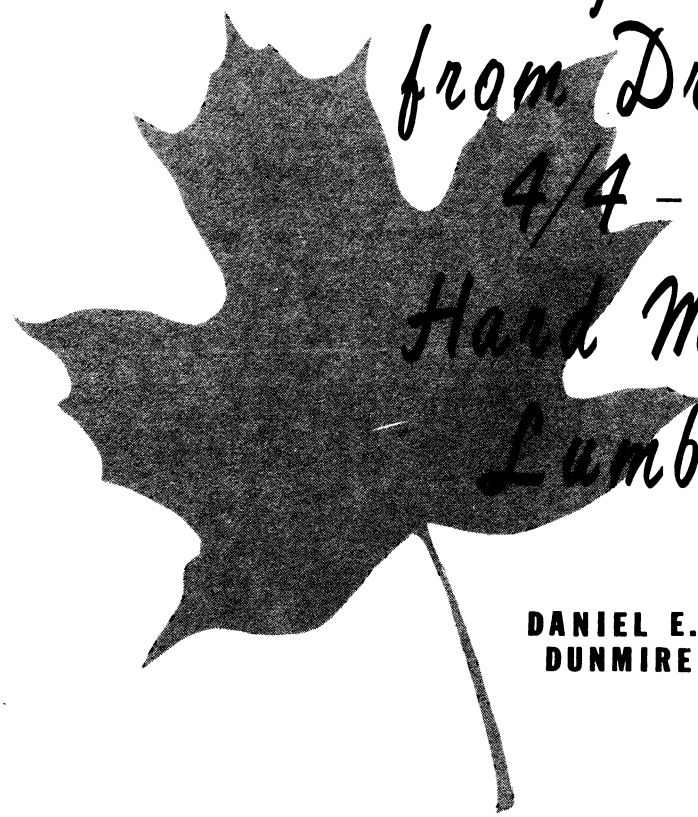
NC-24
RP
cy 2

U. S. FOREST SERVICE
RESEARCH PAPER NC-24
1968

SOUTHERN FOREST EXPERIMENT STATION
LIBRARY
JAN 21 1969

# Shrinkage and Footage Loss from Drying 4/4-Inch Hard Maple Lumber



DANIEL E.
DUNMIRE

NORTH CENTRAL FOREST EXPERIMENT STATION
D. B. King, Director
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

## CONTENTS



NOTE: The author is Associate Forest Products Technologist, North Central Forest Experiment Station. He is headquartered at the Station's field office in Carbondale, Illinois, which is maintained in cooperation with Southern Illinois University.

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
FOLWELL AVENUE
ST. PAUL, MINN. 55101

# Shrinkage and Footage Loss From Drying 4/4-Inch Hard Maple Lumber

Daniel E. Dunmire

When wood dries, it shrinks appreciably tangentially and radially to the grain. Longitudinal shrinkage is almost negligible and can be disregarded when the lumber has normal end trimming allowance. However, tangential and radial shrinkage is important to lumber processors because it affects the utility of their lumber. If air-dry lumber is scant in thickness and width, it may not be possible to cut parts of specific dimension from the lumber after it is kiln-dried. Most hardwood product processors know this, and some have rules of thumb to determine if a package of air-dry lumber will, after kiln-drying, meet their needs for thickness and width.

Methods have been published for estimating wood shrinkage (MacLean 1945, Peck 1960, Rietz 1941),[1] but they are based on data from small, clear samples of wood dried under controlled laboratory conditions. Commercial lumber consists of boards of different widths and lengths with various defects, and of different grain patterns. All of these factors affect shrinkage during drying.

This paper shows how to calculate the shrinkage that can be expected when drying commercial hard maple lumber.

## PROCEDURE

First, we learned how cutting yield varies within grades of lumber by studying the dimension and yield characteristics of about 100,000 board feet of hard maple lumber at 20 sawmills in 10 states throughout the hard maple producing region. With this knowledge to aid us, we graded, selected, and purchased 1,588 4/4-inch-thick, air-dried hard maple (*Acer saccharum* and *A. nigrum*) boards totaling 10,581 board feet for our study.[2] The lumber was selected from all commercial board widths and lengths of the best five grades of hard maple lumber (table 1). Within lumber grades, the boards were classified into 10-percent cutting yield classes.

After selection, an inspector from the National Hardwood Lumber Association (NHLA) measured the lumber with a board rule and graded it to verify our board grades. We also measured the width of each board to the nearest ¼ inch at a point one-third the length from the narrow end of each board, where the surface measure of tapered boards is measured. Lumber lengths were measured in the same manner as standard lengths (NHLA 1960).

Then the lumber was kiln-dried, equalized, and conditioned in a 6,000-board-foot-capacity, forced-air dry kiln, using FPL drying schedule T8-C3 (Rasmussen 1961). Drying results were normal (fig. 1). Based on 20 kiln samples and other moisture meter readings, the average moisture content (MC) was 13 percent prior to drying and 6 percent after drying. The difference between the original and final MC, 7 percent, is referred to hereafter as the drying range (DR).

The lumber was then regraded and volume was remeasured with a board rule by an NHLA inspector. Each board was also classified as plainsawed, bastardsawed, or quarter-

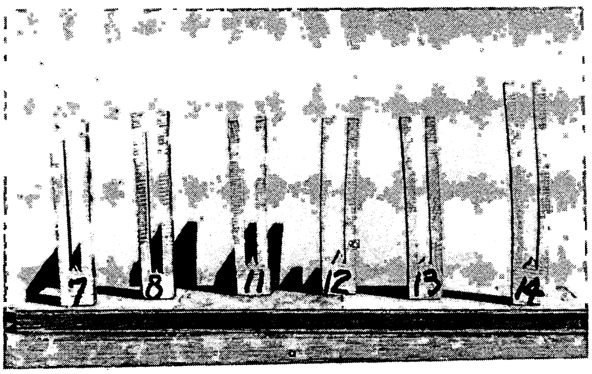
[1] *Names and dates in parentheses refer to Literature Cited.*

[2] *This lumber was obtained to determine the cutting yields of hard maple lumber in a joint study with the Forest Products Laboratory (FPL), Madison, Wis., and has been used since then for several related studies.*

*Table 1. — Number of 4/4 hard maple boards and their surface measure by grade, by length, width, and yield class, and by saw type*

| Item | Number of boards by grade | | | | | | Surface measure (in bd. ft.) of boards by grade | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FAS | Sel | No. 1 Common | No. 2 Common | No. 3A Common | Total | FAS | Sel | No. 1 Common | No. 2 Common | No. 3A Common | Total |
| Length class (feet) | | | | | | | | | | | | |
| 4- 5 | -- | -- | 56 | 62 | 68 | 186 | -- | -- | 153 | 150 | 164 | 467 |
| 6- 7 | -- | 30 | 65 | 57 | 51 | 203 | -- | 133 | 262 | 202 | 177 | 774 |
| 8- 9 | 24 | 32 | 68 | 73 | 64 | 261 | 154 | 184 | 369 | 369 | 313 | 1,389 |
| 10- 11 | 24 | 32 | 69 | 78 | 52 | 255 | 184 | 226 | 479 | 513 | 297 | 1,699 |
| 12- 13 | 24 | 32 | 69 | 76 | 62 | 263 | 218 | 270 | 552 | 613 | 442 | 2,095 |
| 14- 15 | 24 | 30 | 67 | 58 | 39 | 218 | 250 | 279 | 656 | 512 | 311 | 2,008 |
| 16 | 24 | 28 | 62 | 53 | 35 | 202 | 295 | 295 | 693 | 506 | 360 | 2,149 |
| Width class (inches) | | | | | | | | | | | | |
| 3- 4 | -- | 25 | 82 | 93 | 70 | 270 | -- | 102 | 290 | 312 | 214 | 918 |
| 5- 6 | 30 | 40 | 98 | 112 | 113 | 393 | 186 | 217 | 488 | 561 | 532 | 1,984 |
| 7- 8 | 30 | 42 | 98 | 109 | 119 | 398 | 241 | 303 | 639 | 691 | 749 | 2,623 |
| 9- 10 | 30 | 41 | 94 | 88 | 59 | 312 | 294 | 371 | 774 | 708 | 454 | 2,601 |
| 11- 12+ | 30 | 36 | 84 | 55 | 10 | 215 | 380 | 394 | 973 | 593 | 115 | 2,455 |
| Yield class (percent) | | | | | | | | | | | | |
| 31- 40 | -- | -- | -- | -- | 13 | 13 | -- | -- | -- | -- | 66 | 66 |
| 41- 50 | -- | -- | -- | 5 | 84 | 89 | -- | -- | -- | 24 | 487 | 511 |
| 51- 60 | -- | -- | -- | 65 | 122 | 187 | -- | -- | -- | 410 | 731 | 1,141 |
| 61- 70 | -- | -- | 55 | 175 | 103 | 333 | -- | -- | 407 | 1,077 | 544 | 2,028 |
| 71- 80 | -- | -- | 168 | 154 | 39 | 361 | -- | -- | 1,181 | 995 | 195 | 2,371 |
| 81- 90 | 40 | 71 | 170 | 52 | 6 | 339 | 371 | 598 | 1,153 | 329 | 32 | 2,483 |
| 91-100 | 80 | 113 | 63 | 6 | 4 | 266 | 730 | 789 | 423 | 30 | 9 | 1,981 |
| Lumber saw type[1/] | | | | | | | | | | | | |
| Plainsawed | 92 | 123 | 329 | 342 | 198 | 1,084 | 763 | 809 | 1,961 | 1,909 | 986 | 6,428 |
| Bastardsawed | 26 | 56 | 121 | 103 | 130 | 436 | 316 | 540 | 1,168 | 871 | 823 | 3,718 |
| Quartersawed | 2 | 5 | 6 | 12 | 43 | 68 | 22 | 38 | 35 | 85 | 255 | 435 |
| Total | 120 | 184 | 456 | 457 | 371 | 1,588 | 1,101 | 1,387 | 3,164 | 2,865 | 2,064 | 10,581 |

[1/] Average annual ring slope in degrees and the range by lumber grade (in parentheses) were as follows: Plainsawed, 16.9 (16.3-17.8); bastardsawed, 40.5 (39.1-41.5); quartersawed, 73.6 (71.1-80.0); all board types, 25.8 (16.3-80.0).




F-517848

FIGURE 1. — Some stress-free sections of kiln samples from kiln charge No. 1.

sawed[3] by MacLean's (1945) method whereby the average slope, measured in degrees, of four annual rings on the cross-section of a board is determined. Of the study boards, 68 percent were plainsawed, 28 percent bastardsawed, and 4 percent quartersawed (table 1).

Because longitudinal shrinkage of wood is negligible (Koehler 1954), board lengths were not remeasured. But we remeasured board widths to the nearest ¼ inch as we had done before drying. Using these measured air-dried and kiln-dried board widths and the air-dried board lengths we calculated to the nearest hundredth board foot the air-dry and kiln-dry footage for each board. The results, "calculated board measure," are compared in the next sections with the board footages obtained by the lumber inspector, "board rule measure."

## RESULTS

Total width shrinkage of all boards ($\overline{DR}$= 7 percent MC) was 343 inches, 2.8 percent of the combined widths; shrinkage ranged from 2.7 to 2.9 percent by grade and from 2.3 to 3.0 percent by board type. As would be expected, plainsawed lumber shrank more than bastardsawed or quartersawed lumber (table 2).

Total losses in calculated board measure of all boards were 274 board feet, 2.6 percent of the original footage (table 3). By grades, shrinkage ranged from 2.5 to 2.7 percent, but by saw type it ranged from 2.3 to 2.8 percent. Losses were greatest in plainsawed lumber.

Total surface footage of the lumber before kiln-drying was practically the same by both the board rule measure (10,581 board feet) and the calculated board measure (10,571 board feet). However, footage loss determined by board rule (176 board feet) was considerably less than that based on calculated board measurements (274 board feet) (table 3). Although the board rule is the accepted means of measuring lumber for buying and selling, it apparently does not accurately account for footage loss due to drying.

We used the calculated board measure data rather than the board rule measure to derive a set of equations[4] for predicting surface area losses due to kiln-drying hard maple lumber. Since wood shrinkage, for practical purposes, has been found to be directly proportional to its moisture content below fiber saturation point (Rasmussen 1961), our estimating equations may be applied through any drying range below the wood fiber saturation point, which is about 30 percent MC for hard maple.

Board width data, before and after kiln drying, were of course used to derive equations for calculating width losses.

(Warning: Estimates of footage lost in shrinkage, when using these equations, will not equal estimates obtained with a board rule. Equation estimates are more accurate. This will be discussed in the section on Equation Accuracy.)

[3] *A plainsawed hardwood board has annual rings oriented at slopes of 0 to 30 degrees, bastardsawed 31 to 60 degrees, and quartersawed 61 to 90 degrees with the face of the board (USFS, Forest Prod. Lab. 1950).*

[4] *Consultation was with Thomas H. Starks, Ph. D., Associate Professor of Mathematics, Southern Illinois University, Carbondale, Illinois, at which time a suitable computer program was chosen (Fitzpatrick 1965).*

*Table 2.—Actual and estimated board width and shrinkage due to kiln drying 4/4-inch-thick hard maple lumber from 13 to 6 percent moisture content*

| Lumber grade or board type | Cumulative board width: Air-dried | Cumulative board width: Kiln-dried | Cumulative board width: Actual shrinkage | | Estimated shrinkage[1] | |
|---|---|---|---|---|---|---|
| | Inches | Inches | Inches | Percent | Inches | Percent |
| BY LUMBER GRADE | | | | | | |
| FAS | 1,097 | 1,065 | 32 | 2.9 | 30 | 2.7 |
| Sel | 1,507 | 1,464 | 43 | 2.9 | 41 | 2.7 |
| No. 1 Common | 3,667 | 3,564 | 103 | 2.8 | 100 | 2.7 |
| No. 2 Common | 3,385 | 3,292 | 93 | 2.7 | 93 | 2.7 |
| No. 3A Common | 2,555 | 2,483 | 72 | 2.8 | 70 | 2.7 |
| BY BOARD TYPE | | | | | | |
| Plainsawed | 7,623 | 7,395 | 228 | 3.0 | 224[2] | 2.9 |
| Bastardsawed | 4,074 | 3,971 | 103 | 2.5 | 96[3] | 2.4 |
| Quartersawed | 514 | 502 | 12 | 2.3 | 12[3] | 2.3 |
| Total or average | 12,211 | 11,868 | 343 | 2.8 | 334[1] | 2.7 |

1/ Shrinkage estimated from equation $S = 0.391\ \overline{DR}\ W_o$.
2/ Shrinkage estimated from equation $S = 0.419\ \overline{DR}\ W_o$.
3/ Shrinkage estimated from equation $S = 0.338\ \overline{DR}\ W_o$.

*Table 3. — Actual and estimated footage loss due to kiln-drying 4/4-inch-thick hard maple lumber from 13 to 6 percent moisture content*

| Lumber grade or board type | Board rule measure: Air-dried | Board rule measure: Kiln-dried | Board rule measure: Actual shrinkage | | Calculated board measure: Air-dried | Calculated board measure: Kiln-dried | Calculated board measure: Actual shrinkage | | Estimated footage loss | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Board feet | Board feet | Board feet | Percent | Board feet | Board feet | Board feet | Percent | Board feet[1] | Percent |
| BY LUMBER GRADE | | | | | | | | | | |
| FAS | 1,101 | 1,085 | 16 | 1.5 | 1,103 | 1,075 | 28 | 2.5 | 30 | 2.7 |
| Sel | 1,387 | 1,363 | 24 | 1.7 | 1,382 | 1,345 | 37 | 2.7 | 38 | 2.7 |
| No. 1 Common | 3,164 | 3,116 | 48 | 1.5 | 3,171 | 3,086 | 85 | 2.7 | 87 | 2.7 |
| No. 2 Common | 2,865 | 2,812 | 53 | 1.8 | 2,858 | 2,787 | 71 | 2.5 | 78 | 2.7 |
| No. 3A Common | 2,064 | 2,029 | 35 | 1.7 | 2,057 | 2,004 | 53 | 2.6 | 56 | 2.7 |
| BY BOARD TYPES | | | | | | | | | | |
| Plainsawed | 6,428 | 6,315 | 113 | 1.8 | 6,426 | 6,248 | 178 | 2.8 | 188[2] | 2.9 |
| Bastardsawed | 3,718 | 3,663 | 55 | 1.5 | 3,712 | 3,626 | 86 | 2.3 | 88[3] | 2.4 |
| Quartersawed | 435 | 427 | 8 | 1.8 | 433 | 423 | 10 | 2.3 | 10[3] | 2.3 |
| Total | 10,581 | 10,405 | 176 | 1.7[4] | 10,571 | 10,297 | 274 | 2.6[4] | 289[1] | 2.7[4] |

1/ Shrinkage estimated from equation $\overline{FL} = 0.391\ \overline{DR}\ V_o$.
2/ Shrinkage estimated from equation $\overline{FL} = 0.419\ \overline{DR}\ V_o$.
3/ Shrinkage estimated from equation $\overline{FL} = 0.338\ \overline{DR}\ V_o$.
4/ Average.

These equations are:

$$S = 0.391\,\overline{DR}\,W_o \qquad (1)$$

$$W_o = W_r / [1 - (0.391\,\overline{DR})] \qquad (2)$$

$$\overline{FL} = 0.391\,\overline{DR}\,V_o \qquad (3)$$

$$V_r = [1 - (0.391\,\overline{DR})]\,V_o \qquad (4)$$

where $S$ = total shrinkage in inches of width for all boards in a lumber package due to drying, $S = W_o - W_r$.

$\overline{DR}$ = any drying range between 30 percent and 0 percent moisture content, expressed as decimals, through which the lumber is dried. The original moisture content minus the final moisture content of the lumber is $\overline{DR}$. Because wood does not shrink until it is dried to the fiber saturation point, an MC of 30 percent should be used in places of the original MC in computing the $\overline{DR}$ for any hard maple above fiber saturation point.

$W_o$ = total original or air-dried width in inches of all boards in a lumber package before drying.

$W_r$ = total residual width in inches of all boards in a lumber package after drying and conditioning the lumber.

$\overline{FL}$ = footage loss in board feet of all boards in a lumber package due to drying. $\overline{FL}$ is the footage loss due to lumber shrinkage; $\overline{FL} = V_o - V_r$.

$V_o$ = total board feet of a lumber package before drying.

$V_r$ = total residual board feet of lumber after drying and conditioning.

Shrinkage did not differ by lumber grades or cutting yield classes but did differ by board type. Thus, for lumber with specific grain orientation, the equations should be modified. Furthermore, because our quartersawed lumber was not a good sample[5], its shrinkage was the same as for the bastardsawed lumber. Thus, the derivation of the bastardsawed equations included shrinkage values from the quartersawed lumber. The modified equations for plainsawed and bastardsawed lumber saw types are:

*For plainsawed lumber*
(0-30 degrees)

$$S = 0.419\,\overline{DR}\,W_o \qquad (1)$$

$$W_o = W_r / [1 - (0.419\,\overline{DR})] \qquad (2)$$

$$\overline{FL} = 0.419\,\overline{DR}\,V_o \qquad (3)$$

$$V_r = [1 - (0.419\,\overline{DR})]\,V_o \qquad (4)$$

*For bastardsawed lumber*
(31-60 degrees)

$$S = 0.338\,\overline{DR}\,W_o \qquad (1)$$

$$W_o = W_r / [1 - 0.338\,\overline{DR}] \qquad (2)$$

$$\overline{FL} = 0.338\,\overline{DR}\,V_o \qquad (3)$$

$$V_r = [1 - (0.338\,\overline{DR})]\,V_o \qquad (4)$$

[5] *The quartersawed lumber was not a good sample because there were not enough boards in that class, most of the boards were cut from near the center of logs (62 percent contained pith), and most of these boards (81 percent) were No. 2 and No. 3A Common grades.*

# APPLYING THE EQUATIONS

Lumber shrinkage estimating equations are most useful for kiln loads, truck loads, or carload lots of hard maple lumber; but they also predict the average shrinkage of individual boards.

Equation (1) is used when an estimate of average shrinkage (S) in board width is desired. To determine shrinkage accurately, board widths must be measured precisely. For commercial lumber, widths should be measured to the nearest ¼ inch. Shrinkage curves for board widths dried through various drying ranges and derived from equation (1) are shown in figure 2.

Equation (2) is useful in predicting the air-dry board width that will be needed when the required kiln-dry width is known. Figure 3, based on this equation, is useful for making these predictions.

Equation (3) is used when losses in surface measure ($\overline{FL}$) due to lumber shrinkage are desired. Total original footage ($V_o$) may be the board rule measure of the lumber, but it can be determined more precisely by calculating and adding the surface measure of individual boards.

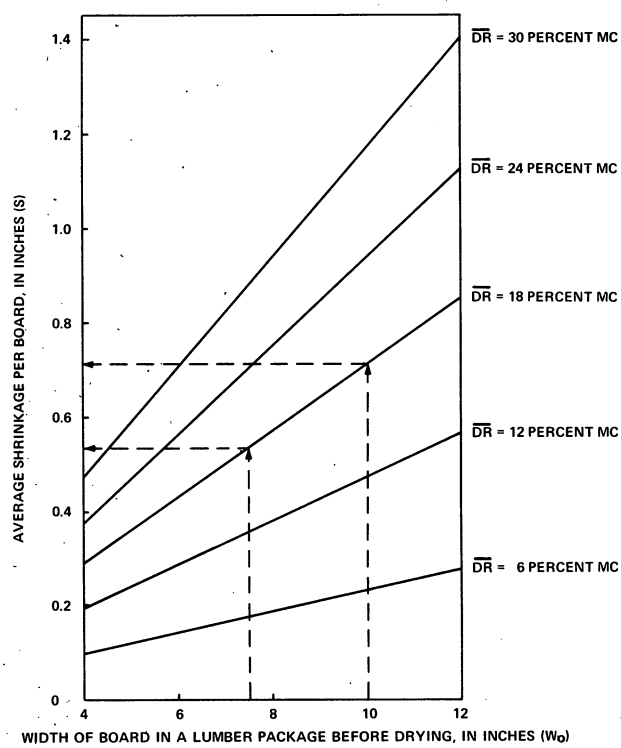



FIGURE 2. — Shrinkage in average board widths of 4/4 hard maple lumber dried through various drying ranges; derived from equation $S = 0.391\,\overline{DR}\,W_o$. As an example assume an original board width ($W_o$) of 10 inches, an original moisture content (MC) of 50 percent, and a final MC of 12 percent. $\overline{DR}$ is the difference between the original and final MC; but whenever the original MC is higher than the fiber saturation percent (30 percent for hard maple), then the fiber saturation percent is used. Therefore $\overline{DR} = 30\text{-}12$ or 18 percent. Following the arrowed lines in the chart, a 10-inch-wide board dried through a range of 18 percent will shrink 0.7 inch. Likewise a 7.5-inch-wide board with an 18-inch $\overline{DR}$ will shrink 0.53 inch.

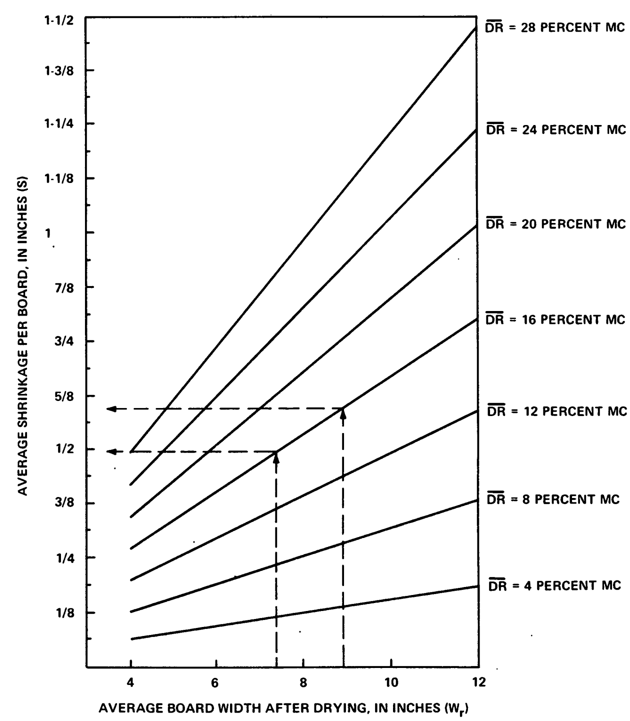



FIGURE 3. — Graph for predicting what the air-dry board width must be to achieve a given kiln-dry board width; derived from equation $W_o = W_r / [1 - 0.391\,\overline{DR}]$. As an example assume that a kiln-dry board width of 9 inches is needed, that the initial MC of boards will be 24 percent, and that the kiln-dry MC will be 8 percent. $\overline{DR}$ then is 16 percent. By following the arrowed lines in the chart, we find that a kiln-dry width of 9 inches requires an air-dry board nearly ⅝ inch wider or about 9⅝ inches. Likewise, a kiln-dry width of 7½ inches will require an air-dry board ½ inch wider (8 inches).

Equation (4) can be used to estimate total residual lumber footage ($V_r$) after drying. If the lumber is measured with a board rule, the footage will not equal $V_r$, which is based on more acurate measurements (table 4). Furthermore, figure 4 may be used to predict $V_r$.

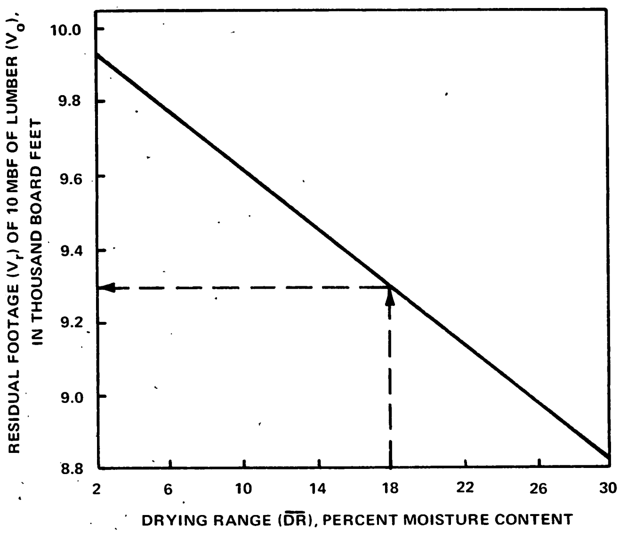



FIGURE 4. — Graph for predicting residual footage after drying 4/4 hard maple lumber; derived from equation $V_r = [1 - (0.391\,\overline{DR})]\,V_o$. As an example, assume an initial volume of 9.0 thousand board feet, an initial MC of 28 percent and a final MC of 10 percent. $\overline{DR}$ then is 28 — 10 or 18 percent. By following the arrowed lines in the chart, we find that at a drying range of 18 percent, the residual footage of 10 thousand board feet is 9.3 thousand. The residual footage of 9 thousand board feet would be 9/10 x 9.3 or 8.37 thousand. Using equation (4), the residual footage would be 8.367 thousand.

A question often asked in the industry is this, "If maple lumber is shipped air-dried, then kiln-dried in transit and inspected, how much footage should the buyer pay for on an air dried basis?" Equation (4) solved for the original volume, $V_o = V_r / [1 - (0.391\,\overline{DR})]$, will give an air-dried footage approximation. However, $V_r$ should be obtained by the calculation method as shown in the last column of table 4.

Moreover, these equations can be adapted for use with automatic data processing equipment. If green boards were machine-measured on the green chain at a mill, immediate dry measurements could be estimated by a computer. This might eliminate the need of remeasuring seasoned boards.

The shrinkage equation (1) can also be modified easily for use with shrinkage rates (values) in table 39 of the *Wood Handbook* (USFS, Forest Prod. Lab. 1955). The derivation follows:

$$S = K\,\overline{DR}\,W_o$$ where K is a constant

$$\overline{SR} = \frac{S}{W_o} = \frac{K\,\overline{DR}\,W_o}{W_o}$$

where $\overline{SR}$ is shrinkage rate

$$\overline{SR} = K_1\,\overline{DR}$$

where $K_1$ is modified constant for *Wood Handbook* shrinkage rates

$$K_1 = \overline{SR}/\overline{DR}$$

For example:

$$K_1 = \frac{0.054}{0.24} = 0.225$$

for quaking aspen, tangential grain (0-45 degrees), dried to 6 percent MC from the green condition (30 percent MC)

and:

$$K_1 = \frac{0.032}{0.24} = 0.133$$

for yellow-poplar, radial grain (45-90 degrees), dried to 6 percent MC from the green condition

These modified constants are substituted in lieu of our equation constants. Equation use, however, should be limited to dimension and cut stock, like flooring, because they have not been tested for lumber stock of species other than hard maple.

*Table 4. — An example: total residual board measure is accurately estimated from total original board measure*

| Number of boards | Board sizes: Original | Board sizes: Residual[1/] | Board rule method: $V_o$ | Board rule method: $V_r$ | Calculation method: $V_o$ | Calculation method: $V_r$ |
|---|---|---|---|---|---|---|
| | Inches Feet | Inches Feet | Board feet | | Board feet | |
| 5 | 4 x 10 | 3.81 x 10 | 15 | 15 | 16.7 | 15.9 |
| 7 | 5 x 12 | 4.77 x 12 | 35 | 35 | 35.0 | 33.4 |
| 3 | 8 x 16 | 7.62 x 16 | 33 | 30 | 32.0 | 30.5 |
| 4 | 10 x 14 | 9.53 x 14 | 48 | 44 | 46.7 | 44.5 |
| 6 | 6 x 13 | 5.72 x 13 | 39 | 36 | 39.0 | 37.2 |
| Total | | | 170 | 160* | 169.4 | 161.5** |

NOTES ON CALCULATIONS:

If $\overline{DR}$ is 12 percent MC, total residual board measure may be estimated quickly by equation $V_r = [1 - (0.391\ \overline{DR})]\ V_o$, as follows:

A. If total $V_o$ is 170 (board rule method), $V_r$ is 162*

B. If total $V_o$ is 169.4 (calculation method), $V_r$ is 161.5**

Answer to "B" indicates that estimated $V_r$ = calculated $V_r$.

Other example problems would show that calculated and estimated methods would give approximately the same answers. Board rule method gives less accurate answers.

[1/] Residual board widths are determined from $W_r = [1 - (0.391\ \overline{DR})]\ W_o$; $\overline{DR}$ = 12% MC.

* Compare board rule $V_r$ with equation $V_r$.

** Compare calculated $V_r$ with equation $V_r$.

# EQUATION ACCURACY

Shrinkage and footage losses can be predicted within ± 0.1 percent of the cumulative width and calculated surface measure of hard maple lumber. We discovered that estimated shrinkage and footage losses occurring through a drying range of 7 percent moisture content are 2.9 percent for plainsawed lumber, 2.4 percent for bastardsawed lumber, and 2.7 percent for both types combined (table 3).

The shrinkage rates observed in this study are somewhat greater than those reported in the *Wood Handbook* (USFS, Forest Prod. Lab. 1955) (fig. 5). *Wood Handbook* shrinkage rates for sugar maple dried through a range of 7 percent moisture content are 2.2 percent tangentially and 1.1 percent radially. These rates differ from our rates because *Wood Handbook* data are based on the average shrinkage of small, clear, square, flat wood specimens; but our rates are for hardwood lumber, which rarely has straight and square edges, and consists of boards of a variety of sizes and with many kinds of defects.

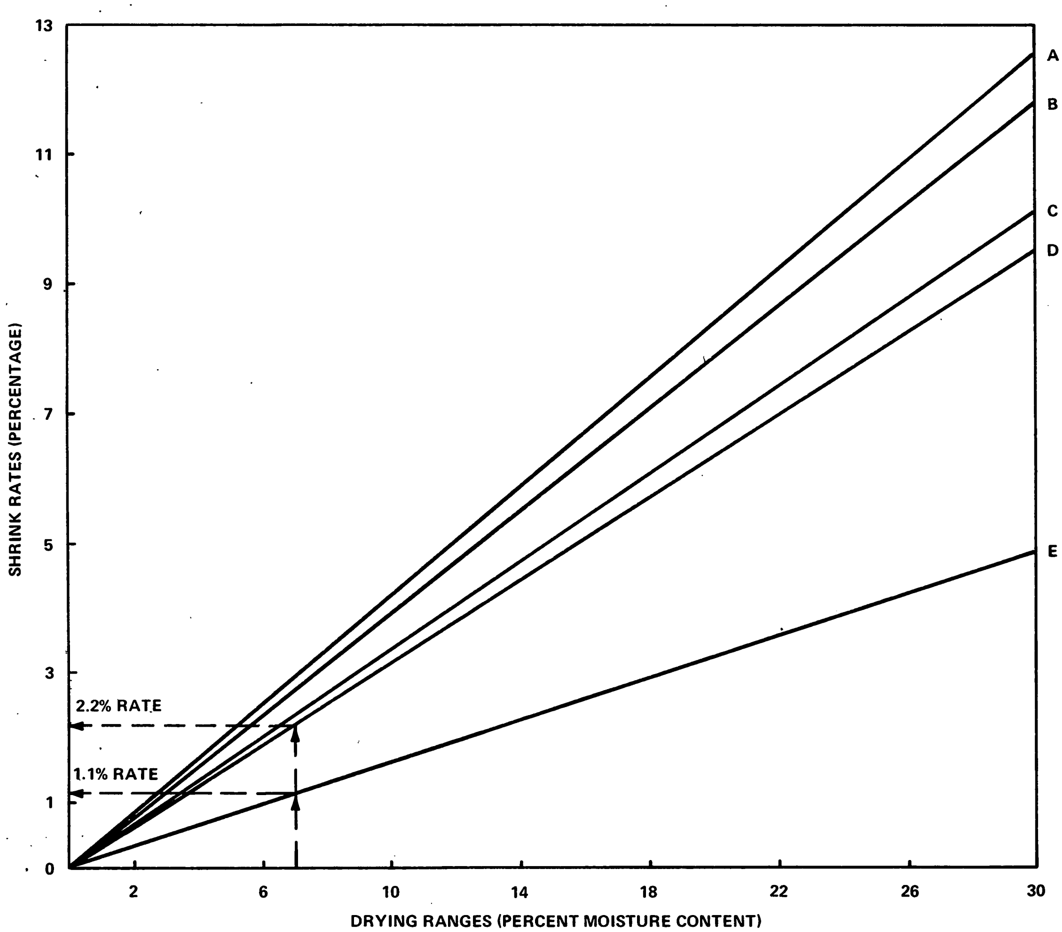



FIGURE 5. — Relationship of estimated and WOOD HANDBOOK shrinkage rates of hard maple lumber dried through various drying ranges. A, plainsawed type ($S = 0.419\ \overline{DR}\ W_o$) (0-30 degrees; B, plainsawed type ($S = 0.391\ \overline{DR}\ W_o$) (0-45 degrees); C, bastardsawed type ($S = 0.338\ \overline{DR}\ W_o$) (31-60 degrees); D, tangential grain (WOOD HANDBOOK) (0 degrees); E, radial grain (WOOD HANDBOOK) (90 degrees).

About 5 percent of all study boards were cupped slightly after kiln-drying. This normal warping probably caused decreased dry width measurements, resulting in increased shrinkage rates. Moreover, our board widths were measured ". . . to the nearest ¼ inch. . .," which were crude measurements for determining shrinkage but refined measurements for calculating footage. An example of this is shown in table 3, wherein the total actual shrinkage by the board rule measure was 98 board feet less than the calculated or more accurate board measure.

Predicting footage lost in shrinkage is complicated because the board rule method, although practical, is crude, especially when board widths are near the ½-board-foot mark on the board rule. For example, a sawmill operator can saw 12-foot-long boards to widths between 5 and 5½ inches, knowing that they will scale 5 board feet after drying, since none of the boards would shrink below 4½ inches. On the other hand, most 12-foot-long boards that are sawed between 4½ and 4¾ inches, when dried, will scale 4 board feet. Thus, for prediction purposes, calculated footage tallies are preferable.

Upon first glance, a reader might doubt that the total original (before drying) volume of a batch of boards of widely varying widths and lengths can be used to determine footage lost during drying. Table 4 is an example that indicates the equation method will work.

Our equations can be modified, of course, to predict shrinkage and footage losses in other lumber species. To do so requires studies of shrinkage in other species.

We used the hard maple equation to estimate shrinkage of nutmeg (*Dialyanthera virola*) lumber (Rice 1966). The actual shrinkage was about 0.6 percent less than estimated with the equation; hard maple lumber shrinks more than nutmeg lumber.

## LITERATURE CITED

Fitzpatrick, E. 1965. Least squares regression for the IBM 7040 by orthonormal linear functions using the Choleski method. South. Ill. Univ. Computing Center, 45 p.

Koehler, A. K. 1954. Longitudinal shrinkage of wood. U.S. Forest Serv., Forest Prod. Lab. Rep. 1093, 20 p., illus.

MacLean, J. D. 1945. Effect of direction of growth rings on the relative amount of shrinkage in width and thickness of lumber and effect of radial and tangential shrinkage on dimensions of round timbers. U.S. Forest Serv., Forest Prod. Lab. Rep. R1473, 19 p., illus.

National Hardwood Lumber Association. 1960. Rules for the measurement and inspection of hardwood lumber. 126 p.

Peck, E. C. 1960. Method of calculating shrinkage or swelling of wood with changes in moisture content. News and Views of this Kiln Drying Business. U.S. Forest Serv., Forest Prod. Lab. Rep. 1769-27, 9 p.

Rasmussen, E. F. 1961. Dry kiln operator's manual. U.S. Dep. Agr., Agr. Handb. 188, 197 p., illus.

Rietz, R. C. 1941. Estimating footage reduction in kiln drying air-dried hardwoods. South. Lumberman 163(2049): 58-59, illus.

Rice, W. W. 1966. Virola's problems unmasked. Woodworking Digest 68(8): 26-30, illus.

U.S. Forest Serv., Forest Products Laboratory. 1955. Wood handbook. U.S. Dep. Agr., Agr. Handb. 72, 528 p., illus.