treated with a water-soluble dye. Because the treatment generally is a full-cell process in which all cell cavities become filled with liquid, the slats may collapse under severe drying conditions. Use low temperatures and high relative humidities at the start of drying and gradually make them more severe as drying progresses. Drying times are quite long, usually 23 to 30 days.

Pine squares, which are 4/4, 5/4, and 6/4 in cross section and 24 to 36 in long, are dried in bundles about 5 in square. Use a constant kiln temperature of 140 °F dry bulb and 110 °F wet bulb. Drying time is 13 to 14 days. Similar drying conditions can be used on other short items made of easily dried softwoods.

Large Timbers and Poles

It is not customary to kiln dry large timbers or poles of many species because of the long drying times required. Such wood is usually air-dried or used green. One notable exception is southern pine. Because of its relative ease of drying and extensive use, successful high-temperature schedules have been developed for southern pine; several schedules are given in table 7-27 for crossarms and poles. Timbers with cross sections of 4 to 5 in are often used for decking and as such require proper drying with a minimum of surface checks. Schedules for such timbers are given in table 7-28. Even more so than with other schedules presented in this chapter, these specialized schedules represent a starting point for the kiln operator to build on. In many cases, the objective of kiln drying large timbers is only to dry the outer shell of the timber to either control surface checking or remove water so that the outer shell can be treated with a waterborne preservative.

Tank Stock

Lumber for tank stock can be dried by the schedules used for the upper grades of the same thickness. Since the stock is used in contact with water or aqueous solutions, it should not be dried lower than 15 to 20 percent moisture content. Therefore, equalization (see Equalizing and Conditioning Treatments section) should be done at an equilibrium moisture content (EMC) of about 12 percent.

Knotty Pine Lumber

Knotty pine lumber is often used for decorative purposes and thus has higher appearance requirements than other low-grade pine lumber. The moisture content or time schedules given for lower grade lumber are generally satisfactory for preventing excessive checking or loosening of knots during the first stages of drying. Drying time, however, should be prolonged to reach a final moisture content of 7 to 8 percent. Somewhat lower relative humidities may be needed to reach this final moisture content without prolonging drying. The pitch should be set with a final temperature of at least 160 °F. Conditioning to relieve stresses is also desirable.

Dehumidification Kiln Schedules

Dehumidification kilns began gaining use in the United States in the late 1970's and have grown in popularity since then. Because of their relative newness, a wide range of schedules is not available for recommendation. The moisture content schedules recommended in this chapter should be satisfactory for most purposes. The major difference between schedules for steam-heated and dehumidification kilns is temperature limitation. Dehumidification kilns cannot attain the common 180 °F final temperature of most conventional schedules. Early dehumidification kilns were limited to a maximum temperature of 120 °F, which resulted in prolonged drying times below the fiber saturation point. Newer models can operate up to 160 °F and can approach the drying times of steam-heated kilns.

The schedules for steam-heated kilns can be converted for use with a dehumidification kiln, as shown in table 7-29. The schedule T4-C2 for 4/4 white oak is converted to accommodate a maximum dry-bulb temperature of 120 °F. To make the conversion, substitute 120 °F for those dry-bulb temperatures above 120 °F and then maintain an EMC in the dehumidification schedule step about the same as in the conventional schedule step. A similar conversion can be made for a dehumidification kiln with a 160 °F maximum temperature, although the converted schedule will differ only in the last step of the schedule. Note that some dehumidification kiln manufacturers recommend that their equipment not be operated at dry-bulb temperatures above 160 °F and wet-bulb temperatures above approximately 110 to 120 °F.

An ideal application of dehumidification kilns is their use in minimizing surface checking in the early stages of drying refractory species. Low dry-bulb temperatures and high relative humidities are sometimes difficult to maintain in steam-heated kilns, particularly in hot weather. Often, the use of steam spray to increase relative humidity only raises the dry-bulb temperature without reducing the wet-bulb depression. In a tightly built dehumidification kiln, it is possible to maintain dry-bulb temperatures of 90 °F or less while still maintaining a relative humidity of 80 percent or more. These conditions are quite successful in preventing surface checking. A general purpose, low-temperature schedule is suggested in table 7-30. Variations of this schedule that apply the general principle of low initial dry-bulb temperature and high humidity followed by a gradual increase of dry-bulb temperature and decrease of relative humidity should also be successfull.

Sterilizing, Equalizing, and Conditioning Treatments

Sterilizing Treatments

A sterilizing treatment can be used in the dry kiln to stop the growth of excessive mold on the surface of wood under certain conditions (ch. 8). The dry kiln can also be used to sterilize wood that has been infected with stain or decay fungi or attacked by wood-destroying insects.

Mold

Mold can develop on green lumber in a kiln operating at temperatures up to 120 °F. Although the mold generally does not penetrate the wood enough to cause serious stain during kiln drying, it can fill up the air spaces in a load of lumber and seriously interfere with air circulation. Not only does this slow drying as a whole, but the lumber under the mold may honeycomb later in drying when the temperature is raised under the false belief that moisture content is low enough to safely raise the temperature.

To sterilize for mold, the kiln charge (green lumber only) should be steamed at or near 100 percent relative humidity at a dry-bulb temperature of 130 °F or higher for 1 h after all parts of the kiln have reached that temperature. After steaming, the normal drying schedule should begin. Infrequently, two sterilizing treatments may be required about a day apart to stop the development of mold. If the growth is not heavy enough to block air circulation, sterilization is not necessary.

Fungal Stain and Decay

The temperatures normally used at the start of kiln drying are usually high enough to stop the growth of stain or decay organisms that may have infected green wood during storage or air drying. A temperature of 110 °F stops the growth of these organisms but does not kill them. Tests show that a temperature of 150 °F or higher for at least 24 h should kill all stain and decay fungi. As long as the wood is kept below 20 percent moisture content, new stain and decay will not start.

Insects

Both softwoods and hardwoods are attacked by a number of wood-boring insects, whether the wood is green or dry. Imported lumber or air-dried lumber that has been stored for a long time should be examined for evidence of insects. If they are found, a sterilizing treatment should be given.

Lyctus (powder-post) beetles and their eggs and larvae are killed by heating the lumber according to the schedule given in table 7-31. The schedule conditions include allowances for heating the lumber to the center, for cold spots in the kiln, and for additional time as a safety factor. To sterilize, use an EMC that is within 2 percent above or below the moisture content of the wood. If the wood has less than 8 percent moisture content, a temperature above 140 °F and a relative humidity somewhat below 60 percent should give satisfactory results, using the times given in table 7-31 for the 130 °F temperature. Exact data on temperatures and times required to kill other insects are not available, but the higher temperature schedule of table 7-31 may be adequate.

Normal kiln drying or temperature sterilization will not prevent future infestation by insects.

Equalizing and Conditioning Treatments

Equalizing and conditioning have been mentioned several times in this manual, and the purpose of this section is to discuss them in detail. Frequently, the moisture content of lumber varies considerably among boards in a kiln charge. This can be because of natural variability in drying rate or initial moisture content, heartwood and sapwood, or wet pockets in the lumber, or variability in drying conditions in various parts of the kiln. Variation in final moisture content can cause serious problems in the subsequent processing and use of the lumber. The purpose of equalizing is to reduce this variation in moisture content.

The drying stresses discussed in chapter 1 often remain in boards even after drying is complete. These residual drying stresses (often called casehardening although there is no actual hardening of the surface) can cause problems of warp and saw blade pinching in manufacture and use (ch. 8) and should be removed from the lumber for many end uses. The purpose of conditioning is to relieve the residual compressive drying stresses in the shell by plasticization with high temperature and high relative humidity. Conditioning has another beneficial effect of producing more uniform moisture content throughout the thickness of the boards. Effective equalizing is necessary before satisfactory conditioning can be accomplished because the effectiveness of conditioning depends on moisture content.

Conditioning is not really necessary for softwood dimension lumber that will be kiln dried to an average moisture content of 15 percent or a maximum of 19 percent; furthermore, it is not effective at such a high moisture content. Equalizing may be necessary or desirable for such lumber. On the other hand, equalizing and conditioning are usually necessary for hardwood or softwood lumber that will be dried to below 11 percent moisture content and used in end products with stricter requirements.

Equalizing and conditioning treatments also depend on the type of kiln schedule. Equalizing depends on knowledge of the variability of moisture content between boards. The only way to get this information is through tests. When a moisture-content-based schedule is used with kiln samples, the samples will serve as the basis for equalizing and can also be used to prepare stress sections (ch. 6). When a time-based schedule is used without kiln samples, it is more difficult to devise effective equalizing and conditioning treatments. One way to devise an equalizing treatment is to use an electric moisture meter during the last stages of drying to estimate variability. If this is done, care must be taken to ensure that the correct temperature is applied to the meter reading. The other way to devise an equalizing treatment to follow a time-based schedule is to develop, by experience, a time-temperature schedule that equalizes relative humidity. This will later minimize rejects in processing lumber with surface fuzziness in planing caused by high moisture content or with planer splits caused by low moisture content. Similarly, the options for developing conditioning treatments to follow a time-based schedule are to cut stress sections or to ascertain the need and develop the procedures for conditioning through trial and error.

The following procedures are based on the use of kiln samples for equalization and stress sections for conditioning. The basic principles can be applied to develop procedures for time-based equalizing and conditioning. The procedures given will be satisfactory for lumber that is dried to final average moisture content of from 5 to 11 percent. Table 7-32 contains basic information on the moisture content of the kiln samples and the kiln EMC conditions for these treatments. Wet-bulb depression values required to obtain desired EMC conditions are given in chapter 1, table 1-6.

Equalizing Treatment

The procedure for equalizing a kiln charge of lumber, using table 7-32, is as follows:

1. Start equalizing when the driest kiln sample in the charge has reached an average moisture content 2 percent below the desired final average moisture content. For example, if the desired final average moisture content is 8 percent, start equalizing when the driest kiln sample reaches 6 percent.
2. As soon as the driest sample reaches the moisture content value stated in step 1, establish an equalizing EMC in the kiln equal to that value. In the example given in step 1, the equalizing EMC would be 6 percent. During equalizing, use as high a dry-bulb temperature as the drying schedule permits.
3. Continue equalizing until the wettest sample reaches the desired final average moisture content. In the example given in step 1, the wettest sample would be dried to 8 percent.

If the equalizing treatment is to be followed by a conditioning treatment, it may at times be necessary to lower the temperature to obtain the desired conditioning EMC condition. If so, begin by lowering the temperature 10 °F 12 to 24 h prior to the start of conditioning. Also, lower the wet-bulb temperature to maintain the desired equalizing EMC.

Conditioning Treatment

The conditioning treatment, whether or not preceded by an equalizing treatment, should not be started until the average moisture content of the wettest sample reaches the desired final average moisture content.

The procedure for conditioning is as follows:

1. The conditioning temperature is the same as the final step of the drying schedule or the highest temperature at which the conditioning EMC can be controlled. For softwoods, set the wet-bulb temperature so the conditioning EMC will be 3 percent above the desired final average moisture content. For hardwoods, the conditioning EMC is 4 percent above the desired final average moisture content. The wet-bulb depression that will give the desired conditioning EMC is given in chapter 1, table 1-6. If, at the dewed conditioning temperature, a wet-bulb depression value is not shown for the desired EMC, choose the wet-bulb depression value for the nearest higher EMC given for that temperature. Set the desired wet-bulb temperature for the proper depression but do not raise the dry-bulb temperature above the equalizing temperature until after the proper wet-bulb temperature is attained.

   Example: Assume a hardwood species with a desired final moisture content of 8 percent and a conditioning temperature of 170 °F. The conditioning EMC from table 7-32 is 12 percent. At 170 °F, an 8 °F wet-bulb depression will give an EMC of 12.4 percent (table 1-6). If the lumber is a softwood, the conditioning EMC would be 11 percent and the wet-bulb depression 10 °F.
2. Continue conditioning until satisfactory stress relief is attained.

The time required for conditioning varies considerably with species and lumber thickness, the type of kiln used, and kiln performance. At a conditioning temperature of 160 to 180 °F, hardwoods generally require 16 to 24 h for 4/4 lumber and up to 48 h for 8/4 lumber. Some 4/4 softwood species can be conditioned in as short as 4 h. If conditioning temperatures are lower than 160. to 180 °F, conditioning time will be prolonged.

The most exact way to determine when conditioning is complete is the casehardening test described in chapter 6. Conditioning time should not be continued any longer than necessary because of excessive steam consumption and excessive moisture pickup, particularly in low-density species.

If tests for average moisture content are made immediately after the conditioning treatment, **the mois**ture content obtained will be about 1 to 1-1/2 percent above the desired value because of the surface moisture regain. After cooling, the average moisture content should be close to that desired.

Kiln-Drying Time

The approximate time required to kiln dry softwood lumber can be estimated from some of the time schedules given earlier in the chapter. Table 7-33 lists approximate drying times for 1-in-thick softwood and hardwood species. The times listed are for kiln drying at conventional temperatures where the final schedule temperature is approximately 180 °F. Lumber thicker than 1 inch will take longer to dry than the times given in table 7-33. The increase in drying time is more than proportional to the increase in thickness. For example, if thickness is doubled, the drying time will be increased by a factor of about 3 to 3.5.

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Table 7-1—Moisture content schedules for hardwoods

Dry-bulb temperature step no.	Moisture content at start of step (percent)	Dry-bulb temperatures (°F) for various temperature schedules													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
1	>30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	115	130	140	140	150	150	160	160	160	170	170	180	190	200
5	15	120	150	160	180	160	180	160	180	160	180	180	180	190	200

Table 7-2—General wet-bulb depression schedules for hardwoods

Wet-bulb depression step no.	Moisture content (percent) at start of step for various moisture content classes						Wet-bulb depressions (°F) for various wet-bulb depression schedules							
	A	B	C	D	E	F	1	2	3	4	5	6	7	8
1	>30	>35	>40	>50	>60	>70	3	4	5	7	10	15	20	25
2	30	35	40	50	60	70	4	5	7	10	14	20	30	35
3	25	30	35	40	50	60	6	8	11	15	20	30	40	50
4	20	25	30	35	40	50	10	14	19	25	35	50	50	50
5	15	20	25	30	35	40	25	30	35	40	50	50	50	50
6	10	15	20	25	30	35	50	50	50	50	50	50	50	50

Table 7-3—Moisture content classes for various green moisture content values

Green moisture content (percent)	Moisture content class
up to 40	A
40 to 60	B
60 to 80	C
80 to 100	D
100 to 120	E
Above 120	F

Table 7-4—Code number index of schedules[1] recommended for kiln drying domestic hardwood 4/4 to 8/4 lumber and other products

Species	Lumber schedules: 4/4, 5/4, and 6/4 — Dry-bulb temperature	Lumber schedules: 4/4, 5/4, and 6/4 — Wet-bulb depression	Lumber schedules: 6/4 — Dry-bulb temperature	Lumber schedules: 6/4 — Wet-bulb depression	Schedules for other products — Name	Schedules for other products — Dry-bulb temperature	Schedules for other products — Wet-bulb depression
Alder, red	T10	D4	T8	D3			
For darker color	T11	D3	—	—			
For lighter color	T5	D5	—	—			
Apple	T6	C3	T3	C2			
Ash, black	T8	D4	T5	D3			
Ash, green, Oregon. white	T8	B4	T5	B3			
Aspen	T12	E7	T10	E6			
Basswood							
Standard	T12	E7	T10	E6			
Light color	T9	E7	T7	E6			
Beech	T8	C2	T5	C1	1-in squares	T8	C3
					2-in squares	T5	C2
Birch, paper	T10	C4	T8	C3	1-in squares	T10	C6
					2-in squares	T8	C4
Birch, yellow	T8	C4	T5	C3	1-in squares	T8	C5
					2-in squares	T5	C4
Blackgum	T12	E5	T11	D3			
Boxelder	T8	D4	T6	C3			
Buckeye, yellow	T10	F4	T8	F3			
Butternut	T10	E4	T8	E3			
Cherry, black	T8	B4	T5	B3			
Chestnut	T10	E4	T8	E3			
Cottonwood, normal	T10	F5	T8	F4			
Cottonwood, wet streak	T8	D5	T6	C4			
Dogwood	T6	C3	T3	C2	Shuttles	T3	B2
Elm, American and slippery	T6	D4	T5	D3			
Elm, rock	T6	B3	T3	B2			
Hackberry	T8	C4	T6	C3			
					White handles		
					Small	T1	D2
					Large	T1	C2
Hickory	T8	D3	T6	D1	Pink handles		
					Small	T8	D1
					Large	T8	C1
Holly	T6	D4	T4	C3			
Hophornbeam (ironwood)	T6	B3	T3	B1			
Laurel, California (Oregon Myrtle)	T6	A4	T5	A3			
Locust, black	T6	A3	T3	A1			
Madrone	T4	B2	T3	B1			
Magnolia	T10	D4	T8	D3			
Maple, bigleaf, red, silver	T8	D4	T6	C3			
					Bowling pins (end coated)	T3	A3
Maple, sugar (hard)	T8	C3	T5	C2	1-in squares	T8	C4
					2-in squares	T5	C3
Oak, California black[2]	T3	B1	T3	B1			
Oak, red (upland)[2]	T4	D2	T3	D1			
Oak. red (southern lowland)[2]	T2	C1	([3])	([3])			
Oak, white (upland)[2]	T4	C2	T3	C1			
Oak, white (lowland)[2]	T2	C1	([3])	([3])			
Osage-orange	T6	A2	T3	A1			
Pecan	T8	D3	T6	D1			
Persimmon	T6	C3	T3	C2	Golf club heads	T3	C2
					Shuttles	T3	B2
Sassafras	T8	D4	—	—			
Sweetgum (sap gum)	T12	F5	T11	D4	1-in squares	T12	F6
					2-in squares	T11	D5

Table 7-4—Code number index of schedules[1] recommended for kiln drying domestic hardwood 4/4 to 8/4 lumber and other products-concluded

Species	Lumber schedules 4/4, 5/4, and 6/4 Dry-bulb temperature	Lumber schedules 4/4, 5/4, and 6/4 Wet-bulb depression	Lumber schedules 8/4 Dry-bulb temperature	Lumber schedules 8/4 Wet-bulb depression	Schedules for other products Name	Schedules for other products Dry-bulb temperature	Schedules for other products Wet-bulb depression
Sweetgum (red gum)	T8	C4	T5	C3			
Sycamore	T6	D2	T3	D1			
Tanoak	T3	B1	T3	B1			
Tupelo, black	T12	E5	T11	D3			
Tupelo, swamp	T10	E3	T8	D2			
Tupelo, water	T6	H2	—	—			
Walnut, black	T6	D4	T3	D3	Gunstock blanks	T3	D4
Willow, black	T10	F4	T8	F3			
Yellow-wofar	T11	D4	T10	D3			

[1]Schedules are given in tables 7-1 and 7-2.
[2]All 6/4 oak species should be dried by the 8/4 schedule.
[3]See table 7-11.

Table 7-5—Code number index of schedules suggested for kiln drying thick domestic hardwoods[1]

Species	10/4 lumber Dry-bulb temperature	10/4 lumber Wet-bulb depression	12/4 lumber Dry-bulb temperature	12/4 lumber Wet-bulb depression	16/4 lumber Dry-bulb temperature	16/4 lumber Wet-bulb depression
	Schedules for various thicknesses of lumber[2]					
Alder, red	T6	C3	T6	C3	—	—
Ash, white	T5	B3	T3	B2	T3	A1
Aspen	T8	E5	T8	D5	T7	C4
Birch, yellow	T5	B3	T3	B2	T3	A1
Blackgum	T11	D3	T9	C2	T7	C2
Boxelder	T5	C2				
Cherry	T5	B2	T3	B2	T3	A1
Cottonwood	T6	E3	T5	D2	—	—
Cottonwood, wet streak	T4	D3	T3	C2	—	—
Elm, American	T5	D2	T3	C2	—	—
Elm, rock	T3	B2	T3	B1	T3	A1
Hackberry	T6	C3	T5	C2	T3	B1
Maple, bigleaf, red, silver	T5	C2	T3	B2	—	—
Maple, sugar (hard)	T3	B2	T3	A1[3]	T3	A1[3]
Oak, red	T3	C1	T3	C1	—	—
Oak, white	T3	B1	T3	B1	—	—
Sweetgum (sap gum)	T11	D3	T9	C3	—	—
Sweetgum (red gum)	T5	C2	T5	B2	—	—
Sycamore	T3	D1	T3	C1	T3	B1
Tupelo, black	T11	D3	T9	C2	T7	C2
Walnut. black	T3	D3	T3	C2	—	—
Yellow-poplar	T9	C3	T7	C2	T5	C2

[1]A good end coating should be applied to all stock in most cases.
[2]For squares, use a web-bulb depression number one unit higher than the one suggested for lumber. Thus, for 3- by 3-in birch, use T3-B3.
[3]After passing 30 percent moisture content, gradually shift to wet-bulb depression schedule B2.

Tabled 7-6—Method of assembly of kiln-drying schedule for green 4/4 sugar maple[1]

Dry-bulb temperature step no.	Wet-bulb depression step no.	Moisture content at start of step (percent)	Dry-bulb temperature (°F)	Wet-bulb depression (°F)	Wet-bulb temperature (°F)	Relative humidity (percent)	Equilibrium moisture content (percent)
1	1	>40	130	5	125	86	16.0
1	2	40	130	7	123	81	14.0
1	3	35	130	11	119	71	11.5
2	4	30	140	19	121	56	8.4
3	5	25	150	35	115	35	5.1
4	6	20	160	50	110	24	3.2
5	6	15	180	50	130	26	3.3

‘Schedule Code no. T8-C3

Table 7-7—Examples of general schedules for kiln drying lumber of certain hardwood Species[1]

Moisture content at start of step (percent)	4/4, 5/4, 6/4 lumber schedules			8/4 lumber schedules		
	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature	Dry-bulb temperature	Wet-bulb depression	Wet-bulb temperature
OAK, RED (UPLAND)						
	SCHEDULE T4-D2			SCHEDULE T3-D1		
>50	110	4	106	110	3	107
50	110	5	105	110	4	106
40	110	8	102	110	6	104
35	110	14	96	110	10	100
30	120	30	90	120	25	95
25	130	40	90	130	40	90
20	140	50	90	140	50	90
15	180	50	130	160	50	110
OAK, WHITE						
	SCHEDULE T4-C2			SCHEDULE T3-C1		
>40	110	4	106	110	3	107
40	110	5	105	110	4	106
35	110	8	102	110	6	104
30	120	14	106	120	10	110
25	130	30	100	130	25	105
20	140	50	(2)	140	50	(2)
15	180	50	(2)	160	50	(2)
MAPLE, HARD						
	SCHEDULE T8-C3			SCHEDULE T5-C2		
>40	130	5	125	120	4	116
40	130	7	123	120	5	115
35	130	11	119	120	8	112
30	140	19	121	130	14	116
25	150	35	115	140	30	110
20	160	50	110	150	50	100
15	180	50	130	160	50	110
ASH, WHITE; CHERRY						
	SCHEDULE T8-B4			SCHEDULE T5-83		
>35	130	7	123	120	5	115
35	130	10	120	120	7	113
30	140	15	125	130	11	119
25	150	25	125	140	19	121
20	160	40	120	150	35	115
15	180	50	(2)	160	50	(2)
BLACKGUM						
	SCHEDULE T12-E5			SCHEDULE T11-D3		
>60	160	10	150	150	5	145
60	160	14	146	150	5	145
50	160	20	140	150	7	143
40	160	35	125	150	11	139
35	160	50	110	150	19	131
30	170	50	120	160	35	125
25	170	50	120	160	50	110
20	180	50	130	170	50	120
15	180	50	130	180	50	130

[1]All temperature values are in degrees Fahrenheit.
[2]Close control of wet-bulb temperature not necessary.

Table 7-8—H-type wet-bulb depression schedules for hardwoods

Wet-bulb depression step no.	Moisture content at start of step (percent)	Wet-bulb depressions (°F) for various wet-bulb depression schedules							
		1	2	3	4	5	6	7	8
1	Green (G)	3	4	5	7	10	15	20	25
2	2/3 G	4	5	7	10	14	20	30	35
3	2/3 G-10	6	8	11	15	20	30	40	50
4	2/3 G-20	10	14	19	25	35	50	50	50
5	2/3 G-30	25	30	35	40	50	50	50	50
6	2/3 G-40	50	50	50	50	50	50	50	50

Table 7-9—Temperature schedule code numbers for maximum strength retention

Species	Schedule numbers according to species thickness				
	1 in	1-1/2 in	2 in	3 in	>3 in
	SOFTWOODS				
Baldcypress	4	4	5	6	7
Douglas-fir	3	4	5	6	7
Fir,					
noble	2	3	4	6	7
red	3	4	5	6	7
Hemlock, western	4	5	6	6	7
Pine,					
northern white	4	5	6	7	8
ponderosa	4	5	6	6	7
red	2	3	4	6	7
sugar	3	4	5	6	7
western white	4	5	6	7	8
Spruce					
red	2	3	4	5	6
Sitka	2	3	4	5	6
white	2	3	4	5	6
White-cedar, Port-Orford					
	HARDWOODS				
Ash, commercial white	5	5	—	—	—
Birch, yellow	5	5	—	—	—
Cherry, black	5	5	—	—	—
African mahogany	5	5	—	—	—
Mahogany, true	5	5	—	—	—
Maple,					
silver	3	3	—	—	—
sugar	3	3	—	—	—
Oak,					
commercial red	8	8	—	—	—
commercial while	8	8	—	—	—
Sweetgum	6	6	—	—	—
Yellow-poplar	3	4	5	6	7
Walnut, black	4	4	—	—	—

Table 7-10—Maximum drying temperatures for maximum strength retention

Moisture content (percent)	Maximum drying temperature (°F) for various schedules[1]							
	1	2	3	4	5	6	7	8
≥45	140	135	130	125	120	115	110	105
[2]40	145	140	135	130	125	120	115	110
30	150	145	140	135	130	125	120	115
25	155	150	145	140	135	130	125	120
20	160	155	150	145	140	135	130	125
15	165	160	155	150	145	140	135	130
to final	170	165	160	155	150	145	140	135

[1]Temperature schedule code numbers described in table 7-9.
[2]When the initial moisture content of the stock exceeds 40 percent, the initial temperature should be maintained until the moisture content reaches 40 percent, at which time the temperature may be increased 5°F.

Table 7-11—Special schedules for certain hardwood species

Moisture content at start of step (percent)	Temperatures (°F) for various thicknesses of lumber					
	4/4		6/4		8/4	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
	HICKORY-UPPER GRADES FOR SPECIAL PURPOSES					
>50	130	125	120	115	120	117
50	130	123	120	113	120	116
40	130	114	125	114	120	113
35	130	114	130	97	125	114
30	150	112	140	104	130	97
25	150	100	140	104	140	90
20	180	130	180	130	150	100
15	180	130	180	130	180	130
	TUPELO, SWAMP—HEARTWOOD					
>60	140	135	140	135	—	—
60	140	133	140	133	—	—
50	140	129	140	129	—	—
40	140	121	140	121	—	—
35	140	105	140	105	—	—
30	150	100	150	100	—	—
25	160	110	160	110	—	—
20	170	120	170	120	—	—
15	180	130	180	130	—	—
	TUPELO, SWAMP—SAPWOOD					
>60	160	150	160	150	—	—
60	160	146	160	150	—	—
50	160	146	160	140	—	—
40	160	146	160	125	—	—
35	160	110	160	125	—	—
30	170	120	170	120	—	—
25	170	120	170	120	—	—
20	180	130	180	130	—	—
15	180	130	180	130	—	—
	TUPELO, WATER—HEARTWOOD					
>70	130	123	120	[1]116	—	—
70	130	120	120	[2]90	—	—
60	130	115	120	90	—	—
50	130	105	120	90	—	—
40	130	[2]90	120	90	—	—
35	130	90	120	90	—	—
30	140	90	130	90	—	—
25	150	100	140	90	—	—
20	160	110	150	100	—	—
15	180	130	180	130	—	—

Table 7-11—Special schedules for certain hardwood species-continued

Moisture content at start of step (percent)	Temperatures (°F) for various thicknesses of lumber					
	4/4		6/4		8/4	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
			TUPELO, WATER—SAPWOOD			
>70	160	150	140	133	—	—
70	160	150	140	130	—	—
60	160	146	140	125	—	—
50	160	146	140	115	—	—
40	160	146	140	100	—	—
35	160	110	140	90	—	—
30	170	120	150	100	—	—
25	170	120	160	110	—	—
20	180	130	170	120	—	—
15	180	130	180	130	—	—
			ASPEN—LOW COLLAPSE			
>70	110	100	110	100	140	133
70	110	100	110	100	140	130
60	115	100	115	100	140	125
50	120	100	120	100	140	120
40	130	105	130	105	140	110
30	150	110	150	110	[3]150	100
25	150	110	150	110	170	120
20	[3]180	135	[3]180	135	170	120
[4]12	180	130	180	130	180	130
[5]8	180	130	180	130	200	140
			SUGAR MAPLE, WHITE COLOR—INITIAL MOISTURE CONTENT BELOW 50 PERCENT			
[6]>28	105	95	—	—	—	—
28	108	95	—	—	—	—
24	108	90	—	—	—	—
20	108	90	—	—	—	—
16	115	90	—	—	—	—
13	125	90	—	—	—	—
10	160	105	—	—	—	—
(Condition)	170	154	—	—	—	—
			SUGAR MAPLE, WHITE COLOR—INITIAL MOISTURE CONTENT ABOVE 50 PERCENT			
[6]>40	105	95	—	—	—	—
40	108	95	—	—	—	—
35	108	90	—	—	—	—
30	108	90	—	—	—	—
26	108	90	—	—	—	—
20	115	90	—	—	—	—
16	125	90	—	—	—	—
12	160	105	—	—	—	—
(Condition)	170	154	—	—	—	—

Table 7-11—Special schedules for certain hardwood species—continued

Moisture content at start of step (percent)	Temperatures (°F) for various thicknesses of lumber					
	4/4		6/4		8/4	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
			UPLAND RED OAK—PRESURFACED			
[7] >53	115	111	—	—	—	—
53	115	110	—	—	—	—
43	115	107	—	—	—	—
37	115	101	—	—	—	—
[8] 35	120	90	—	—	—	—
30	125	90	—	—	—	—
27	130	90	—	—	—	—
21	140	90	—	—	—	—
17	180	130	—	—	—	—
			UPLAND WHITE OAK—PRESURFACED			
[7] >42	115	111	—	—	—	
42	115	110	—	—	—	
37	115	107	—	—	—	
33	115	101	—	—	—	
[8] 35	120	90	—	—	—	
30	125	90	—	—	—	
27	130	90	—	—	—	
21	140	90	—	—	—	
17	180	130	—	—	—	
			RED OAK, 4/4 AND 5/4—BACTERIA INFECTED			
>55	105	102	—	—	—	—
55	105	100	—	—	—	—
45	105	96	—	—	—	—
35	105	92	—	—	—	—
30	105	90	—	—	—	—
27	110	93	—	—	—	—
25	120	100	—	—	—	—
20	130	100	—	—	—	—
15	150	110	—	—	—	—
12	180	130	—	—	—	—
			RED OAK, 6/4—BACTERIA INFECTED			
>50	—	—	100	97	—	—
50	—	—	100	95	—	—
45	—	—	100	93	—	—
40	—	—	100	90	—	—
35	—	—	105	92	—	—
30	—	—	110	95	—	—
25	—	—	120	100	—	—
20	—	—	130	100	—	—
16	—	—	150	110	—	—
12	—	—	180	130	—	—

Table 7-11—Special schedules for certain hardwood species—continued

Moisture content at start of step (percent)	Temperatures (°F) for various thicknesses of lumber					
	4/4		6/4		8/4	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
RED OAK, 8/4—BACTERIALLY INFECTED, AIR DRIED OR PREDRIED (DRYING HISTORY UNKNOWN)						
>20	—	—	—	—	110	100
20	—	—	—	—	125	110
18	—	—	—	—	140	110
14	—	—	—	—	160	110
10	—	—	—	—	180	130
RED OAK, 8/4—BACTERIALLY INFECTED, DRIED FROM GREEN IN PREDRYER, THEN KILN DRIED						
>80	—	—	—	—	90	87
80	—	—	—	—	96	93
75	—	—	—	—	100	96
65	—	—	—	—	100	95
44	—	—	—	—	105	95
32	—	—	—	—	115	100
30	—	—	—	—	120	100
26	—	—	—	—	125	100
21	—	—	—	—	150	110
18	—	—	—	—	160	110
16	—	—	—	—	170	120
12	—	—	—	—	180	130
SOUTHERN LOWLAND RED AND WHITE OAK, 6/4 AND 8/4—AIR DRIED OR PREDRIED TO 25 PERCENT MOISTURE CONTENT						
>30	—	—	105	97	105	97
25	—	—	110	99	110	99
20	—	—	120	105	120	105
15	—	—	130	100	130	100
11	—	—	160	110	160	110
(Equalize)	—	—	173	130	173	130
(Condition)	—	—	180	170	180	170
MAPLE—MINIMUM HONEYCOMB IN 6/4 AND 8/4 MINERAL STREAK						
[8-10]>40	—	—	110	106	—	—
40	—	—	110	105	—	—
35	—	—	110	102	—	—
30	—	—	120	106	—	—
25	—	—	125	95	—	—
20	—	—	130	90	—	—
[11]30	—	—	140	95	—	—
25	—	—	150	100	—	—
20	—	—	160	110	—	—
15	—	—	180	130	—	—
NORTHERN RED OAK—PRESURFACED 1-INCH						
>53	115	111	—	—	—	—
53	115	110	—	—	—	—
43	115	107	—	—	—	—
37	115	101	—	—	—	—
35	120	90	—	—	—	—

Table 7-11—Special schedules for certain hardwood species—concluded

Moisture content at start of step (percent)	Temperatures (°F) for various thicknesses of lumber					
	4/4		6/4		8/4	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
30	125	90	—	—	—	—
27	130	90	—	—	—	—
21	140	90	—	—	—	—
17	180	130	—	—	—	—

[1]See figure 7-3 for changes between 110 and 70 percent moisture content on the H2 schedule.
[2]It may not be possible to achieve 90 °F wet-bulb temperature in hot weather.
[3]Operate with vents closed; no steam spray until equalizing.
[4]For 8/4, continue until wettest sample is 8 percent.
[5]For 8/4, time on this step is about 5 days
[6]The 4/4 schedule also applies to 5/4.
[7]Average moisture content of all samples controls.
[8]Average moisture content of wettest half of samples controls.
[9]This schedule should also be used for mineral-streaked yellow birch.
[10]Kiln samples should be 2 ft longer than normal so that three or four intermediate moisture content tests can be made. For green stock, start with normal kiln sample proceduire. For air-dried stock, cut both an average section and a "darkest zone" section at the start. Cut out the darkest, wettest appearing portion of the latter section with a bandsaw. Weight and ovendry this portion separately to determine when temperature of 140 °F and higher can be used. After the final drying condition has run 1 day, revert to the full-size kiln sample method to start equalizing and conditioning.
[11]Begin control on darkest zone of wettest sample.

Table 7-12—Time schedules for domestic hardwood lumber species

step no.	Time (h)	Temperature (°F) Dry bulb	Wet bulb
	ALDER, RED—4/4, 5/4, 6/4		
1	0 to 12	150	145
2	12 to 24	150	140
3	24 to 48	155	140
4	48 to 72	165	140
5	72 to 120	180	140
6	(or until dry)	180	140
	ALDER, RED—8/4		
1	0 to 48	130	120
2	48 to 72	135	120
3	72 to 96	140	125
4	96 to 120	145	125
5	120 to 144	150	125
6	144 to 168	155	125
7	168 to 192	160	130
8	192 to 216	165	135
9	(or until dry)	165	135
	ALDER, RED—10/4, 12/4		
1	0 to 12	130	125
2	12 to 36	135	130
3	36 to 84	140	135
4	84 to 132	145	135
5	132 to 180	150	135
6	180 to 228	155	135
7	228 to 276	160	135
8	276 to 324	170	135
9	(or until dry)	170	135
	ASH, OREGON—4/4, 5/4, 6/4		
1	0 to 12	150	145
2	12 to 48	150	140
3	48 to 84	155	140
4	84 to 132	165	140
5	132 to 156	180	140
6	(or until dry)	180	140
	ASH, OREGON—8/4, 10/4, 12/4		
1	0 to 12	130	125
2	12 to 36	135	130
3	36 to 84	140	135
4	84 to 132	145	135
5	132 to 180	150	135
6	180 to 228	155	135
7	228 to 276	160	135
8	276 to 324	170	135
9	(or until dry)	170	135
	LAUREL, CALIFORNIA OR OREGON MYRTLE—4/4, 5/4, 6/4		
1	0 to 24	130	123
2	24 to 28	135	125
3	48 to 72	140	125
4	72 to 96	150	135
5	96 to 120	155	135
6	120 to 144	160	135
7	144 to 168	180	140
8	(or until dry)	180	140
	MAPLE, BIG LEAF—4/4. 5/4, 6/4		
1	0 to 48	130	120
2	48 to 72	135	120
3	72 to 96	140	125
4	96 to 120	145	125
5	120 to 144	150	125
6	144 to 168	155	125
7	168 to 192	160	130
8	192 to 216	165	135
9	(or until dry)	165	135
	MAPLE, OREGON—8/4		
1	0 to 12	130	125
2	12 to 36	135	130
3	36 to 84	140	135
4	84 to 132	145	135
5	132 to 180	150	135
6	180 to 228	155	135
7	228 to 276	160	135
8	276 to 324	170	135
9	(or until dry)	170	135
	OAK, CALIFORNIA SLACK AND OREGON WHITE, AND TANOAK—4/4, LOWER GRADES		
1	0 to 216	110	106
2	216 to 312	110	104
3	312 to 384	115	104
4	384 to 432	120	104
5	432 to 492	180	105
6	(or until dry)	180	105
	OAK, CALIFORNIA BLACK AND OREGON WHITE—6/4, LOWER GRADES		
1	0 to 360	110	106
2	360 to 504	110	104
3	504 to 576	110	100
4	576 to 672	115	100
5	672 to 816	120	100
6	816 to 980	180	145
7	(or until dry)	180	145

Table 7-13—High-temperature kiln schedules for domestic hardwood lumber species

Temperature step no.	Moisture content (percent)	Time (h)	Temperature (°F) Dry bulb	Wet bulb
		ALDER, RED—4/4, 5/4		
1	—	0-3	215	210
2	—	3-9	210	210
3	—	9-21	230	205
4	—	21-36	230	200
5	—	36-39	230	195
6	—	39-51	215	210
7	—	51-59	Cool lumber in kiln	
		ASPEN AND BALSAM POPLAR—2 BY 4 DIMENSION		
1	—	0-2	180	180
2	—	2-59	250	180
3	—	59-61	Kiln off, no fans	
4	—	61-79	204	196
5	—	79-94	250	180
		BASSWOOD, BLACKGUM, RED MAPLE, SWEETGUM SAPWOOD, AND YELLOW-POPLAR—4/4, 5/4		
1	Green to 7%	20-26	230	180
2	(Cool to below 212 °F)			
3	(Equalize)	11-16	203	160
4	(Condition)	10-12	192	180
		ASPEN—4/4, 5/4,6/4, 7/4, AND 2-IN DIMENSION		
1	(Warmup)	3	201	201
2	(Green to dry)	—	220	201
3	(Condition)	—	205	201
		RED ALDER, BASSWOOD, BLACKGUM, RED MAPLE, AND YELLOW-POPLAR—7/4 FLITCHES		
1	Green to 10%	20-26	235	180
2	(Cool to below 212 °F)			
3	(Equalize)	24-48	200	188

Table 7-14—Code number index of schedules recommended for kiln drying Imported species

Species (common name)	4/4, 5/4, and 6/4 lumber schedules		8/4 lumber schedules	
	Dry bulb temper- ature	Wet-bulb depres- sion[1]	Dry bulb temper- ature	Wet-bulb depres- sion[1]
Afrormosia	T10	D5S	T8	D4S
Albarco	T3	D2	T3	D1
Andiroba	T3	C2	T3	C1
Angelique	T2	B2	—	—
Apitong	T3	D2	T3	D1
Avodire	T6	D2	T3	D1
Balata	T1	B1	—	—
Balsa	T10	D4S	T8	D3S
Banak	T3	C2	T3	C1
Benge	T3	C2	T3	C1
Bubinga	T2	C2	T2	C1
Caribbean pine	T10	D4S	T8	D3S
Cativo	T3	C2	T3	C1
Ceiba	T10	D5S	T8	D4S
Cocobolo	T2	C2	T2	C1
Courbaril	T3	C2	T3	C1
Cuangare	T5	C3	—	—
Cypress, Mexican	T10	D5S	T8	D4S
Degame	T2	C2	T2	C1
Determa	T6	D2	T3	D1
Ebony, East Indian	T3	C2	T3	C1
Ebony, African	T6	D2	T3	D1
Gmelina	T13	C4S	T11	D3S
Goncalo alves	T3	C2	—	—
Greenheart	T2	C2	T2	C1
Hura	T6	D2	T3	D1
Ilomba	T3	C2	T3	C1
Imbuia	T6	D2	T3	D1
Ipe	T3	C1	—	—
Iroko	T6	D2	T3	D1
Jarrah	T3	C2	T3	C1
Jelutong	T10	D4S	T8	D3S
Kapur	T10	D4S	T8	D3S
Karri	T3	C2	T3	C1
Kempas	T6	D2	T3	D1
Keruing	T3	D2	T3	D1
Lauan, red and white	T6	D4	T3	D3
Lignumvitae	T2	C2	T2	C1
Limba	T10	D5S	T8	D4S
Mahogany, African	T6	D4	T3	D3
Mahogany, true	T6	D4	T3	D3
Manni	T3	C2	T3	C1
Merbau	T3	C2	T3	C1
Mersawa	T6	D2	T3	D1
Mora	T2	C2	T2	C1
Obeche	T14	C5S	T12	C5S
Ocote pine	T10	D4S	T8	D3S
Okoume	T6	D2	T3	D1
Opepe	T6	D2	T3	D1
Parana pine	T3	D2	T3	D1
Pau Marfim	T6	C3	T5	C2
Peroba de campos	T3	D2	T3	D1
Peroba rosa	T6	D2	T3	D1
Primavera	T6	F3	—	—
Purpleheart	T6	D2	T3	D1
Ramin	T3	C2	T2	C1
Roble (Quercus)	T2	C2	T2	C1
Roble (Tabebuia)	T6	D2	T3	D1
Rosewood, Indian	T6	D2	T3	D1
Rosewood, Brazilian	T3	C2	T3	C1
Rubberwood	T6	D2	—	—
Sande	T5	C3	—	—
Santa Maria	T2	D4	T2	D3
Sapele	T2	D4	T2	D3
Sepetir	T8	B3	T5	B1
Spanish cedar	T10	D4S	T8	D3S
Sucupira (Bowdichia)	T5	B2	—	—
Sucupira (Diplotropis)	T7	B3	—	—
Teak	T10	D4S	T8	D3S
Wallaba	T2	C2	T2	C1

1 The letter S denotes softwood schedule code number from table 7-15.

Table 7-15—Moisture content schedules for softwoods

Dry-bulb temperature step no.	Moisture content at start of step (percent)	Dry-bulb temperatures (°F) for various temperature schedules													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
1	>30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	115	130	140	140	150	150	160	160	160	170	170	180	190	200
5	15	120	150	160	180	160	180	160	180	160	180	180	180	190	200

Table7-16—Moisture content wet-bulb depression schedules for softwoods

Wet-bulb depression step no.	Moisture content (percent) at start of step for various moisture content classes						Wet-bulb depressions (°F) for various wet-bulb depression schedules							
	A	B	C	D	E	F	1	2	3	4	5	6	7	8
1	>30	>35	>40	>50	>60	>70	3	4	5	7	10	15	20	25
2	30	35	40	50	60	70	4	5	7	10	14	20	25	30
3	25	30	35	40	50	60	6	8	11	15	20	25	30	35
4	20	25	30	35	40	50	10	14	15	20	25	30	35	35
5	(1)	20	25	30	35	40	15	20	20	25	30	35	35	35
6	—	(1)	20	25	30	35	20	25	25	30	35	35	35	35
7	—	—	(1)	20	25	30	25	30	30	35	35	35	35	35
8	—	—	—	(1)	20	25	30	35	35	35	35	35	35	35
9	—	—	—	—	(1)	20	35	35	35	35	35	35	35	35
10	15	15	15	15	15	15	50	50	50	50	50	50	50	50

[1]Go directly to step 10..

Table 7-17—Code number index of moisture content schedules[1] recommended for kiln drying 4/4, 6/4, and 8/4 softwood lumber

Species	Schedules for lower grades[2]			Schedules for upper grades[2]		
	4/4	6/4	8/4	4/4	6/4	8/4
Baldcypress	—	—	—	T12-E3	—	T11-D2
Cedar						
Alaska	—	—	—	T12-A3	—	T11-A2
Atlantic white	—	—	—	T12-A4	—	T11-A3
Eastern redcedar	—	—	—	T5-A4	—	T5-A3
Incense	—	—	—	T11-B5	—	T10-B4
Northern white	—	—	—	T12-B4	—	T11-B3
Port-Orford	—	—	—	T11-B4	—	T10-B3
western redcedar						
Light	T9-A6	—	—	T10-B5	—	T10-B3
Heavy	—	—	—	T5-F4	—	T5-F3
Douglas-fir						
coast region	T7-A4	—	[3]T7-A4	T11-A4	—	T10-A3
Inland region	[4]T9-A4	—	[4]T9-A4	—	—	—
Fir						
Balsam	—	—	—	T12-E5	—	T10-E4
California red	—	—	—	T12-E5	—	T10-E4
Grand	—	—	—	T12-E5	—	T10-E4
Noble	—	—	—	T12-A5	T11-A4	T10-A3
Pacific silver	—	—	—	T12-B5	—	T10-B3
Subalpine	—	—	—	T12-B5	—	T12-B[illegible]
White	T9-D6	—	T9-D5	T12-E5	T11-E5	T10-E4
Hemlock						
Eastern	—	—	—	T12-C4	—	T11-C3
Western	[3]T11-E5	—	T11-E5	T12-C5	T11-C5	T11-C4
Larch	[4]T7-C5	—	[3]T7-C5	T9-B4	T7-C4	T7-C3
Pine						
Eastern white						
Regular	T9-C5	—	T9-C4	T11-C5	—	T10-C4
Jack	T9-C4	—	T9-C3	—	—	—
Lodgepole	T5-C5	—	—	T10-C4	—	T9-C3
Ponderosa						
Heartwood	T9-A6	T7-A6	T5-A5	—	—	—
Sapwood	T11-C7	—	—	T9-C6	T7-C5	T7-C5
Antibrown-stain	—	—	—	T7-E6	—	T7-E5
Red	—	—	—	T12-B4	—	T11-B3
Southern yellow	T12-C5	—	—	T13-C6	T12-C5	T12-C5
sugar						
Light	T9-E7	T7-E6	—	T5-E6	T5-E6	T5-E5
Heavy	—	—	—	T5-F6	T5-F6	T5-F5
Western white						
Regular	T9-C6	—	[4]T7-C6	T9-C5	T7-C5	T7-C4
water core	T9-E6	—	—	—	—	—
Redwood						
Light	—	—	—	T5-D6	—	T5-D4
Heavy	—	—	—	T4-F5	T3-F5	T3-F4
Spruce						
Eastern (black, red, white)	—	—	—	T11-B4	—	T10-B3
Englemann	T7-B6	T5-B5	[3]T5-B5	T9-E5	—	T7-E4
Sitka	T7-A5	—	—	T12-B5	T12-B4	T11-B3
Tamarack	—	—	—	T11-B3	—	T10-B3

[1]Schedules are given in tables 7-20 and 7-21.
[2]Lower grades include commons, dimension, and box; upper grades include clears, selects, shop, and factory; also tight-knotted paneling.
[3]Maximum wet-bulb depression 25 °F.
[4]Maximum wet-bulb depression 20 °F.

Table 7-18—Code number index of moisture content schedules[1] suggested for kiln drying thick softwood lumber[2]

Species	Index for various lumber thicknesses		
	10/4	12/4	16/4
Baldcypress	T8-A4	T8-A4	—
Cedar			
Atlantic white	T7-A3	T7-A3	—
Incense	T5-F3	T5-F3	—
Northern white	T7-A3	T7-A3	—
Western redcedar (light)	T7-A2	T7-A2	—
Douglas-fir, coast region	T5-A1	T5-A1	T5-A1
Fir			
Balsam	T8-A4	T8-A4	—
California red	T8-A3	T8-A3	—
Grand	T8-A4	T8-A3	—
Noble	T5-A2	T5-A2	—
White	T8-A4	T8-A4	—
Hemlock			
Eastern	T8-A3	T8-A2	—
Western	T8-A4	T8-A3	—
Larch, western	T7-A3	T7-A2	—
Pine			
Eastern white	T10-C4	T8-C3	T5-C2
Ponderosa	T7-A4	T7-A4	—
Red	T7-A3	T7-A3	—
Southern	T10-C4	T10-C4	—
Western white	T7-C4	T5-C3	—
Redwood (light)	T5-C4	T5-C3	—
Spruce			
Eastern (black, red, white)	T5-A2	T5-A2	—
Engelmann	T7-A4	T7-A3	—
Sitka	T5-B2	T5-B2	—
Tamarack	T7-A3	T7-A3	—

[1]Schedules are given in table 7-20 and 7-21.
[2]Upper grades, including clears, selects, and factory lumber.

Table 7-19—Index of time schedules1 for kiln drying softwood species at conventional temperatures

Common name (botanical name)	Schedules for lower grades[2]			Schedules for upper grades[3]				Comments[4]
	4/4,5/4	6/4	8/4	4/4,5/4	6/4	8/4	12/4, 16/4	
Cedar								
Alaska yellow *(Chamaecyparis nootkatensis)*	EC	HC	HC	EC	HC	HC		Light to medium sorts only. Prone to collapse. For heavy sort, air dry to 20 percent moisture content and kiln dry with table HC, starting with step 4.
Incense *(Libocedrus decurrens)*	HC[a]	HC	GC	HC[a]	HC	GC	LC	[a]Use 12 h for each setting.
Port-Orford *(Chamaecyparis lawsoniana)*	HC	—	FC	HC	LC	LC		Decrease dry- and wet-bulb settings by 10°F for first 46 h.
Western juniper *(Juniperus occidentalis)*	HC	HC	—	HC	HC	—	—	
Western redcedar *(Thuja plicata)*	HC	HC	GC	HC	HC	LC	—	
Douglas-fir *(Pseudotsuga menziesii)*	IC[b]	IC[c]	IC[c]	JC[d]	JC[d]	JC[d]	FC	Upper grades, including laminated stock, dimension, 4/4 common. Clears and shop require conditioning in most cases. Ladder stock requires lower temperature to prevent strength reduction. [b]Omit step 1 and reduce step 3 to 12 h. [c]Reduce step 3 to 12 h. [d]Omit step 1 for vertical grain.
Fir, true	IC	IC	IC[e]	JC[f]	JC[g]	JC[g]	FC	True fir and hemlock can be dried together, but problems with percent overdry and wets are likely. [e]96 to 108 h all widths. [f]96 h flat grain; start with step 2 for vertical grain, 60 h. [g]10 to 14 days for sinker heartwood.
Alpine *(Abies lasiocarpa)*								
Balsam (A. *balsamera)*								
California red (A. *magnifica)*								
Grand *(A. grandis)*								
Noble (A. *nob/is)*								
Pacific silver *(A. amabilis)*								
White *(A. concolor)*								
Hemlock								Hemlock and true fir can be dried together, but problems with percent overdry and wets are likely. Prone to excessive warp and checking. [h]96 to 108 hall widths. [i]96 h flat grain; start with step 2 for vertical grain, 60 h. [j]14 days for sinker heartwood.
Mountain *(Tsuga mertensiana)*	IC	IC	IC	—	—	—	—	
Western (T. heterophylla)	IC	IC	IC[h]	JC[i]	JC[j]	JC[j]	FC	

Table 7-19—Index of time schedules[1] for kiln drying softwood species at conventional temperatures—concluded

Common name *(botanical name)*	Schedules for lower grades[2]			Schedules for upper grades[3]				Comments[4]
	4/4,5/4	6/4	8/4	4/4,5/4	6/4	8/4	**12/4, 16/4**	
Larch								
Alpine *(Larix lyalli)*	IC	IC	IC	—	—	—	—	
Western *(L. occidentalis)*	IC	IC	IC	JC	JC	JC	FC	
Pine								
Eastern white *(Pinus strobus)*	BBC	—	CCC	—	—	—	—	
Jack *(P. banksiana)*	IC[k]	IC[k]	IC[k]	IC[k]	—	—	—	[k]Omit first 12 h of schedule
Jeffrey *(P. jetfreyi)*	IC[k]	IC[k]	IC[k]	—	—	—	—	
Limber *(P. flexilis)*	IC[k]	IC[k]	IC[k]	IC[k]	JC	JC	—	
Lodgepole *(P. contorta)*	IC[k]	IC[k]	IC[k]	IC[k]	JC	JC	GC	
Ponderosa *(P. ponderosa)*	QC	RC	RC	SC	TC	UC	VC	
Southern	AC	—	BC	AC	—	BC	CC	3 by 5 timbers use table PC. 10/4 and 12/4 flitches use table OC.
Loblolly *(Pinus taeda)*								
Longleaf *(P. palustris)*								
Shortleaf *(P. echinata)*								
Slash *(P. elliottii)*								
Sugar (P. lambertiana)								
Heavy	WC	XC	XC	WC	XC	—	—	
Light.	YC	YC	ZC	YC	YC	XC	AAC	
Eastern white *(P. strobus)*	MC	—	NC	MC	—	NC	—	
Idaho white/western white *(P. monticola)*	KC	UC	UC	KC	UC	UC	—	
Redwood *(Sequoia sempervirens)*								[l]Air dry to 20 percent moisture content. then dry with table DC.
Light	GC	FC	([l])	GC	FC	([l])	—	
Heavy and medium	([m])	([m])	([m])	([m])	([m])	([m])	—	[m]Air dry to 20 percent moisture content, then dry with table GC. Prone to collapse.
Spruce								
Slack *(Picea mariana)*	IC[n]	IC[n]	IC[n]	IC	GC	GC	FC	[n]Reduce last 3 steps of schedule from 24 to 18 h each setting.
Engelmann *(P. engelmannii)*	IC[n]	IC[n]	IC	IC	GC	GC	FC	
Red *(P. rubens)*	IC[o]	IC[o]	IC	IC	IC	IC	—	
Sitka *(P. sitchensis)*	JC	JC	EC	EC	EC	HC	FC[o]	[o]Air dry to 20 percent moisture content, then dry with table IC
White *(P. glauca)*	IC[n]	IC[n]	IC	IC	GC	GC	FC	
Yew, Pacific *(Taxus brevifolia)*	HC	HC	FC	HC	HC	HC[o]	—	

[1]See table 7-20 for description of schedules.
[2]Lower grades include commons, dimensions, box, and studs.
[3]Upper grades include clears, selects, shop, and factory.
[4]Comments are cross-referenced to column entries by superscript letters.

Table 7-20—Time schedules for kiln drying softwood lumber at conventional temperatures

Step no.	Time (h)	Temperature (°F)	
		Dry-bulb	Wet-bulb
SCHEDULE AC (SP[1]—4/4,5/4; STEAM)[2]			
1	0 to 24	140	130
2	24 to 48	160	130
3	48 to 72	185	125
4	72 to 96	185	120
SCHEDUAL BC (SP—8/4; STEAM)[2]			
1	0 to 24	140	[3]130
2	24 to 48	160	130
3	48 to 72	185	125
4	72 to 96	185	120
5	96 to 120	185	115
SCHEDULE CC (SP—12/4 DIMENSION; STEAM)[2]			
1	0 to 24	130	130
2	24 to 48	140	130
3	48 to 72	160	130
4	72 to 96	185	125
5	96 to 120	185	120
6	120 to 144	185	115
SCHEDULE DC[2]			
1	0 to 12	150	145
2	12 to 24	150	140
3	24 to 48	155	140
4	48 to 72	165	140
5	72 to 120 (or until dry)	180	140
SCHEDULE EC[2]			
	0 to 12	150	145
	12 to 48	150	140
	48 to 84	155	140
	84 to 132	165	140
	132 to 156 (or until dry)	180	140
SCHEDULE FC[2]			
	0 to 12	130	125
	12 to 36	135	130
	36 to 84	140	135
	84 to 132	145	135
	132 to 180	150	135
	180 to 228	155	135
	228 to 276	160	135
	276 to 324 (or until dry)	170	135

Step no.	Time (h)	Temperature (°F)	
		Dry-bulb	Wet-bulb
SCHEDULE GC[2]			
1	0 to 48	130	120
2	48 to 72	135	120
3	72 to 96	140	125
4	96 to 120	145	125
5	120 to 144	150	125
6	144 to 168	155	125
7	168 to 192	160	130
8	192 to 216	165	135
9	216 to 240 (or until dry)	170	135
SCHEDULE HC[2]			
1	0 to 24	130	123
2	24 to 48	135	125
3	48 to 72	140	125
4	72 to 96	150	135
5	96 to 120	155	135
6	120 to 144	160	135
7	144 to 168 (or until dry)	180	140
SCHEDULE IC[2]			
1	0 to 12	180	170
2	12 to 36	180	165
3	36 to 60	180	155
4	60 to 84 (or until dry)	180	145
SCHEDULE JC[2]			
1	0 to 12	170	164
2	12 to 24	170	160
3	24 to 48	175	160
4	48 to 72	180	160
5	72 to 96 (or until dry)	180	140
SCHEDULE KC[2]			
1	0 to 24	130	115
2	24 to 48	140	120
3	48 to 72	160	135
4	72 to 96 (or until dry)	170	135

Table 7-20—Time schedules for kiln drying softwood lumber at conventional temperatures—continued

SCHEDULE LC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 24	110	100
2	24 to 48	115	105
3	48 to 72	120	110
4	72 to 96	125	110
5	96 to 120	130	115
6	120 to 144	140	120
7	144 to 168	150	125
8	168 to 192	160	130
9	192 to 216 (or until dry)	170	135

SCHEDULE MC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 24	140	130
2	24 to 48	145	130
3	48 to 72	150	130
4	72 to 96	155	130
5	96 to 120	160	130
6	120 to 144	170	135
7	144 to final	180	130

SCHEDULE NC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 24	145	138
2	24 to 48	150	140
3	48 to 72	155	140
4	72 to 96	160	140
5	96 to 120	170	145
6	120 to 144	180	150
7	144 to final	180	145

SCHEDULE OC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 72	140	133
2	72 to 84	140	130
3	84 to 96	140	125
4	96 to 104	150	130
5	104 to 116	160	135
6	116 to 128	170	140
7	128 to 130	180	130

SCHEDULE PC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 72	130	126
2	72 to 96	130	125
3	96 to 120	135	125
4	120 to 132	140	132
5	132 to 144	150	138
6	144 to 156	155	140
7	156 to 168	160	130

SCHEDULE QC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
	0 to 24	150	130
	24 to 48	150	120
	48 to 72 (or until dry)	170	130

SCHEDULE RC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
	0 to 24	160	140
	24 to 36	165	140
	36 to 60 (or until dry)	170	140

SCHEDULE SC'

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 24	130	115
2	24 to 48	140	115
3	48 to 72	150	120
4	72 to 84 (or until dry)	170	140

SCHEDULE TC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
	) to 24	130	115
	l to 48	140	115
	l to 72	145	115
	: to 96	160	125
	to 136	170	140

SCHEDULE UC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 16	120	105
2	16 to 24	125	105
3	24 to 36	130	105
4	36 to 48	135	115
5	48 to 60	145	120
6	60 to 72	150	125
7	72 to 96	160	130
8	96 to 108	165	135
9	108 to 120	170	140
10	120 to 144	170	135
11	144 to 156	180	140

SCHEDULE VC[2]

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
1	0 to 24	115	108
2	24 to 48	120	110
3	48 to 72	125	115
4	72 to 96	130	120
5	96 to 216	140	130
6	216 to 264	145	130
7	264 to 336	150	135
8	336 to 408	155	140
9	408 to 504 (or until dry)	160	140

Table 7-20—Time schedules for kiln drying softwood lumber at conventional temperatures—concluded

Step no.	Time (h)	Temperature (°F)	
		Dry-bulb	Wet-bulb
	SCHEDULE WC’		
1	0 to 48	120	(Vents open)
2	48 to 72	125	(Vents open)
3	72 to 84	130	(Vents open)
4	84 to 96	135	(Vents open)
5	96 to 120	140	(Vents open)
6	120 to 132	150	100
7	132 to 144	155	105
8	144 to 168 (or until dry)	160	110
	SCHEDULE XC’		
1	0 to 24	105	(Vents open)
2	24 to 48	110	(Vents open)
3	48 to 72	115	(Vents open)
4	72 to 96	120	(Vents open)
5	96 to 120	125	100
6	120 to 144	130	100
7	144 to 168	135	105
8	168 to 192	140	105
9	192 to 216	145	105
10	216 to 240	150	108
11	240 to 264	155	108
12	264 to 288 (or until dry)	160	110
	SCHEDULE YC[4]		
1	0 to 24	120	(Vents open)
2	24 to 48	130	100
3	48 to 72	140	105
4	72 to 84	150	105
5	84 to 96 (or until dry)	170	120
	SCHEDULE ZC[4]		
1	0 to 12	115	(Vents open)
2	12 to 36	130	95
3	36 to 60	140	95
4	60 to 72	150	100
5	72 to 96 (or until dry)	160	115
	SCHEDULE AAC[4]		
1	0 to 168	105	(Vents open)
2	168 to 336	130	105
3	336 to 504	145	105
4	504 to 672	150	105
5	672 to 840	160	110
	SCHEDULE BBC		
1	0 to 24	115	[2]100
2	24 to 72	120	[2]100
3	72 to 96	125	[2]105
4	96 to 120	130	[2]110
5	120 to 144	140	[2]120
6	144 to 156 (or until dry)	140	[2]127
	SCHEDULE CCC		
1	0 to 12	110	[2]100
2	12 to 36	120	[2]110
3	36 to 60	120	[2]105
4	60 to 84	120	[2]100
5	84 to 108	130	[2]105
6	Equalize	140	130

[1]SP, southern pine.
[2]Equalize and condition as necessary
[3]Spray off; vents working.
[4]No conditioning.

Table 7-21—Index of time schedules[1] for kiln drying softwood lumber at high temperature (>212 °F)

Common name (botanical name)	Lumber schedules 4/4,5/4	6/4	8/4	Schedules for other products	Comment
Ceder, northern white					
(Thuja occidentalis)	IH	—	—		
Douglas-fir	AH	AH	AH		Can be dried with western larch.
(Pseudotsuga menziesii)			OH		
Fir, true					
Balsam *(Abies balsamera)*	AH	AH	AH		
California red (A. magnifica)	AH	AH	AH		
Grand (A. *grandis)*	AH	AH	AH		
Noble *(A. procera)*	AH	AH	AH		
Pacific silver (A. *amabilis)*	AH	AH	AH		Can be dried with western hemlock.
			PH		
Subalpine *(A. lasiocarpa)*	AH	AH	AH		
QH					
White *(A. concolor)*	AH	AH	AH	4 by 6-in decking, FH Studs, GH	
Hemlock					
Mountain *(Tsuga mertensiana)*	AH	AH	AH		
Western (T. heterophylla)	AH	AH	AH		Can be dried with Pacific silver fir.
			PH		
Larch, western					
(Lark occidentalis)	AH	AH	AH		Can be dried with Douglas-fir.
			OH		
Pine					
Jack *(Pinus banksiana)*	AH	AH	AH	Studs, MH	
Limber *(P. flexilis)*	AH	AH	AH		
Lodgepole *(P. contorta)*	AH	AH	AH	Studs, MH	
Ponderosa *(P. ponderosa)*	AH	AH	AH	Studs, HH	
Red (Norway) *(P. resinosa)*	JH	—	KH		
Southern	—	—	—	2 by 4, DH	Can be used with steam heat.
Loblolly *(P. taeda)*	BH, CH	—	—	2 by 10, DH	
Longleaf *(P. palustris)*	—	—	—	4 by 4, EH	
Shortleaf *(P. echinata)*	—	—	—		
Slash *(P. elliottii)*	—	—	—		
Spruce					
Black *(Picea mariana)*	AH	AH	AH		
	JH	—	KH		
Engelmann *(P. engelmannii)*	AH	AH	AH		
Red *(P. rubens)*	JH	—	KH		
White *(P. glauca)*	AH	AH	AH	Studs, MH	Can be dried with jack and lodgepole pine.
	JH	—	KH		Use NH with gas-fired kilns.

[1]See table 7-22 for description of schedules.

Table 7-22—Time schedules for kiln drying softwood lumber at high temperatures

Step no.	Time (h)	Temperature (°F) Dry-bulb	Temperature (°F) Wet-bulb
	SCHEDULE AH[1]		
1	0 to 12	230	205
2	12 to 24	230	200
3	24 to 36 (or until dry)	230	195
	SCHEDULE BH (C&BTR SYP–5/4; DIRECT FIRED)[1,2]		
1	0 to 16 (or until dry[3])	220	180
	SCHEDULE CH (C&BTR SYP–1-IN RANDOM WIDTH; DIRECT FIRED)[1]		
1	0 to 15 (or until dry[4])	220	180
	SCHEDULE DH (SYP–2 BY 4-2 BY 10; DIRECT FIRED)[1]		
1	0 to 24 (or until dry[5])	240	180
	SCHEDULE EH (SYP–4 BY 4; DIRECT FIRED)[1]		
1	0 to 41 (or until dry[6])	220	165
	SCHEDULE FH[1]		
1	0 to 8	220	210
2	8 to 24	220	205
3	24 to 60	220	200
4	60 to 96	225	200
5	96 until dry	235	200
	SCHEDULE GH[1]		
1	0 to 6 or 2 h past period when temperatures leveled off	212	212
2	6 to 16	240	190
3	16 until dry (30-36 h)[7]	240	170
	SCHEDULE HH[1]		
1	0 to 4	210	210
2	4 to 8	220	210
3	8 to 12	230	205
4	12 to 18	230	200
5	18 to 24	230	190
6	24 until dry	230	180
	SCHEDULE MH (LODGEPOLE, JACK PINE, WHITE SPRUCE–STUDS)[1]		
1	0 to 6	180	160
2	6 to 12	180	160
3	12 to 26	220	185
4	26 to 35	220	180
5	35 to 46	220	160
	SCHEDULE NH (WHITE SPRUCE–2-IN DIMENSION; GAS FIRED)[1]		
1	0 to 28	230	185
	SCHEDULE OH (DOUGLAS-FIR, LARCH–2- BY 4-IN DIMENSION)[1]		
1	0 to 12	225	190
2	12 to 21	240	190
3	21 to 24	205	180
	SCHEDULE PH (WESTERN HEMLOCK, AMABILIS FIR–2- BY 4-IN DIMENSION)[1]		
1	0 to 42	240	205
	SCHEDULE QH (ALPINE FIR–2-IN DIMENSION)[1]		
1	0 to 54	235	180
2	54 to 58	(Steam)	—
3	58 to 62	235	180
4	62 to 66	(Steam)	—
5	66 to 90	235	180

[1]Equalize and condition as necessary.
[2]C&BTR, common and Better grade; SYP, southern yellow pine.
[3]At 10 percent moisture content, final wet-bulb temperature will be approximately 145°F for direct-fired kilns and approximately 175°F for steam-heated kilns.
[4]At 10 percent moisture content, final wet-bulb temperature will be approximately 150°F for direct fired kilns.
[5]At 15 percent moisture content, final wet-bulb temperature will be approximately 155°F.
[6]At 20 percent moisture content, final wet-bulb temperature will be approximately 140°F.
[7]Pull charge when sapwood and corky heartwood are dry.

Table 7-23—Time schedules for kiln drying softwood lumber at high temperatures

Step no.	Moisture content (percent)	Temperature (°F)	
		Dry-bulb	Wet-bulb
SCHEDULE IH			
1	(Warmup—2 h)	—	212
2	Above 30	230	208
3	Below 30	230	192
4	(Conditioning)	190	180
SCHEDULE JH			
1	(Warmup—2 h)	—	210
2	Above 35	235	200
3	35 to 20	240	190
4	Below 20	245	180
5	(Conditioning)	190	180
SCHEDULE KH			
1	(Warmup—3 h)	—	210
2	(Hold for 1/2 h)	240	210
3	(Green to dry)	240	200
4	(Conditioning)	219	212

Table 7-24—Anti-brown-stain moisture content schedules for 4/4-6/4 eastern white pine, western white pine, and sugar pine

Moisture content at start of step (percent)	Dry-bulb temperature (°F)	Wet-bulb depression (°F)	Wet-bulb temperature (°F)
>100	120	15	([1])
100	120	15	105
85	120	20	100
60	130	25	105
45	130	30	100
30	140	35	105
25	150	35	115
20	160	35	125
15	180	28	152
(Conditioning—4 h)	152	12	140

[1]Spray value shut.

Table 7-25—Anti-brown-stain time schedules for eastern white pine, western white pine, and sugar pine

Step no.	Time (h)	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)
4/4-5/4 LUMBER			
1	0 to 16	120	([1])
2	16 to 32	125	([1])
3	32 to 64	130	([1])
4	64 to 80	135	([1])
5	80 to 96	140	([1])
6	96 to 112	145	110
7	112 to 128	150	110
8	128 to 144	155	115
9	144 to 160	160	120
10	160 to 220	170	125
11	220 until dry	170	125
7/4-8/4 LUMBER			
1	0 to 12	120	([1])
2	12 to 55	125	([1])
3	55 to 74	130	([1])
4	74 to 96	135	([1])
5	96 to 144	145	110
6	144 to 168	160	120
7	168 until dry	170	125

[1]Spray off, vents open.

Table 7-26—Recommended kiln schedules for Douglas-fir plywood treated with chromated copper arsenate preservative

Schedule[1]	Temperature (°F)		Drying time to approximately 14 percent(h)
	Dry-bulb	Wet-bulb	
3/4-IN-THICK PLYWOOD			
1	165	160	49
2	185	180	41
1/2-IN-THICK PLYWOOD			
1	165	160	27
2	185	180	24

[1]Two alternative schedules are given for each size of plywood.
[2]Initial wet-bulb temperature–the schedule calls for a 1 °F per h decrease in wet-bulb temperature as drying progresses.

Table 7-27—Suggested kiln schedules for large southern Pine timbers and poles

Time in each step (h)	Temperature (°F)		Comment
	Dry-bulb	Wet-bulb	
	3 BY 6- AND 4 BY 8-IN TIMBERS		
48	140	125	The 180 °F final step is prolonged until the timbers reach 18 percent moisture content.
48	150	130	
48	160	135	
48	170	138	
48	180	140	
	4-1/2-BY 5-1/2-IN CROSSARMS		
30	160	150	Final moisture content at a 1 -in depth is 17 to 22 percent.
24	170	150	
24	180	150	
24	190	150	
10 to 12	195	175	
	3-1/2- BY 4-1/2-IN PARTIALLY AIR-DRIED CROSSARMS		
69	135	125	
24	145	125	
29	150	125	
15	165	132	
	UP TO 6- BY 6-IN TIMBERS		
36	230	No control	Fan reversal every 3 h with 3-min venting at that time. Dry outer 2 in. to below fiber saturation point.
	6- BY 6-IN AND GREATER TIMBERS AND POLES (SEVERE SCHEDULE)		
48	230	No control	Fan reversal every 3 h with 3-min venting at that time. Dry outer 2 in. to below fiber saturation point.
	10-1/2-IN-DIAMETER POLES AND PILING (MILD SCHEDULE)		
24	134	120	
47	144	120	
47	153	120	
46	165	120	
	8- TO 10-IN-DIAMETER POLES AND PILING (ACCELERATED SCHEDULE)		
114	170	120	Initial moisture content about 85 percent. Final moisture content 30 percent in outer 3 in.

Table 7-28—Time schedules for kiln drying 4- by 5-in roof decking

Step no.	Time (h)	Dry-bulb temperature (°F)	Wet-bulb temperature (°F)
		WHITE FIR	
1	0 to 24	150	140
2	24 to 48	155	140
3	48 to 72	160	145
4	72 to 96	165	150
5	96 to 192	170	155
		ENGELMANN SPRUCE	
1	0 to 144	165	145
2	144 to 168	177	120
		WESTERN REDCEDAR	
1	0 to 48	130	120
2	48 to 72	135	120
3	72 to 96	140	125
4	96 to 120	145	125
5	120 to 144	150	125
6	144 to 168	155	125
7	168 to 192	160	130
8	192 to 216	165	135
9	216 to 240	170	140

Table 7-29—Conversion of a schedule from a steam-heated kiln to dehumidification kiln

Moisture content at start of step (percent)	Temperature (°F)		Relative humidity (percent)	Equilibrium moisture content (percent)
	Dry-bulb	Wet-bulb		
		4/4 WHITE OAK–T4-C2 FOR STEAM-HEATED KILN		
>40	110	106	87	17.5
40	110	105	84	16.2
35	110	102	75	13.3
30	120	106	62	10.0
25	130	100	35	5.6
20	140	90	19	2.6
15	180	130	26	3.3
(Equalize)	173	130	30	4.1
(Condition)	180	170	79	11.1
		4/4 WHITE OAK–T4-C2 CONVERTED TO DEHUMIDIFICATION SCHEDULE WITH MAXIMUM TEMPERATURE OF 120 °F		
>40	110	106	87	17.5
40	110	105	84	16.2
35	110	102	75	13.3
30	120	106	62	10.0
25	120	91	35	5.6
20	120	80	17	3.3
15	120	80	17	3.3
(Equalize[1])	120	84	22	4.2
(Condition[2])	120	108	67	11.0

Table 7-30—General low-temperature schedule for kiln drying refractory species

Moisture content at start of step (percent)	Temperature (°F)		Relative humidity (percent)	Equilibrium moisture content (percent)
	Dry-bulb	Wet-bulb		
>50	90	86	85	17.3
50	90	84	78	14.7
45	95	88	75	13.9
40	95	85	66	11.6
35	100	88	62	10.6
30	100	85	54	9.2
25	105	88	50	8.7
20	110	87	40	6.8
15	120	90	31	5.4

Table 7-31—Schedule for killing Lyctus (powder-post) beetles and their eggs

Temperature (°F)		Relative humidity (percent)	Equilibrium moisture content (percent)	Thickness of lumber (in)	Kiln reaches set conditions (h)
Dry-bulb temperature	Wet-bulb depression				
				1	3
140	7	82	13.8	2	5
				3	7
				1	10
130	16	60	9.4	2	12
				3	14
				1	46
125	15	61	9.7	2	48
				3	50

Table 7-32—Kiln sample moisture content and equilibrium moisture content values for equalizing and conditioning a charge of lumber

Desired final average) moisture content (percent)	Equalizing moisture content values (percent)			Conditioning equilibrium moisture content values (percent)	
	Moisture content of driest sample at start	Equilibrium moisture content conditions in kiln	Moisture content of wettest sample at end	Softwoods	Hardwoods
5	3	3	5	8	9
6	4	4	6	9	10
7	5	5	7	10	11
8	6	6	8	11	12
9	7	7	9	12	13
10	8	8	10	13	14
11	9	9	11	14	15

Table 7-33—Approximate kiln-drying periods for 1-in lumber[1]

Species	Time (days) required to kiln dry 1-in lumber	
	20 to 6 percent moisture content	Green to 6 percent moisture content
	SOFTWOODS	
Baldcypress	4-8	10-20
Cedar		
Alaska	—	4- 6
Atlantic white	—	8-10
Eastern redcedar	2-3	6- 8
Incense	—	3- 6
Northern white	—	8-10
Port-Orford	—	4- 8
Western redcedar	—	10-15
Douglas-fir		
Coast type	—	2- 4
Intermediate type	—	4- 7
Rocky Mountain type	—	4- 7
Fir		
Balsam	—	3- 5
California red	—	3- 5
Grand	—	3- 5
Noble	—	3- 5
Pacific silver	—	3- 5
Subalpine	—	3- 5
White	—	3- 5
Hemlock		
Eastern	—	3- 5
Western	—	3- 5
Larch, western	—	3- 5
Pine		
Eastern white	2-3	4- 6
Lodgepole	—	3- 5
Ponderosa	—	3- 6
Red	—	6- 8
Southern yellow		
Loblolly	—	3- 5
Longleaf	—	3- 5
Shortleaf	—	3- 5
Sugar		
Light	—	3- 4
Heavy	—	5-10
Western white	—	3- 5
Redwood		
Light	3- 5	10-14
Heavy	5- 7	20-24
Spruce		
Eastern, black, red, white	—	4- 6
Engelmann	—	3- 5
Sitka	—	4- 7
Tamarack	—	3- 5

Species	Time (days) required to kiln dry l-in lumber	
	20 to 6 percent moisture content	Green to 6 percent moisture content
	HARDWOODS	
Alder, red	3- 5	6-10
Apple	4- 7	10-15
Ash		
Black	5- 7	10-14
White	4- 7	11-15
Aspen	3- 5	6-10
Basswood, American	3- 5	6-10
Beech, American	5- 8	12-15
Birch		
Paper	—	3- 5
Yellow	5- 8	11-15
Buckeye, yellow	5- 8	12-16
Butternut	5- 8	10-15
Cherry black	5- 7	10-14
Chestnut, American	4- 8	8-12
Chinkapin, golden	7-12	22-28
Cottonwood	4- 8	8-12
Dogwood, flowering	5- 8	12-16
Elm		
American	4- 6	10-15
Rock	5- 8	13-17
Hackberry	4- 6	7-11
Hickory	4-12	7-15
Holly, American	5- 8	12-16
Hophornbeam, eastern	5- 8	12-16
Laurel, California	5- 7	10-15
Locust, black	5- 8	12-16
Madrone, Pacific	8-11	15-20
Magnolia	4- 6	10-15
Mahogany	4- 7	12-15
Maple		
Red, silver (soft)	4- 6	7-13
Sugar (hard)	5- 8	11-15
Oak		
California black	6-10	25-35
Live	—	30-40
Red	5-10	16-28
White	6-12	20-30
Osage-orange	5- 8	12-16
Persimmon, common	5- 8	12-16
Sweetgum		
Heartwood	8-12	15-25
Sapwood	5- 7	10-15
Sycamore, American	4- 7	6-12
Tanoak	7-12	24-30
Tupelo		
Black	4- 6	6-10
Water	5- 7	6-12
Walnut, black	5- 8	10-16
Willow, black	5- 8	12-16
Yellow-poplar	3- 6	6-10

[1]Because of the many factors affecting drying rate and the lack of specific data covering each case, wide variation from these values must be expected. These values represent only a general idea of average drying periods and should not be used as time schedules. Some of the drying times shown were obtained from commercial kiln operators.