Chapter 5
Drying and Heat Sterilization of Maple Lumber for Structural Uses

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Traditional hardwood lumber drying processes were developed for appearance-type products such as furniture, cabinetry, and millwork. This means that air-drying practices were managed to minimize the chemical and fungal stains that occur in white woods such as maple, as well as surface checking that is common in some species. It also means that the kiln schedules which were developed are conservative, slow, and designed to virtually eliminate even minor drying defects such as small surface checks or discolorations. In structural products, surface checks and discoloration do not detract from utility. They are not considered defects in softwood structural lumber grading rules. Therefore, for structural lumber, air-drying and pre-drying practices can be relaxed and kiln schedules can be more severe, faster, and more efficient than traditional hardwood schedules.

Additional factors that will shorten kiln-drying time compared with traditional hardwood schedules are the higher final moisture content (MC) and wider allowable MC distribution of 15 to 19 percent in structural products compared with 6 to 8 percent for traditional hardwood appearance products. Drying from 15 to 19 percent MC to 6 to 8 percent is a significant portion of total drying time and would be eliminated in lumber for structural uses. Efficient drying methods would make a positive contribution to the economics of producing structural wood products from undervalued hardwoods.

There are several options available for drying hardwood lumber for structural uses. The most basic option is the exclusive use of air-drying. Exclusive use of air-drying is not an option for appearance-type products because MC levels of 6 to 8 percent are not possible in the areas of the country where hardwoods are a significant timber resource. However, when the desired MCs are as high as 19 percent, air-drying is possible. On the negative side, air-drying can be a long process whose time requirements can be difficult to estimate, making production planning difficult. Nevertheless, it is a drying option some producers might consider.

It is also possible to combine air-drying, to some level such as 30 percent MC, followed by kiln-drying to final MC. The rationale for this approach is that air-drying from green to approximately 30 percent MC is the fastest part of drying, and below 30 percent MC the air-drying rate slows significantly. The drying rate can be considerably increased with the higher temperatures and lower relative humidities available when kiln-drying. Pre-dryers can also be used either exclusively or, similar to air-drying, in combination with final-stage kiln-drying. Because pre-dryers are at temperatures in the 80" to 90°F range and relative humidities are in the 65 percent or lower range, their exclusive use results in a find MC of approximately 19 percent. Combining the use of pre-dryers with final-stage kiln-dryers at a MC of less than 30 works as well. And finally, it is also possible to employ kiln-drying from green MC to a final MC of 15 to 19 percent, though this method may not be wise economically.

Structural hardwood products can include such items as dimension lumber as used in light-frame construction as well as engineered wood products such as I-joists. In addition to light-frame construction applications, another type of structural product, already in common use and sometimes engineered, is wood packing material such as pallets. A current concern involving wood packing material is its role in transporting insects and pathogens between countries in international trade. Because of this problem, many countries are requiring wood packing material to be heat sterilized before it is allowed to enter. One issue in heat sterilization is the time required for the center of any of a variety of wood sizes and configurations to reach the temperature necessary to kill the insect or pathogen.

The remainder of this chapter will focus on drying studies conducted at the Forest Products Laboratory and at Michigan Technological University with 2-

by 6-inch sugar and red maple lumber, and also heating time studies associated with heat sterilization for killing insects and pathogens.

Drying Options

Air-Drying

Air-drying is a viable option because it is possible, although lengthy, to air-dry to below 19 percent MC. It is also viable when used as a predecessor to kiln-drying. One problem with use of air-drying, either alone or as a predecessor, is the difficulty in estimating the time required to reach the desired MC level, which makes production planning and inventory control difficult. There are several factors that influence air-drying time. Wood species and lumber thickness are important factors, but remain constant in considering nominal 2-inch-thick maple structural lumber. Two other important factors are the geographical location of the air-drying operation and the time of the year the lumber is stacked for air-drying. In general, air-drying takes longer in northern locations of the United States than in southern U.S. locations. And if lumber is stacked for air-drying in the late summer or early fall, it is subjected to cold winter weather before it reaches the target final MC. If lumber is stacked in the early spring, it will very likely be air-dried before it can be subjected to the cold winter weather. Simpson and Hart (2000,2001) developed a method for estimating air-drying times as they depend on various influencing factors. They also presented a series of graphs showing how air-drying time depends on wood species, lumber thickness, final target MC, geographical location, and the time of the year the lumber is stacked. Figure 5.1 shows a series of this type of graph for nominal 2- by 6-inch maple lumber air-dried in various locations in the maple growing range, from as far north as Duluth, Minnesota to as far south as Montgomery, Alabama. Each graph shows estimated drying time according to stacking date and to several final MCs ranging from 18 to 30 percent.

Pre-Drying

Pre-dryers offer a way to dry lumber which is a compromise between air-drying and kiln-drying in terms of drying time. It offers controlled drying that avoids the long air-drying times associated with rainy weather and cold winter temperatures. Pre-dryers are typically large warehouse-type structures where temperature is controlled at relatively low levels, in the 80° to 90°F range, relative humidity is controlled, venting is provided, and air circulation is provided. Pre-drying is typically used as a substitute for air-drying, and MC is lowered to about 25 percent before going into a dry-kiln for final drying to 6 to

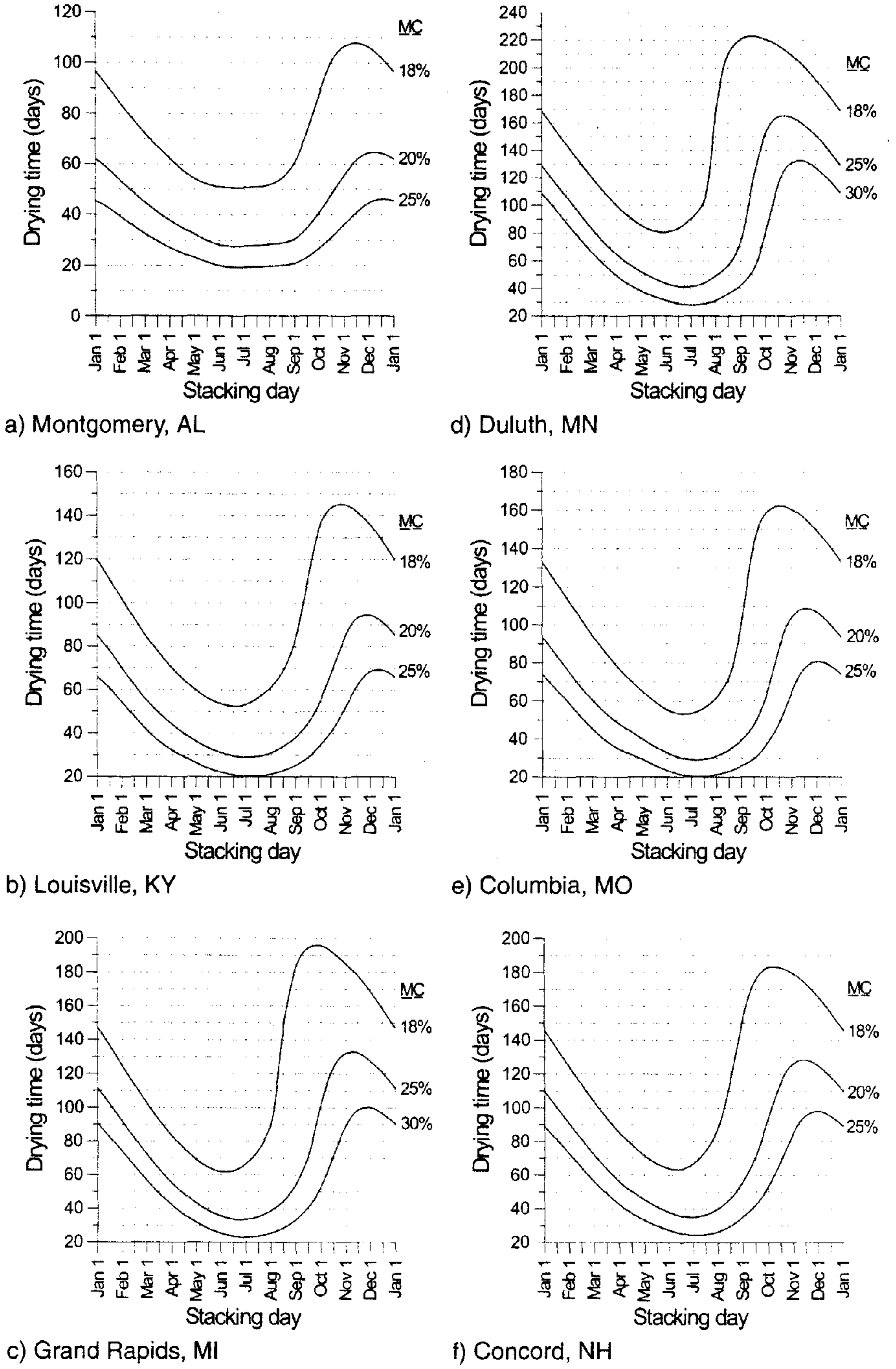


Figure 5.1. – Estimated air-drying times for nominal 2- by 6-inch maple lumber as they depend on geographical location, stacking date, and final moisture content. (Figure continued on next page.)

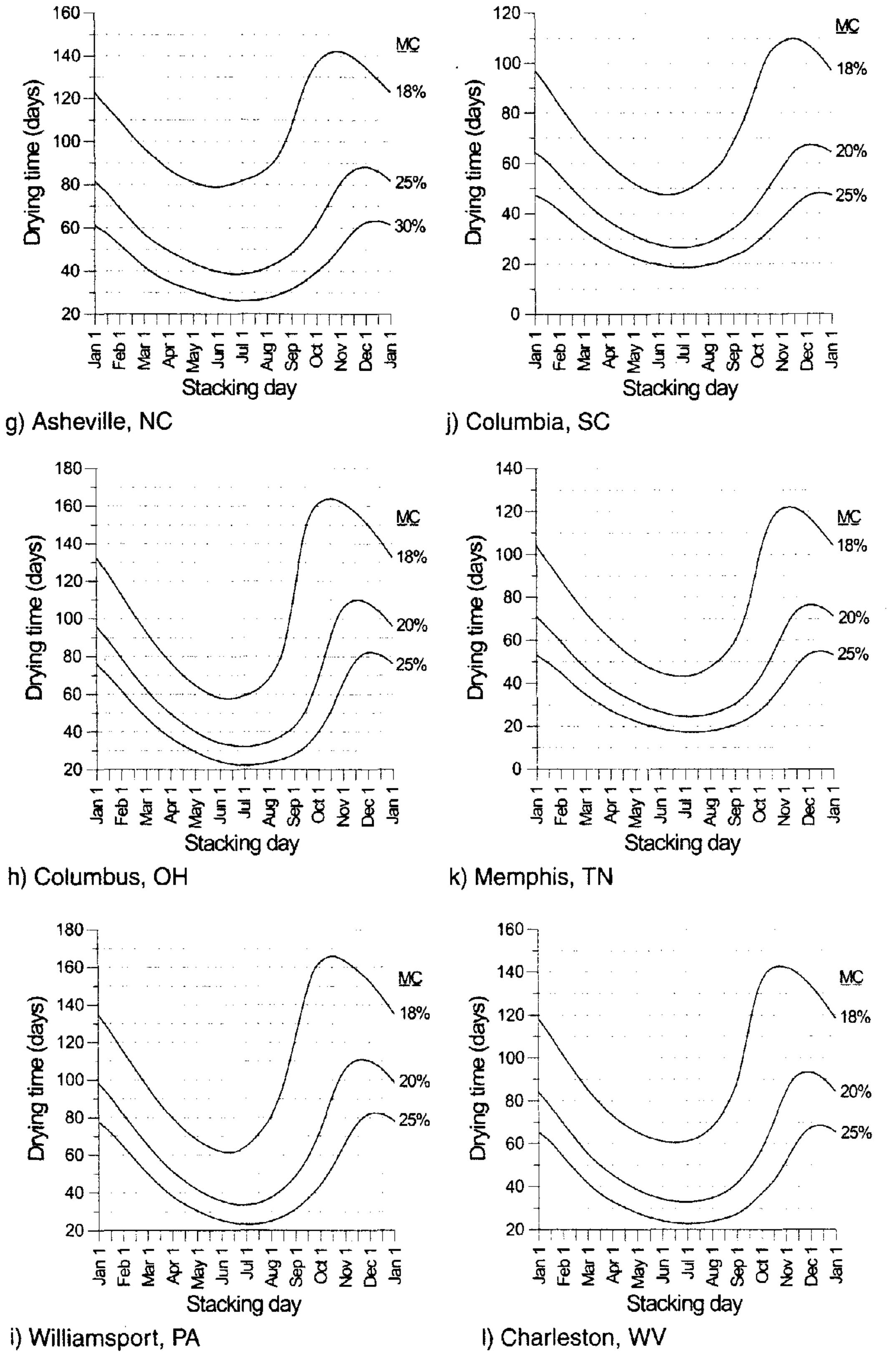
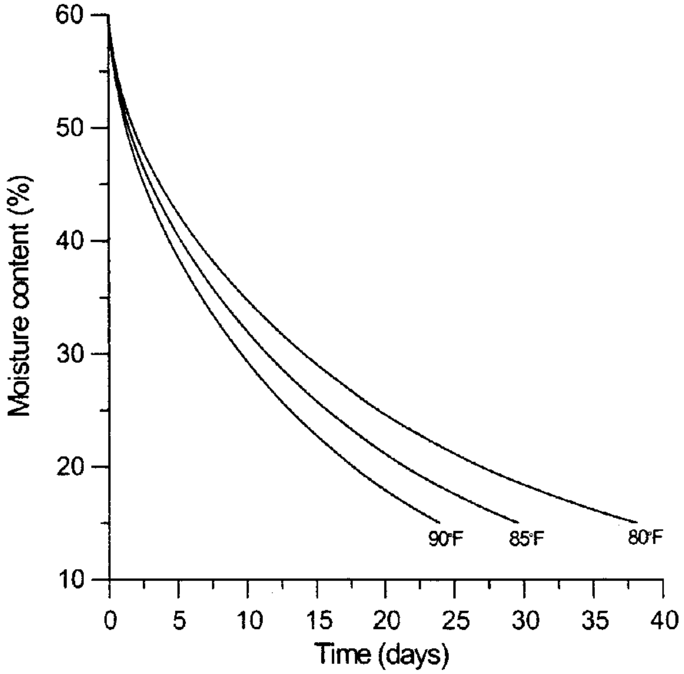


Figure 5.1 ***(continued).*** **–** Estimated air-drying times for nominal 2- by 6-inch maple lumber as they depend on geographical location, stacking date, and final moisture content.

8 percent MC for use in traditional hardwood products. However, for structural lumber where the required final MC is 15 to 19 percent, pre-dryers could accomplish the entire drying process. **Figure 5.2** shows estimated drying times (same method as Simpson and Hart 2000,2001) in a pre-dryer controlled at three typical temperatures (80°, 85°, and 90°F) and 65 percent relative humidity. Drying times vary from about 24 to 38 days, depending on temperature. The important contrast here is that in northern states air-drying time could be 200 days or more if stacking is done in the late summer or fall, instead of a constant 24 to 38 days year round in a pre-dryer.

Figure 5.2. – Graphs of moisture content versus time for 2- by 6-inch maple lumber in a pre-dryer at three temperature levels (80°, 85°, and 90°F) and 65 percent relative humidity.



Kiln-Drying

Studies have been conducted to develop kiln schedules especially designed for maple to be used as structural lumber (Simpson et al. 1998, Simpson and Wang 2001). These schedules are more severe than maple schedules intended for the traditional appearance-type end-use, and thus faster and more efficient. In the first study cited (Simpson et al. 1998), an accelerated MC-based maple schedule was developed. The starting point in the study was the maple schedule intended for traditional appearance-type products. This schedule starts with a dry-bulb temperature of 120°F and a wet-bulb depression of 7°F and ends with a dry-bulb temperature of 180°F and a wet-bulb depression of 50°F. In the study, the starting dry-bulb temperature was increased in increments of 10°F up to 160°F, while keeping the same final dry-bulb temperature of 180°F. The result was that even the most severe schedule that started with a dry-bulb temperature of 160°F caused no more structural grade loss than did the mildest schedule that started with a dry-bulb temperature of 120°F. All in all, about 12 percent of maple 2 by 6's lost grade because of warp or end splits. Drying time from 60 to 15 percent MC with the severe schedule that started at 160°F was about 5 days.

In the MC-based kiln schedule just described, kiln conditions are changed when the lumber reaches various MCs during drying. This requires some method of estimating MC. Because of the lower quality requirements of structural lumber compared to appearance grade lumber, traditional kiln schedules for softwood structural lumber are usually based on time. In these time-based schedules, changes in kiln conditions are made at predetermined time intervals rather than at predetermined MC levels. Thus, periodic estimates of MC during kiln-drying are not necessary. Time-based schedules are therefore more efficient than MC-based schedules. Using the drying rate data from the study on the MC-based schedule, a time-based schedule was developed to dry maple 2 by 6's in approximately 5 days (Simpson and Wang 2001), and that schedule is shown in **Figure 5.3.** An equalizing period following the kiln-drying is advisable.

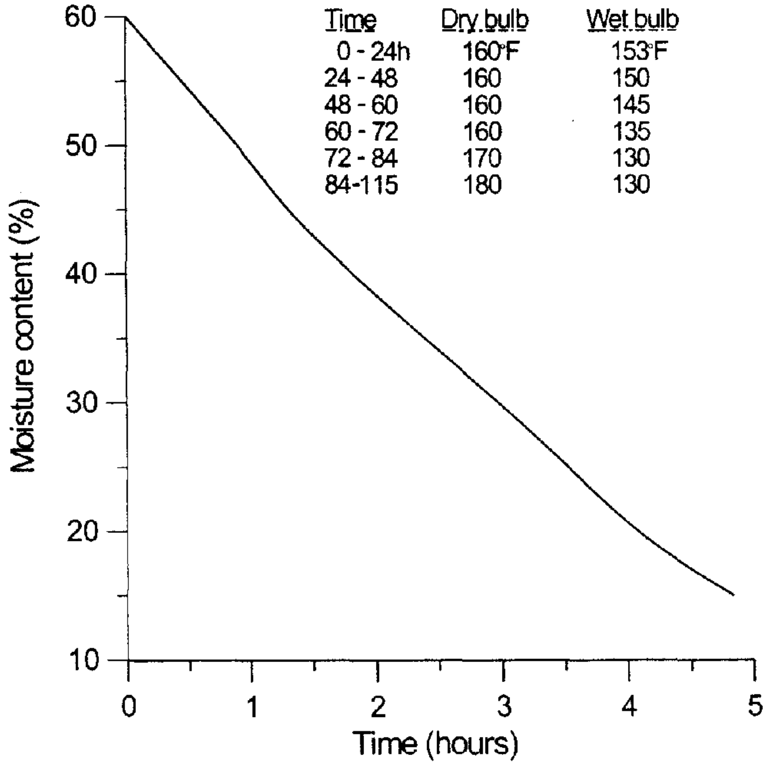


Figure 5.3. – Graph of moisture content versus time for 2- by 6-inch maple lumber kiln-dried by a time-based schedule.

Figure 5.4 shows comparative estimated drying times to 15 percent MC for kiln-drying alone, pre-drying alone, and combined pre-drying (to 30% MC) and kiln-drying. Kiln-drying alone is estimated to take 5 days, pre-drying to 30 percent MC followed by kiln-drying about 17 days, and pre-drying alone about 30 days.

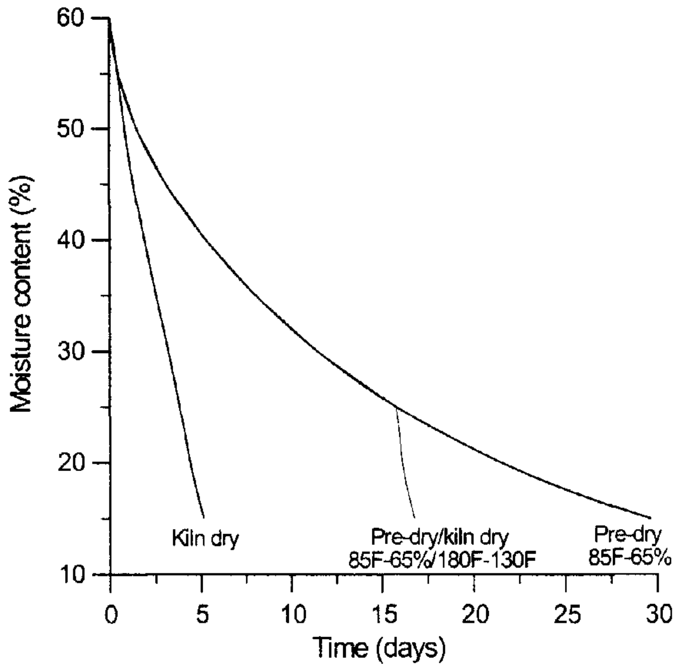


Figure 5.4. – Graph of moisture content versus time for 2- by 6-inch maple lumber dried in a kiln, in a pre-dryer, and sequentially in a pre-dryer and then a dry kiln.

Warp

One of the serious possible defects in structural lumber is the warp that is developed during drying. Crook, bow, twist, and cup can interfere with the utility of a board, and grading rules for softwood structural lumber impose limits on allowable warp. Warp development in maple 2 by 6's was investigated in a previous study (Simpson and Forsman 1999). **Table 5.1** and **Table 5.2** show warp limits for southern pine Structural Light Framing 2- by 6-inch, 8-foot-long lumber (SPIB 1994) as an example of warp limits that could be applied to hardwood structural lumber, and Table 5.3 shows the percentage of maple 2 by 6's that would meet the southern pine warp limits for No. 2 grade. **Tables 5.1, 5.2,** and **5.3** show that serious warp does not develop in maple 2 by 6's.

Heat Sterilization

Insects and other pests sometimes travel between countries in wood packing material such as pallets, and perhaps other engineered wood products during international trade. Because these pests can cause ecological damage, their

Table 5.1. – Warp limits for 8-foot-long southern pine 2 by 6's.

Grade	Southern pine warp limits			
	Crook	Bow	Twist	Cup
	- - - - - - (in.) - - - - - -			
Select Structural	0.250	0.500	0.563	0.063
No.1	0.250	0.500	0.563	0.063
No. 2	0.313	0.750	0.750	0.063
No. 3	0.500	1.000	1.125	0.125

Table 5.2. – Observed average warp for maple 2 by 6's dried to 19 and 12 percent target moisture contents.

Final target moisture content	Observed maple warp			
	Crook	Bow	Twist	Cup
(Yo)	- - - - - - (in.) - - - - - -			
19	0.050	0.045	0.065	0.056
12	0.042	0.066	0.100	0.051

Table 5.3. – Percentage of maple 2 by 6's that meet southern pine No. 2 grade limits for warp.

Final target moisture content	Percentage of maple meeting southern pine No. 2 grade limits			
	Crook	Bow	Twist	Cup
(%)	- - - - - - (%) - - - - - -			
19	100	100	100	100
12	100	99.1	97.3	100

Source: Structural Light Framing; SlPB 1994.

invasion into non-native countries is undesirable and regulations requiring heat sterilization are becoming more and more common. One important issue in heat sterilization is the time it takes for the center of any wood configuration to reach the target temperature required to lull the pest. A common current requirement is 133°F held at the center of the wood configuration for 30 minutes. But the important issue is how long does it take for the center to reach 133°F. The time can vary depending on several variables. Wood species, specific gravity, MC, and initial temperature are all factors that have a moderate influence on heating time. One of the largest factors is the wood configuration.

A 4-inch square pallet runner requires a much longer heating time than the 1- by 4-inch deck boards of the pallet. The heating medium can also have a significant effect on heating time. Heating in the water saturated atmosphere of live steam, that is, wet heat, results in the shortest heating times. The use of dry heat can significantly extend heating time because in a dry atmosphere the wood is also drying at the same time it is attempting to heat up. The evaporation of water from the wood surface cools the surface and thus slows the rate of heat transfer from the surface of the wood to the center. With wet heat there is little evaporation and thus little surface cooling to slow heat transfer. Studies on heating times have been conducted and are reported by Simpson (2001, 2002, 2003) and Simpson and Wang (2003).

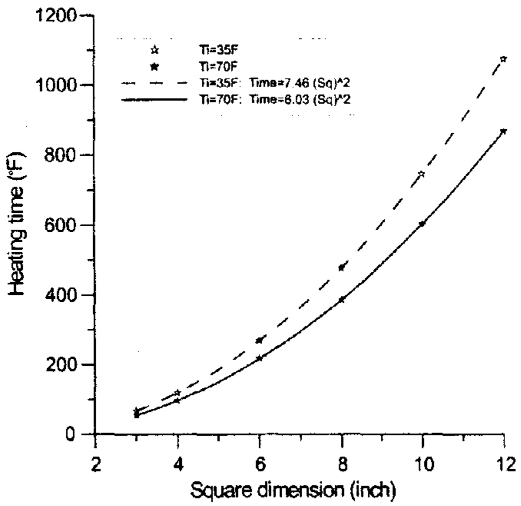
When heating is done in a saturated steam atmosphere, it is possible to apply equations of heat transfer to estimate heating times as they depend on wood specific gravity, MC, size, initial temperature, heating temperature, and target center temperature (Simpson 2001). Table 5.4 lists estimated heating times for various board and square sizes common to wood pallets, other packing containers, and timbers that might be imported or exported for any pur-

Table 5.4. – Estimated times to heat the center of various wood configurations as they depend on heating temperature, target center temperature, and initial wood temperature. Assumed wood moisture content and specific gravity are 60 percent and 0.53, respectively.[a]

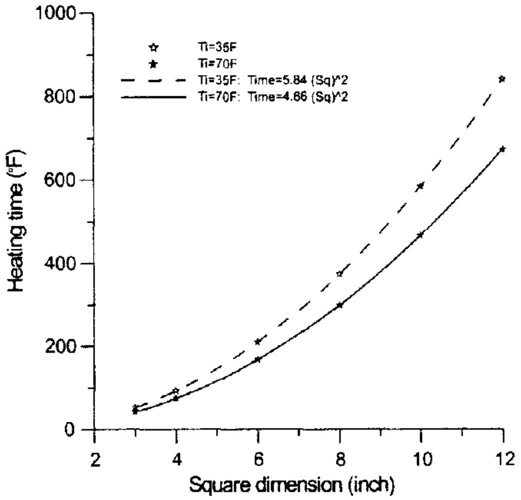
T_h	160°F				180°F			
T_c	133°F		158°		133°F		158°F	
T_i	35°F	70°F	35°F	70°F	35°F	70°F	35°F	70°F
Sample size (in.)	Time needed to heat center of wood (min.)							
0.625 by 4	5	4	13	11	4	3	6	5
1.0 by 4	13	10	32	29	10	8	15	13
1.5 by 4	29	23	68	61	22	17	34	28
2.0 by 4	48	38	110	98	37	29	55	47
2.0 by 6	52	41	123	110	40	31	61	51
3 by 3	67	54	154	138	53	42	77	66
4 by 4	120	97	274	246	94	75	138	118
6 by 6	269	217	616	553	210	168	310	264
8 by8	478	386	1,095	982	374	299	551	470
10 by 10	747	604	1,712	1,535	584	467	860	735
12 by 12	1,076	869	2,465	2,210	842	673	1,239	1,058

[a] T_h is heating temperature; T_c is target center temperature; and T_i is initial temperature.

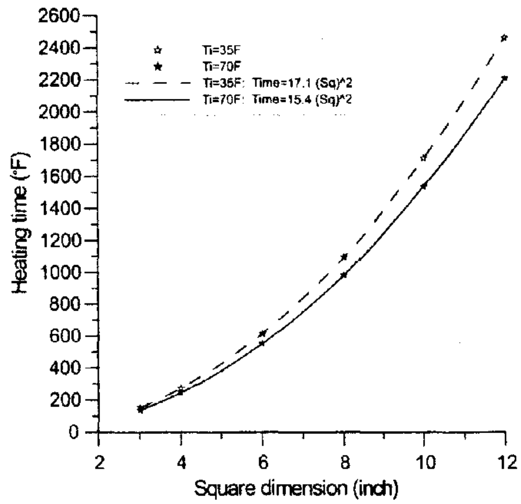
pose. Heating times are shown for two heating temperatures (160°F and 180°F), two target center temperatures (133°F and 158°F), and two initial temperatures (35°F and 70°F). The different sizes range from 0.625 by 4 inch boards to 12- by 12-inch square timbers. Graphs for estimating heating times for square timbers of intermediate listed in Table 5.4 are shown in Figure 5.5.



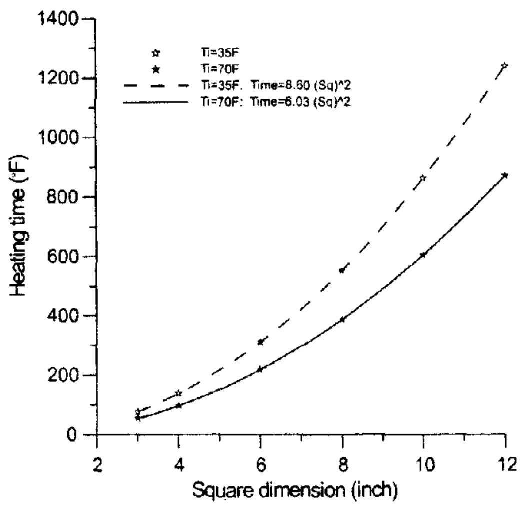
a) Heating temperature = 160°F; target center temperature = 133°F



c) Heating temperature = 180°F; target center temperature = 133°F



b) Heating temperature = 160°F; target center temperature = 158°F



d) Heating temperature = 180°F; target center temperature = 158°F

Figure 5.5. – Graphs of the time required to heat the center of square maple timbers to a target temperature versus the dimension of the square timber.

Summary

Hardwood lumber for engineered and non-engineered structural wood products requires different drying strategies than hardwood lumber used for the more traditional hardwood appearance-type products, such as furniture, cabinetry, and millwork, that require drying. The application of air-drying and pre-dryers can be expanded from their current hardwood applications, and kiln-drying can be accelerated to be faster and more efficient than current practices for appearance-type products because of the irrelevance of discolorations and minor surface checking in structural products. Heat sterilization to kill insects and pathogens in wood packing is becoming a requirement in international trade. Manufacturers and users of wood packing need to know the time necessary to heat the center of any wood configuration to the temperature required to kill the insect or pathogen of concern, and research has offered guidelines to do this.

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