United States
Department of
Agriculture

Forest Service

Forest
Products
Laboratory

Research
Paper
FPL–RP–613

Estimating Air Drying Times of Small-Diameter Ponderosa Pine and Douglas-Fir Logs

William T. Simpson
Xiping Wang

Abstract

Because dense stands of softwood trees are causing forest health problems in the western United States, new ways to use this material need to be found. One option is to use this material as logs rather than sawing it into lumber. For many applications, logs require some degree of drying. Even though these logs may be considered small diameter, they are large compared with the thickness of typical lumber, and they may require uneconomically long kiln drying times. Air drying is a logical alternative to kiln drying, but the variables involved make estimating air drying times difficult. In this study, we developed experimental air drying time data for 4- to 8-in.- (102- to 203-mm-) diameter ponderosa pine and Douglas-fir debarked logs stacked at four different times of the year. These data were used to develop multiple linear and nonlinear regression models that relate daily moisture content loss to moisture content at the start of the day, average daily temperature and relative humidity, and log diameter. The models provide a way to calculate estimated air drying times for logs stacked at any time of the year and at any location where historic weather data is available. It also provides a way to estimate the benefit of simple, low-cost dryers in reducing drying time.

Keywords: air drying, small-diameter timber, ponderosa pine, Douglas-fir

September 2003

Simpson, William T.; Wang, Xiping. 2003. Estimating air drying times of small-diameter ponderosa pine and Douglas-fir logs. Res. Pap. FPL–RP–613. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 14 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726–2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

Estimating Air Drying Times of Small-Diameter Ponderosa Pine and Douglas-Fir Logs

William T. Simpson, Research Forest Products Technologist
Forest Products Laboratory, Madison, Wisconsin
Xiping Wang, Research Associate
Natural Resources Research Institute, Duluth, Minnesota

Introduction

Dense stands of small-diameter softwood trees in the western United States are creating a fire and forest health hazard. Removing these trees is expensive, so there is a need to find value-added uses for these logs and lumber from them to increase the incentive to cut them. One option is to use them in log form, which requires some degree of drying for most uses. Even though logs from this source are considered small from the forestry perspective, they are large from the kiln drying perspective. Drying logs leads to long kiln drying times, which is usually expensive. Two practical alternatives to kiln drying are air drying and low-temperature drying.

Air drying times can be quite variable and difficult to predict. These times can vary from as low as several weeks to several months or longer, depending on species, diameter, local weather conditions, and the time of year the logs are stacked. This large degree of uncertainty makes it difficult to plan material flow in production and to control the quality of final product. Under-dried logs will continue drying in service and may cause shrinkage and durability problems. Over-dried logs have wasted time in inventory and may have developed excessive drying defects.

The general objective of this study was to correlate air drying times of ponderosa pine and Douglas-fir logs in the 4- to 8-in.- (102- to 203-mm-) diameter range to weather conditions, log diameter, and the time of year the logs were stacked for air drying. More specifically, the goal was to develop an analytical method, based on experimental data, to estimate air drying times of ponderosa pine and Douglas-fir logs of any diameter between approximately 4 and 8 in. (102 to 203 mm), stacked at any time of the year, at any location where historical weather data are available.

Background

Attempts have been made to estimate air drying times for lumber. A review of some of the early attempts is given in Simpson and Hart (2001). Most of these early attempts resulted in only general ranges of estimated drying times and were not specific enough to be of much use. The first study to estimate drying times that were more specific than just general ranges of times was done by Denig and Wengert (1982) on 1-in.- (25-mm-) thick red oak and yellow poplar lumber. Air drying sample boards were exposed to environmental conditions in three commercial air drying yards for 5 months. The daily rate of moisture loss was related to meteorological data obtained from a regional weather station. That result was developed into the following regression relationship for estimating daily moisture content loss:

$$\triangle M = a + bM^n + cT + dH \tag{1}$$

where $\triangle M$ is daily moisture content loss; M, moisture content at the beginning of the day; T, daily average temperature; H, daily average relative humidity; a, b, c, d, regression coefficients; $n = 1$ for yellow poplar and $n = 2$ for red oak.

This result allows the useful capability of estimating air drying time for any stacking date during the year if local temperature and relative humidity data are available.

Simpson and Hart (2000, 2001) used a different approach to develop an analytical way to estimate air drying times of several hardwood and softwood species from local weather data and for lumber stacked any day of the year. They also included the effect of lumber thickness on drying time. The method is based on a computer drying simulation developed by Hart (1982) and uses experimental air drying times for six wood species to develop parameters for the drying simulation. Once these parameters were found for each species in the geographical location for the experimental data, they could be used in the drying simulation to estimate air drying times at other locations where historical weather data are available. The results made it possible to estimate air drying times of the six species stacked for air drying any day of the year at any location where average temperature and relative humidity data are available and for any thickness of lumber dried to any final moisture content.

Experimental Methods

The experimental material was ponderosa pine and Douglas-fir logs that ranged from about 4 to 8 in. (102 to 203 mm) in diameter and was taken from near Hayfork, California, which is about 40 miles (64 km) west of Redding. The general experimental scheme was to stack logs for air drying at four different times of the year so that a variety of weather conditions were included, monitor their moisture content loss, and collect local temperature and relative humidity data.

The four stacking dates were July 18, 2001; October 25, 2001; February 25, 2002; and May 13, 2002. On each of these dates in Hayfork, two stacks were set up, one with ponderosa pine logs and one with Douglas-fir logs (Fig. 1). Each stack consisted of twenty-four 8-ft- (2.4-m-) long debarked logs. Twelve debarked log sections (36 in. (0.914 m) long, end-coated) were embedded in the stack so that they would experience consistent stack surroundings. These log sections were removed periodically (Fig. 2) and weighed to monitor their moisture content. For each stacking date, the logs were debarked just before stacking.

The 12 monitored log sections for each species were cut from full-length logs, then 1-in.- (25.4-mm-) thick moisture sections were cut from each end. After that, the monitored sections were end-coated and weighed. The circumference of the monitored log sections was measured at each end, averaged, and later converted to diameters. The two 1-in.- (25.4-mm-) long moisture sections from each 36-in.- (0.9-m-) long monitored section were weighed, ovendried, and used to calculate moisture content estimates of the monitored sections during the air drying period.

The stacks were covered with plywood to protect the logs from rain and direct sun exposure. After air drying was complete, all 36-in.- (0.9-m-) long monitored sections were ovendried so that exact moisture contents could be calculated for each of the periodic weights taken during air drying.

The weather data were monitored and recorded using a battery-powered data logger mounted near the drying stacks. The data logger measured the temperature and relative humidity every 10 minutes and stored the data in memory along with the time and date (with this sampling interval, the data logger can operate continuously up to 226 days). When air drying was complete, the weather data were off-loaded on site using a data shuttle (a pocket-sized device that can be used to off-load or restart the data logger) and transported back to a personal computer. The temperature and relative humidity data were then averaged for each day to be used in data analysis.

Figure 1—Air drying stacks of ponderosa pine and Douglas-fir logs in Hayfork, California. Black end-coated logs are moisture-content-monitored log sections.

Figure 2—Moisture-content-monitored log section being removed for periodic weighing.

Analytical Methods

There are two ways to develop an analytical method for estimating air drying times—a multiple linear regression approach similar to the one used by Denig and Wengert (1982) or the computer drying simulation used by Simpson and Hart (2000, 2001). The computer drying simulation provides good estimates of air drying times for lumber, but it is difficult to develop the simulation parameters from the experimental data. Furthermore, once the parameters are developed, the drying simulation computer program is not readily available to most potential users. Therefore, we decided to pursue the multiple regression approach because once developed, the results are readily usable in simple user-built computer programs or in spreadsheet analyses.

Denig and Wengert (1982) developed the multiple linear regression model of Equation (1). For this study, two models were investigated:

$$\triangle M = a + bM + cT + dH + eD \quad (2)$$

and

$$\triangle M = aM^b T^c H^d D^e \quad (3)$$

where $\triangle M$ is daily loss of moisture content (%); M, moisture content at the start of any day during air drying (%); T, average daily temperature (°F); H, average daily relative humidity (%); D, log diameter (in.); a,b,c,d,e, coefficients determined by regression.

Monitored log section weights were taken at somewhat irregular times. Early in drying, weights were taken often (every few days), but as drying rate slowed down, weights were taken less often (7- to 10-day intervals). Regression analysis using Equation (2) or (3) requires daily moisture losses at exactly 24-h intervals, and it was not practical to weigh the monitored sections on this precise schedule. Therefore, daily moisture contents were determined by linearly interpolating between the moisture contents calculated on the days the monitored sections were weighed. The daily moisture loss, $\triangle M$, could then be determined by subtraction of moisture contents between successive days. With this information, we had all of the necessary variables to insert into the regression analysis of Equation (2) or (3).

Results

The average initial moisture contents of ponderosa pine and Douglas-fir were 120% and 47%, respectively. The distributions of moisture contents for the two species are shown in Figure 3. The average diameters of ponderosa pine and Douglas-fir logs were 5.9 and 5.5 in. (150 and 140 mm), respectively, and the distributions of diameter are shown in Figure 4.

Figure 5 shows moisture content with time for ponderosa pine and Douglas-fir and includes the four stacking dates. Because each monitored log in the experiment had a different diameter and initial moisture content, it is not possible to construct plots that represent an average of the stacking date and species. Each curve in Figure 5 is a representative example of one monitored log, with initial moisture content and diameter chosen to be near the average value for the stacking date and species. Several general observations can be made from Figure 5. Regardless of whether the stacking date was in the winter or summer, moisture content decreased rapidly during the first few days. After that, the rate of moisture content loss decreased (the later in the year the date of stacking, the slower the rate of moisture content loss was). Drying was greatly prolonged for the October 25 stacking date because the logs were caught in the cold, damp winter weather before their moisture contents were low enough to be considered at an air-dried moisture content in the 19% to 25% range. Figure 6 shows the temperature and relative humidity data for Hayfork during the year that this air drying was done.

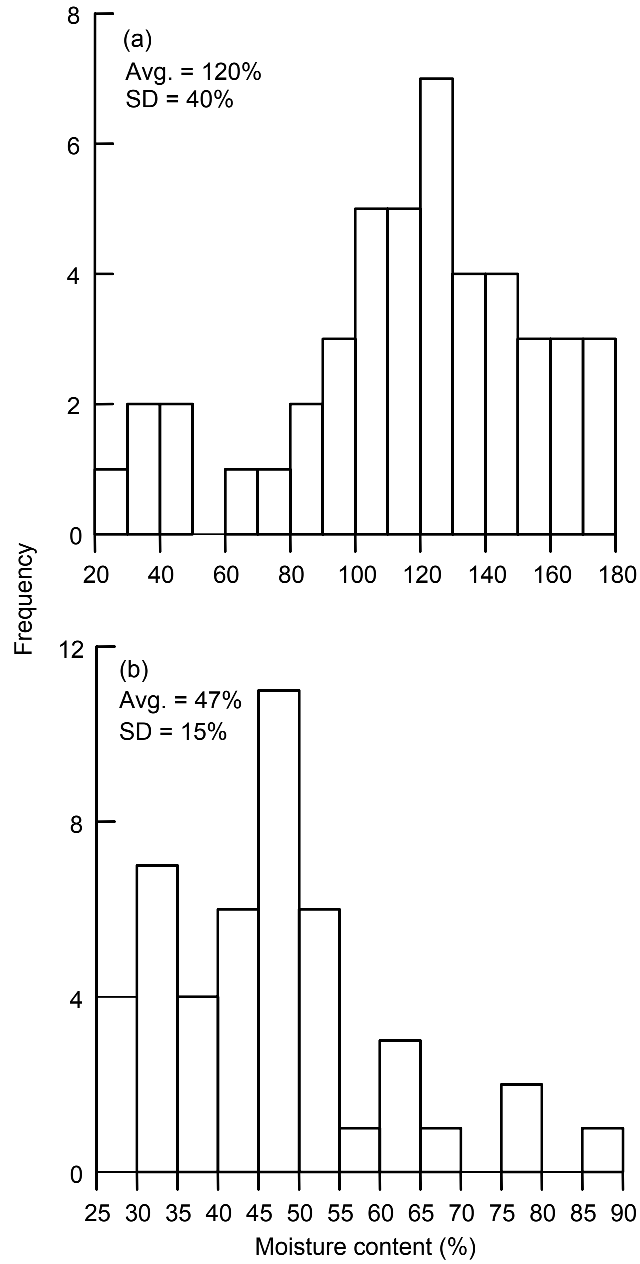

Figure 3—Distribution of initial moisture contents for (a) ponderosa pine and (b) Douglas-fir logs (SD, standard deviation).

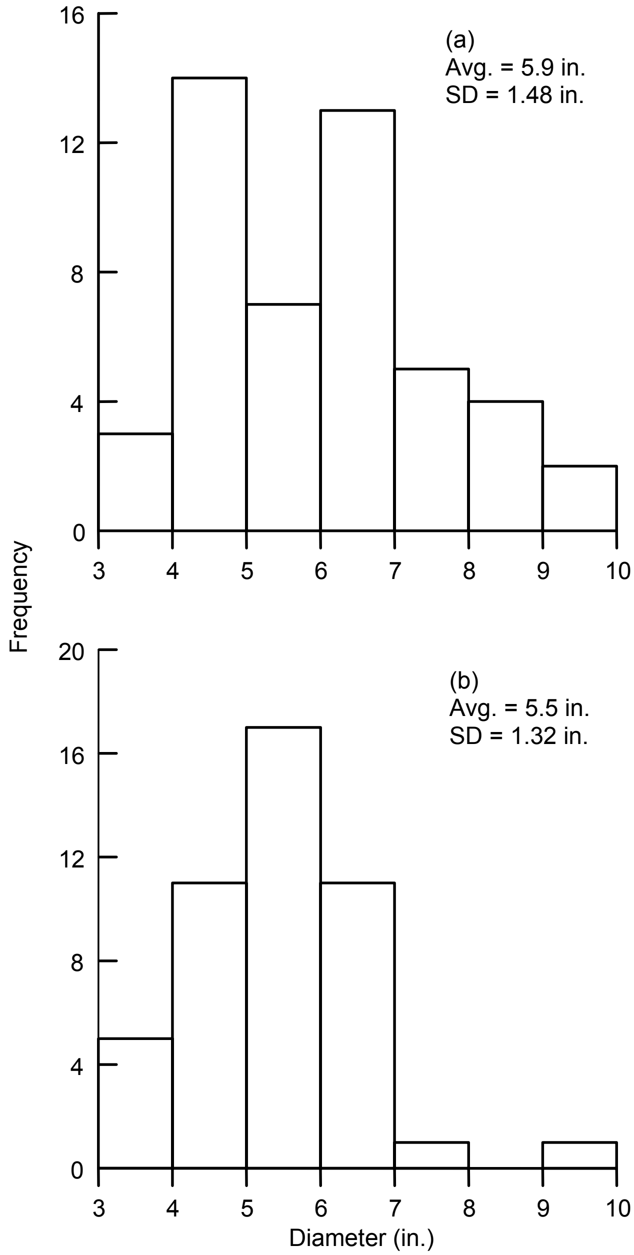

Figure 4—Distribution of diameters (average of small and large ends, inside bark) of (a) ponderosa pine and (b) Douglas-fir logs (SD, standard deviation; 1 in. = 25.4 mm).

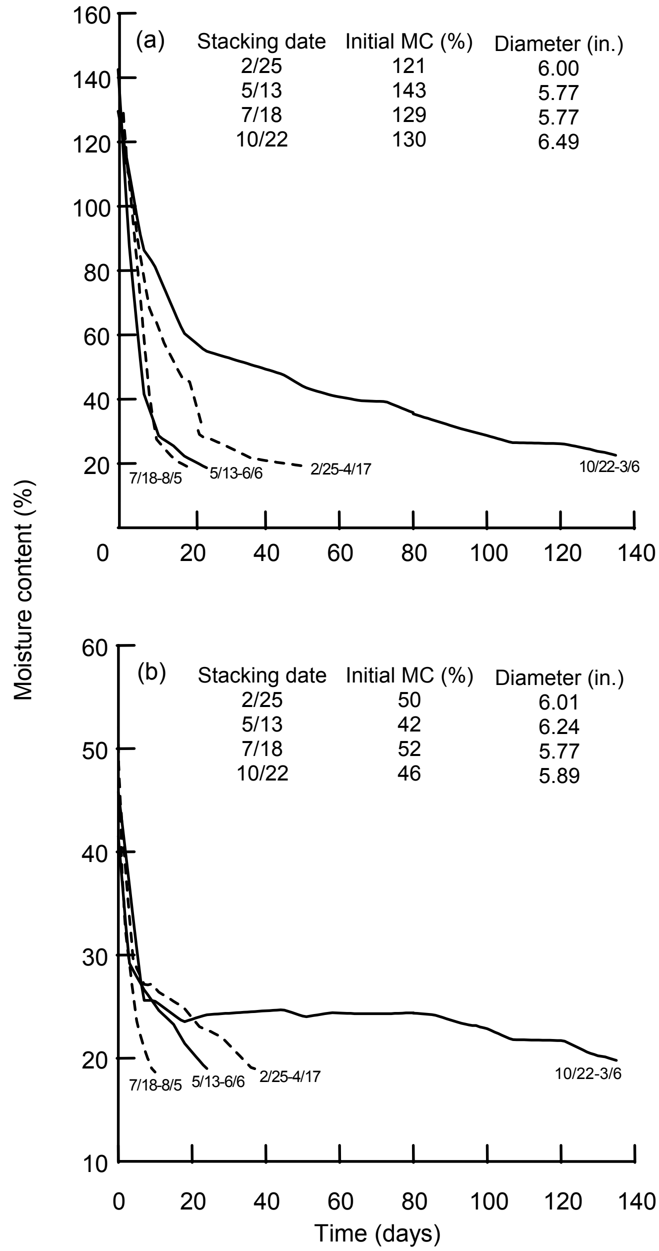

Figure 5—Moisture content–time graphs for (a) ponderosa pine and (b) Douglas-fir logs stacked at four different times for air drying in Hayfork, California (1 in. = 25.4 mm).

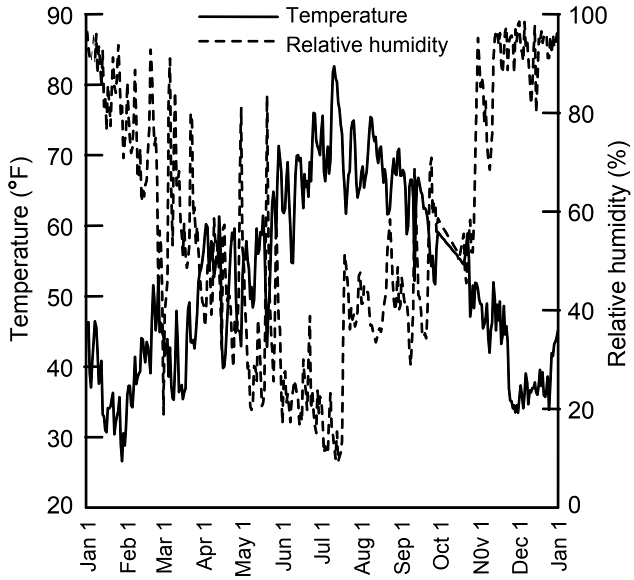

Figure 6—Average monthly temperature and relative humidity in Hayfork, California, for the period 7/18/2002 to 7/18/2003 (°F = 1.8(°C) + 32).

Table 1—Regression coefficients, coefficients of determination (R^2), and standard error of the estimate for model of Equation (4) for air drying ponderosa pine and Douglas-fir logs

Coefficient	Ponderosa pine[a]	Douglas-fir[b]
a	0.00117	–2.67
b	1.38	0.156
c	1.69	0.0262
d	–0.558	–0.0189
e	–1.30	–0.0885
R^2	0.786	0.723
Standard error	1.368	0.652

[a] $\triangle M = aM^b T^c H^d D^e$
[b] $\triangle M = a + bM + cT + dH + eD$

The experimental data were fit by multiple linear regression to Equation (2) and by multiple nonlinear regression to Equation (3); the regression coefficients are listed in Table 1. The coefficient of determination, R^2, was used as the criterion for choosing either Equation (2) or (3) as the better one to represent the experimental data. The result was that Equation (3) was better for ponderosa pine, with R^2 = 0.786, and Equation (2) was better for Douglas-fir, with R^2 = 0.723. The experimental and regression results are given in more detail in Table 2 for ponderosa pine and Table 3 for Douglas-fir. Data for each of the 12 monitored logs for each of the four stacking dates are included. These data include diameter, initial moisture content, the actual number of days required for the monitored logs to reach 20% moisture content, the number of days required to reach 20% moisture content as estimated by regression, and the percentage deviation between the experimental and regression-estimated number of days. The moisture contents of the monitored logs stacked October 25 did not quite reach 20% when the stack was dismantled, so the times listed are for the slightly higher moisture contents noted in Tables 2 and 3. The average deviation between experimental and regression-estimated drying days was 25.5% for ponderosa pine and 16.1% for Douglas-fir. The best agreement for ponderosa pine was for the May 13 stacking date (13.4% deviation), and for Douglas-fir, the best date was October 25 (4.5% deviation). The deviations of most concern are those for the ponderosa pine stacking date of October 25 (53.3%) and the Douglas-fir stacking date of May 13 (39.7%). These deviations were large enough to question the usefulness of the regression estimates.

Another way to evaluate the usefulness of the regression estimates is shown in the last two columns of Tables 2 and 3. Instead of comparing experimental and regression-estimated drying times to 20% moisture content, we can compare the moisture content predicted by the regression analysis at the experimental time required to reach 20% moisture content. For example, in Table 2, log number 1 stacked on February 25 required 46.1 days to reach 20% moisture content, and the regression analysis predicted 48.9 days. The regression analysis also predicts that the moisture content after the 46.1 experimental days is 21.8%, which is a 1.8% moisture content deviation from the experimental value of 20.0% after 46.1 days. Which method is used depends on how closely we need to estimate an air dry moisture content. It can be argued that the difference between 21.8% and 20.0% moisture content is insignificant from any practical standpoint. At what point a moisture content difference becomes significant is a matter of interpretation that is best left to the user. If we look at the results in this way, the overall error in estimated air dry moisture content is 7.4% moisture content for ponderosa pine and 1.6% moisture content for Douglas-fir. Again, in this method of comparison, the results for ponderosa pine stacked October 25 and Douglas-fir stacked May 13 are the only poor estimates, missing the target air dry moisture contents by 17.9% and 3.6%. In contrast, the best result for ponderosa pine (stacked May 13) missed the target air dry moisture content by 3.3%, and the best result for Douglas-fir (stacked February 25) missed the target air dry moisture content by only 0.5%. There is no apparent explanation for the poor results of the ponderosa pine stacked October 25 and the Douglas-fir stacked May 13.

Application of Results

The main objective of this study was to provide the basis to calculate estimates of air drying times for any diameter (in the approximate 4- to 8-in. (102- to 203-mm) range) of debarked ponderosa pine and Douglas-fir logs stacked on

Table 2—Comparison of experimental air drying times for ponderosa pine to 20% moisture content (MC) and times calculated by the regression models of Equation (3)

Stacking date and log number	Diameter (in.)[a]	Initial MC (%)	Exp. drying time (days)	Regression drying time (days)	Deviation (%)	Regression MC at exp time (%)	Deviation from 20% MC (%)
Feb. 25, 2002							
1	7.25	83	46.1	48.9	6.1	21.8	1.8
2	4.84	103	31.4	36.7	16.9	26.5	6.5
3	5.69	111	35.2	42.6	21.0	28.6	8.6
4	8.12	75	51.2	54.2	5.9	21.0	1.0
5	3.88	27	9.5	5.1	46.3	16.8	3.2
6	4.74	40	32.6	20.1	38.3	13.5	6.5
7	6.51	96	36.6	46.7	27.6	29.2	9.2
8	4.36	154	33.5	36.8	9.9	24.6	4.6
9	6.01	121	45.3	46.4	2.4	20.7	0.7
10	3.66	37	21.2	10.9	48.6	14.3	5.7
11	4.38	132	34.0	36.0	5.9	22.3	2.3
12	3.78	138	32.0	32.3	0.9	20.0	0.0
				Average	19.2		4.2
May 13, 2002							
1	6.17	41	23.7	13.2	44.3	10.8	9.2
2	7.36	187	31.8	31.6	0.6	19.5	0.5
3	5.77	143	21.7	22.8	5.1	21.5	1.5
4	6.11	156	24.6	24.5	0.4	19.5	0.5
5	8.66	66	17.9	26.3	46.9	30.4	10.4
6	9.14	119	34.1	34.7	1.8	20.5	0.5
7	4.30	147	20.1	17.1	14.9	13.7	6.3
8	4.88	46	16.4	11.5	29.9	13.9	6.1
9	9.12	165	38.6	38.2	1.0	19.5	0.5
10	6.21	186	26.5	25.9	2.3	19.0	1.0
11	6.79	92	21.6	23.6	9.3	22.6	1.6
12	6.49	178	26.1	27.2	4.2	20.9	0.9
				Average	13.4		3.3
July 18, 2001							
1	6.27	155	21.8	23.8	9.5	23.7	3.7
2	5.00	116	12.1	16.3	34.7	27.9	7.9
3	4.40	109	11.8	13.2	11.9	22.7	2.7
4	4.72	130	15.5	15.7	1.3	20.5	0.5
5	4.50	118	12.2	14.1	15.6	23.6	3.6
6	7.17	129	24.7	26.5	7.3	20.0	0.0
7	6.25	105	19.8	21.2	7.1	22.4	2.4
8	4.26	87	9.0	11.1	23.3	25.4	5.4
9	7.23	125	23.8	26.4	10.9	23.8	3.8
10	4.56	96	15.7	13.1	16.5	16.5	3.5
11	6.41	104	17.5	21.7	24.0	26.5	6.5
12	5.77	129	15.7	20.7	31.8	28.4	8.4
				Average	16.2		4.0
Oct. 25, 2001							
1	5.08	175	134 (21)[b]	67.6	49.6	6.4	14.6
2	6.17	167	134 (31)	64.4	51.9	10.1	20.9
3	5.04	178	132 (21)	67.3	49.0	6.6	14.4
4	4.26	131	132 (20)	46.9	64.5	4.0	16.0
5	7.36	115	133 (30)	68.5	48.5	13.0	17.0
6	6.49	130	133 (23)	78.9	40.7	10.5	12.5
7	8.38	142	133 (38)	74.2	44.2	18.0	20.0
8	4.22	163	132 (21)	48.5	63.3	4.2	16.8
9	5.08	134	132 (21)	61.8	53.2	6.3	14.7
10	5.57	143	129 (25)	62.5	51.6	8.5	16.5
11	8.62	126	133 (51)	47.4	64.4	18.3	32.7
12	6.19	102	133 (27)	55.6	58.2	8.6	18.4
				Average	53.3		17.9
				Overall ponderosa pine deviation	25.5		7.4

[a]1 in. = 25.4 mm.
[b]Final moisture contents were higher than 20% and are shown in parentheses.

Table 3—Comparison of experimental air drying times for Douglas-fir to 20% moisture content (MC) and times calculated by the regression model of Equation (2)

Stacking date and log number	Diameter (in.)[a]	Initial MC (%)	Exp. drying time (days)	Regression drying time (days)	Deviation (%)	Regression MC at exp time (%)	Deviation from 20% MC (%)
Feb. 25, 2002							
1	3.90	48	24.1	23.7	1.7	19.8	0.2
2	5.75	55	34.5	32.3	6.4	18.9	1.1
3	4.82	64	31.3	31.2	0.3	19.9	0.1
4	5.20	39	30.8	31.4	1.9	20.1	0.1
5	4.14	33	28.0	23.3	16.8	19.9	0.1
6[b]	—	—	—	—	—	—	—
7	3.42	48	23.6	23.1	2.1	19.7	0.3
8	6.01	50	33.5	32.5	3.0	19.5	0.5
9	9.87	62	40.1	37.2	7.2	19.5	0.5
10	4.78	48	28.6	24.9	12.9	20.4	0.4
11	10.07	59	37.7	37.4	.8	19.9	0.1
12	5.23	78	35.2	31.9	9.4	18.4	1.6
				Average	5.7		0.5
May 13, 2002							
1	6.59	43	18.1	12.2	32.6	16.6	3.4
2	4.28	29	10.5	4.7	55.2	18.1	1.9
3	6.55	67	22.7	15.3	32.6	15.1	4.9
4	6.09	32	19.0	10.0	47.3	15.2	4.8
5	6.79	50	20.6	12.9	37.4	15.6	4.4
6	5.55	41	17.2	11.3	34.3	16.5	3.5
7	4.94	47	15.3	11.8	22.9	17.6	2.4
8	9.19	44	18.9	13.6	28.0	17.5	2.5
9	4.42	29	13.8	5.0	63.8	16.0	4.0
10	6.24	42	21.4	11.8	44.9	14.8	5.2
11	4.95	32	15.0	6.3	58.0	16.6	3.4
12	4.62	38	13.1	10.5	19.8	17.4	2.6
				Average	39.7		0.6
July 18, 2001							
1	5.77	52	8.0	10.5	31.3	23.7	3.7
2	5.33	40	8.0	8.3	3.8	20.3	0.3
3	6.11	27	6.3	5.2	17.5	18.9	1.1
4	5.27	32	6.1	6.5	6.6	20.5	0.5
5	5.79	38	8.7	8.1	6.9	19.3	0.7
6	6.33	45	10.2	9.6	5.9	19.3	0.7
7	5.18	31	5.7	6.3	10.5	20.8	0.8
8	3.94	31	5.3	5.9	11.3	20.9	0.9
9	5.16	26	4.9	4.3	12.2	19.4	0.6
10	7.01	47	11.2	10.2	8.9	19.2	0.8
11	5.39	49	7.0	9.9	41.4	24.8	4.8
12	5.73	47	11.9	9.7	18.5	18.1	1.9
				Average	14.6		1.4
Oct. 25, 2001							
1	3.70	40	126	124	1.6	20.7	0.7
2	3.72	32	131	124	5.3	18.9	1.1
3	5.37	41	135	127	5.9	19.8	0.2
4	5.12	88	130	127	2.3	20.1	0.1
5	4.18	49	132	125	5.3	18.7	1.3
6	6.91	53	131 (22)[c]	124	5.3	20.6	1.4
7	4.12	96	130	125	3.8	19.7	0.3
8	4.76	51	133	126	5.3	18.8	1.2
9	5.89	46	133	127	4.5	19.4	0.6
10	6.27	62	131 (22)[c]	123	6.1	20.0	2.0
11	5.06	47	134	127	5.2	19.0	1.0
12	5.93	75	130 (21)[c]	125	3.8	20.3	0.7
				Average	4.5		0.9
				Overall Douglas-fir deviation	16.1		1.6

[a]1 in. = 25.4 mm.
[b]Data for log 6 stacked Feb. 25 were lost.
[c]Final moisture contents were higher than 20% and are shown in parentheses.

any day of the year at any location where historic temperature and relative humidity data are available. This basis is the regression coefficients of Equations (2) and (3) as listed in Table 1 and weather data available in terms of 30- to 40-year averages from the National Climate Data Center (2002) of the National Oceanic and Atmospheric Administration.

Several locations for estimates were chosen in the ranges of ponderosa pine and Douglas-fir, and estimates of air drying times were calculated. The locations for ponderosa pine were Albuquerque, New Mexico; Boise, Idaho; Flagstaff, Arizona; and Redding, California. Locations for Douglas-fir were Boise, Idaho; Medford, Oregon; Redding, California; and Spokane, Washington. Figure 7 shows the annual temperature and relative humidity data for these locations. Figure 8 is a series of graphs, for each of the species–location combinations, where air drying time to 20% moisture content was plotted against the day of the year logs were stacked and for 4-, 6-, and 8-in. (102-, 152-, and 203-mm) diameter logs.

Figure 8 assumes an initial moisture content of 120% for ponderosa pine and 47% for Douglas-fir. Initial moisture content does have some effect on air drying time, and this is illustrated in Figure 9 for 6-in.- (152-mm-) diameter ponderosa pine in Flagstaff, Arizona, with initial moisture contents of 80%, 120%, and 160%. As expected, the higher the initial moisture content, the longer it takes ponderosa pine to air dry to 20% moisture content. The predicted effect of initial moisture content on air drying time of Douglas-fir is minimal, mostly because green Douglas-fir moisture content is low and does not vary widely.

Another factor that affects air drying time is target final moisture content. This report has focused on 20% as the target final moisture content, but other values could also be of interest. The effect of target final moisture content is illustrated in Figure 10 for 6-in.- (152-mm-) diameter Douglas-fir stacked in Redding, California, and air dried to 20%, 22.5%, and 25% final moisture contents. The effect of target final moisture content is quite large, and moving up from 20% to just 22.5% results in a large reduction in predicted air drying time.

The air drying times of Figures 8 to 10 are only rough estimates. There are several reasons for the imprecision of the estimates. Between the natural variability of wood (including initial moisture content), possible experimental error, and weaknesses in the experimental design (more replicate monitored logs and a more systematic and representative distribution of log diameters might have improved results), the regression estimates were subject to error. Another factor is the variability in weather. The estimates are based on average weather data, and any given year can have some degree of deviation from the average. Nevertheless, the estimated times can serve as somewhat useful guidelines to offer some idea of drying times. One observation that stands out in most of the plots, especially for the more northerly locations, is that there is a time in late summer or early fall beyond which air drying time is greatly extended because of the cold, humid winter weather that greatly slows drying and makes it very difficult for logs to dry much below about 25% moisture content. This helps to point out the possible need for follow-up indoor drying (after some air drying) for certain log products if lower moisture contents are required.

Another factor to be considered is the approach to final air drying moisture content. Near the end of air drying, the drying rate becomes quite slow (Fig. 5), and a decrease in moisture content of only a few percentage points may take many days. This is especially true for late summer–early fall stacking dates. For example, if it takes 20 days to dry to 22.5% moisture content and another 30 days to dry to 20% moisture content, then some thought should be given to when air drying is considered finished—either as low enough for the final product (22.5% moisture content may be just as good as 20%) or as the end of a practical air drying period and time to consider kiln drying for a lower moisture content.

Accelerated Air Drying

Some log processors may consider the air drying times to be too long for the efficiency of their operations, yet they cannot justify a dry kiln. There is an option that may offer a reasonable compromise between the inefficiency of long air drying times and the high expense of a dry kiln. Any enclosure in which the temperature could be raised above the outside ambient temperature could be used to shorten drying time, assuming the water from the drying logs is vented. This might be done in a simple solar-heated enclosure or with a differential thermostat that operates a heating system based on the difference between the inside and outside temperatures to keep the inside temperature a set number of degrees above the outside temperature. This type of system would decrease drying time in two ways. A modest temperature increase will increase drying rate, and when inside temperature is raised above outside temperature without adding any moisture to the inside air, the relative humidity of the inside air is reduced. This is because specific humidity (the mass of water per unit mass of dry air) of the air remains the same when its temperature is raised, but the capacity of the air to hold water increases as temperature increases, therefore lowering relative humidity.

This lowering of relative humidity can be calculated (see Appendix), and Figure 11 is an example of the effect on the annual variation of relative humidity (in Redding, California) as the temperature in an enclosure is raised in 5°F increments above outside ambient temperature. The effect of incremental 5°F (2.8°C) temperature increases above ambient (up to a 20°F (11.1°C) increase) and the effect of lowering relative humidity are shown on estimated drying times in Figure 12 for 6-in.- (152-mm-) diameter ponderosa pine and

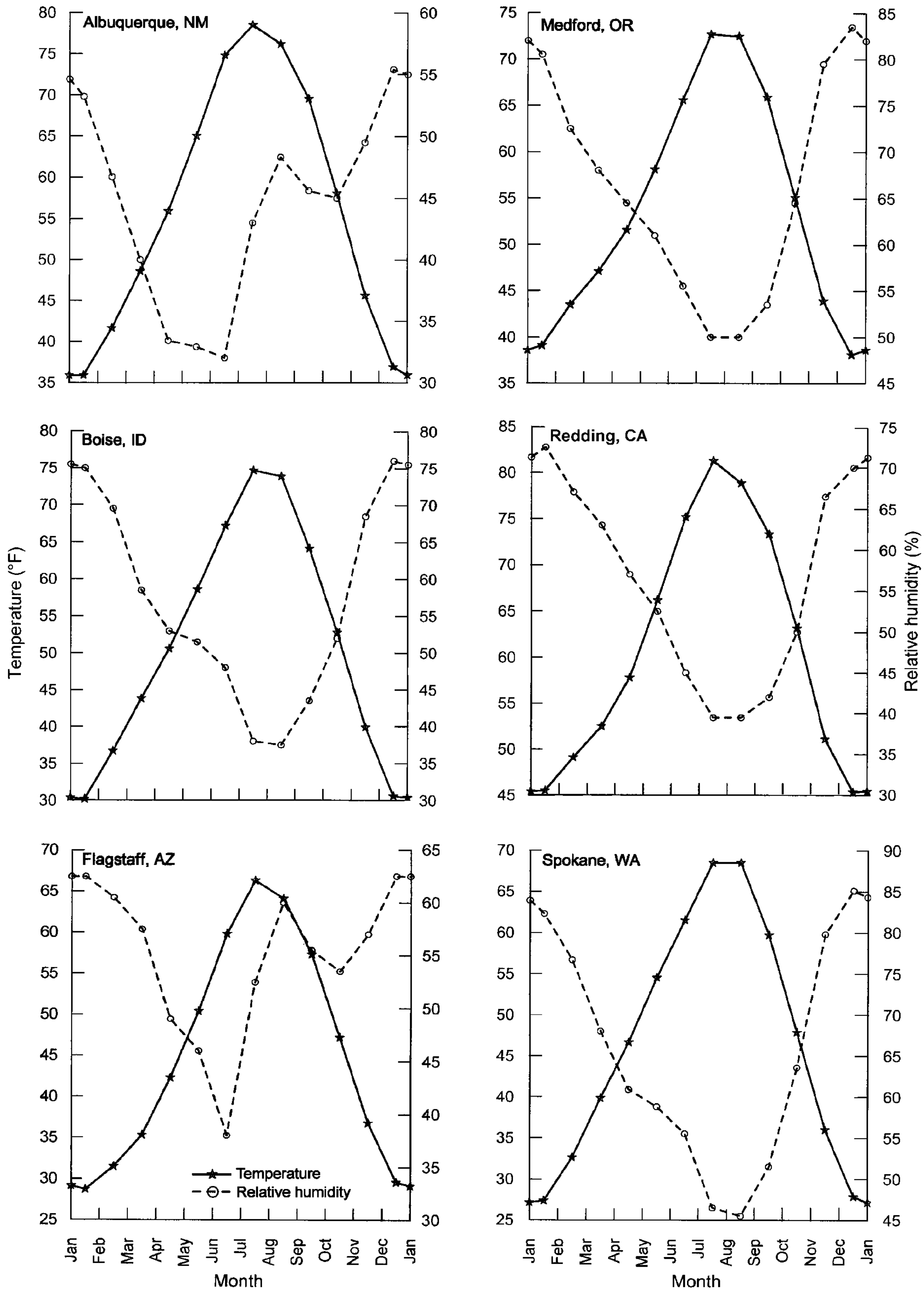

Figure 7—Temperature and relative humidity for selected locations in the growing range of ponderosa pine and Douglas-fir (°F = 1.8(°C) + 32).

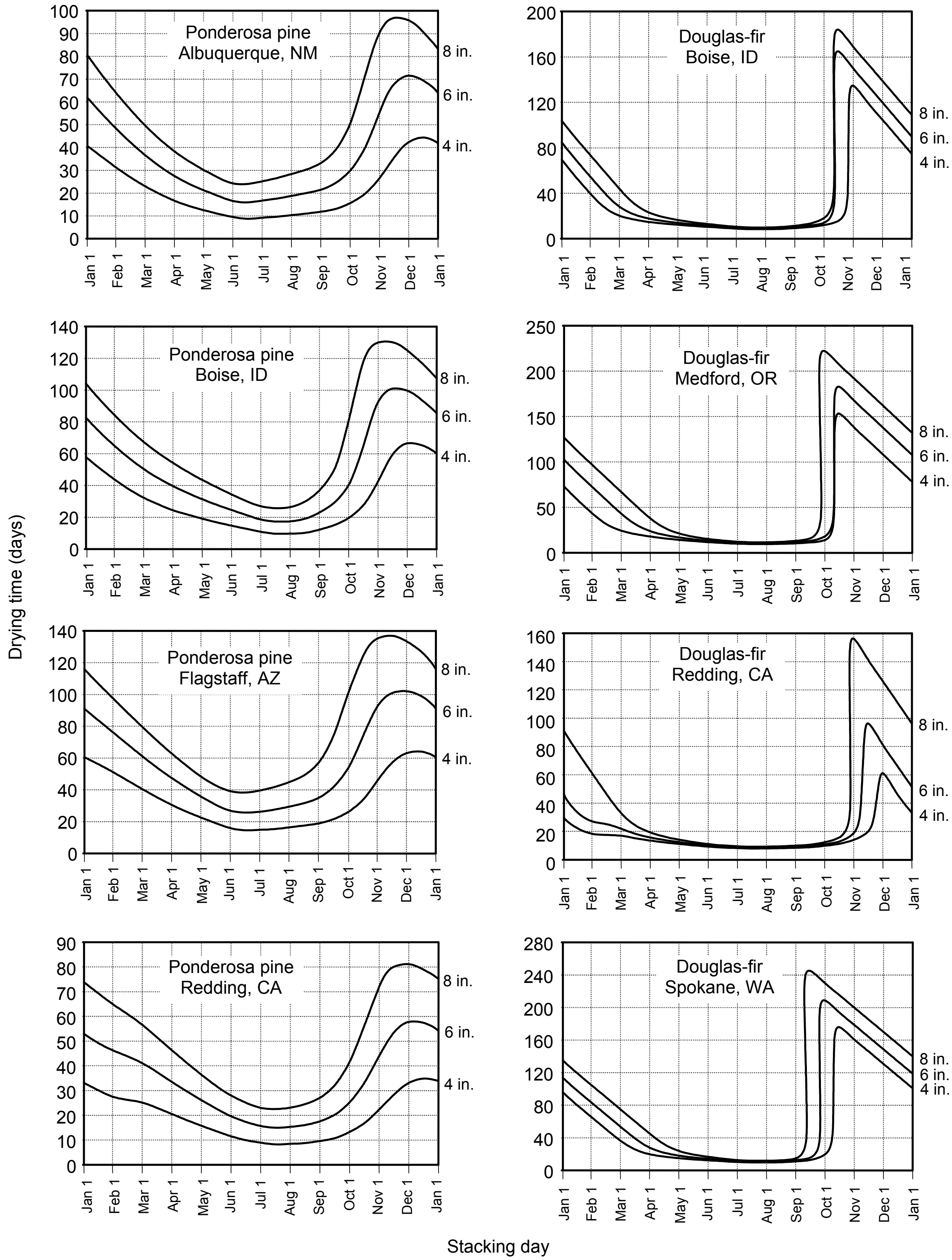

Figure 8—Estimated air drying times (to final MC of 20%) of 4-, 6-, and 8-in.- (102-, 152-, and 203-mm-) diameter ponderosa pine (MC = 120%) and Douglas-fir (MC = 47%) stacked on any day of the year at selected locations within their growing range.

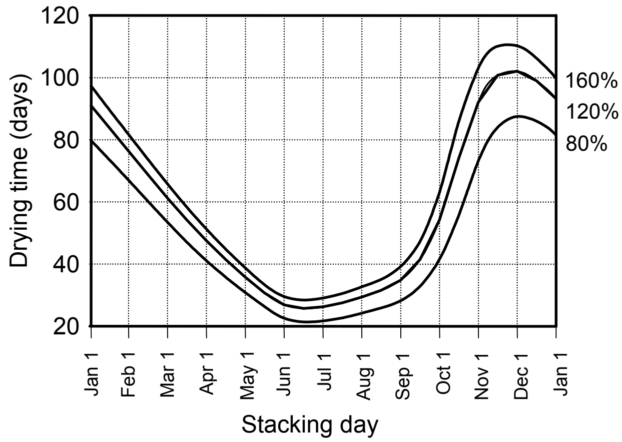

Figure 9—Effect of initial moisture content (80%, 120%, or 160%) on estimated air drying time to 20% moisture content of 6-in.- (152-mm-) diameter ponderosa pine in Flagstaff, Arizona.

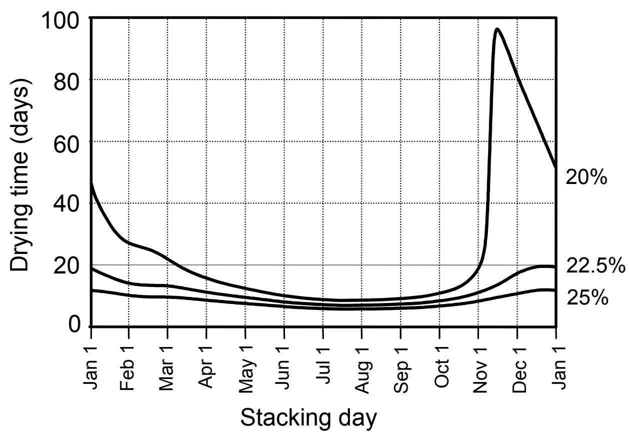

Figure 10—Effect of target final moisture content (20%, 22.5%, or 25%) on estimated air drying time of 6-in.- (152-mm-) diameter Douglas-fir, initial moisture content of 47%, air dried in Redding, California.

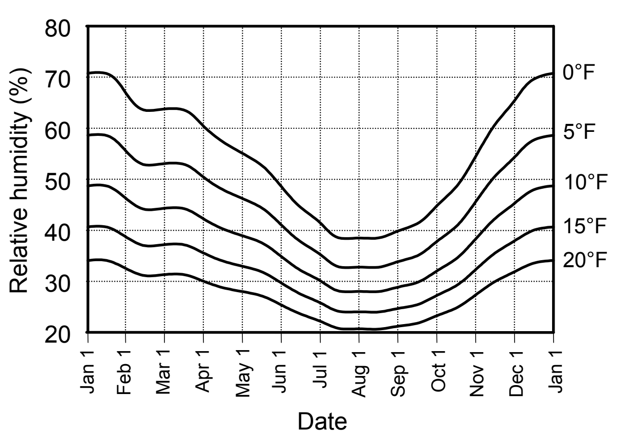

Figure 11—Decrease in relative humidity by heating outside air brought into an enclosure during the year in Redding, California (temperature increase shown in 5°F increments;°F = 1.8(°C) + 32).

Douglas-fir logs in several locations. The drying times in Figure 12 assume that venting is sufficient so that no water is added to the inside air; that is, the specific humidity remains the same as in the outside air. In practice, this exact balance is a requirement that would be difficult to attain. The purpose of the drying times in Figure 12 is to illustrate the principle that any enclosure where temperature can be increased by only a modest 10°F to 15°F (5.6°C to 8.3°C) over outside ambient temperature and relative humidity lowered by about 10% (which would probably require some sort of venting system such as a simple humidistat operating a vent flap or a powered blower vent) from ambient outside conditions will significantly reduce drying time compared with the time required for outside air drying.

Concluding Remarks

The application of regression analysis to experimental air drying data for ponderosa pine and Douglas-fir logs has resulted in a method for estimating air drying times of 4- to 8-in.- (102- to 203-mm-) diameter logs stacked any day of the year at any location where historic weather data are available. The resulting regression models relate daily moisture content loss to moisture content at the start of the day, average daily temperature and relative humidity, and log diameter. The model can readily be used in spreadsheet analyses or in user-built computer programs. Examples of drying time estimates are given for several locations within the growing range of the two species. While there is a degree of uncertainty in the estimates, they can serve as useful first-estimate guidelines that may be helpful in production planning. The model also offers guidelines on the benefit of simple, low-temperature dryers in reducing drying time.

Acknowledgments

We gratefully acknowledge the Watershed Research and Training Center, Hayfork, California, for their assistance in making this study possible. Special thanks also to Dr. John R. Shelly, University of California, Forest Products Laboratory, whose thorough review improved the analysis.

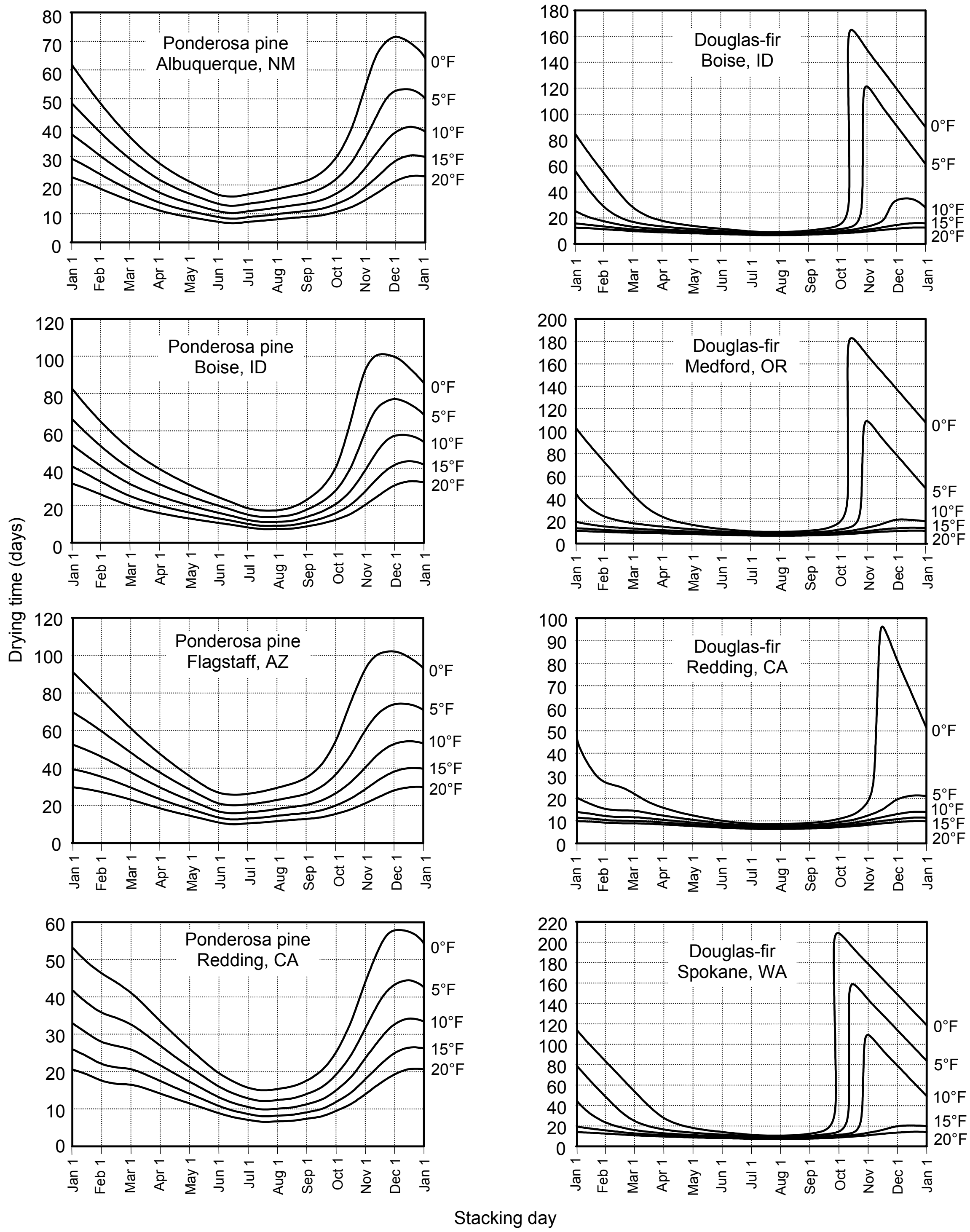

Figure 12—Estimated drying times to 20% moisture content for 6-in.- (152-mm-) diameter ponderosa pine and Douglas-fir logs in a dryer where temperature was increased in 5°F increments over ambient outside temperature and relative humidity was allowed to fall to the level where sufficient venting did not allow any moisture to be added to the inside air (°F = 1.8(°C) + 32).

Literature Cited

Denig, J.; Wengert, E. 1982. Estimating air-drying moisture content loss for red oak and yellow-poplar lumber. Forest Products Journal. 32(2): 26–31.

Hart, C.A. 1982. SIMSOR: A computer simulation of water sorption in wood. Wood and Fiber. 13(1): 46–71.

Liley, P.E.; Hottel, H.C.; Sarofin, A.F.; Smith, A.F. 1996. Heat. In: Avallone, E.A.; Baumeister, T. Mark's Standard Handbook for Mechanical Engineers. Ch. 4, 10th ed. New York, NY: McGraw–Hill.

National Climate Data Center. 2002. Climate products/comparative climate data. Asheville, NC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climate Data Center.
Temperature:
http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/meantemp.html
Relative humidity:
http://lwf.ncdc.noaa.gov/oc/climate/online/ccd/avgrh.html

Simpson, W.T.; Hart, C.A. 2000. Estimates of air drying times for several hardwoods and softwoods. Gen. Tech. Rep. FPL–GTR–121. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 70 p.

Simpson, W.T.; Hart, C.A. 2001. Method for estimating air-drying times of lumber. Forest Products Journal. 51(11/12): 56–63.

Appendix—Calculation of Relative Humidity Decrease With Temperature Increase

$$\text{Relative humidity} = r = \frac{100 \text{ actual vapor pressure of water}}{\text{saturated vapor pressure}} = 100\, p_v/p_d \tag{1A}$$

(Liley and others 1996)

Over the range of 20°F to 100°F (–6.7°C to 38°C), the saturated vapor pressure of water can be approximated by

$$p_d = \exp(-3.079 + 0.0452T - 0.0000783T^2) \text{ (inHg)} \tag{2A}$$

When temperature is raised, p_v remains the same but p_d increases according to Equation (2A).

For example, assume 50°F (10°C) outside temperature and 90% relative humidity. From Equation (1A),

$$\begin{aligned} p_v &= (r/100)p_d = (r/100)\exp(-3.079 + 0.0452T - 0.0000783T^2) \\ &= (90/100)\exp(-3.079 + 0.0452(50) - 0.0000783(50^2)) \\ &= 0.3262 \text{ inHg} \end{aligned}$$

Now raise the inside temperature to 60°F (15.6°C) and keep p_v the same at 0.3262 inHg.

p_d increases according to

$$p_d = \exp(-3.079 + 0.0452(60) - 0.0000783(60^2)) = 0.5226 \text{ inHg}$$

and $\quad r = 100p_v/p_d = 100(0.3262/0.5226) = 62.4\%$