KILN PERFORMANCE EVALUATION

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When a kiln vendor comes to your plant to discuss either new or remodeled drying equipment he needs to know the answers to four basic questions, namely

1. What is the size of the job to be done? How much water must be removed from how much lumber during a year of operation?
2. What are the specifications of the drying capabilities of a new kiln? Or what are the capabilities of the existing equipment and what modifications are required?
3. Once installed and de-bugged, how satisfactorily does the equipment perform? How uniformly and precisely are set-point conditions produced and maintained?
4. Finally, does the facility operate with maximum economic efficiency for the purchaser? Is the schedule or other operating conditions such that maximum net product value for the customer is being realized? What modifications are required?

These same questions are of major importance to the kiln operator. However, it is frequently found that kiln operators are not knowledgeable concerning the solutions to these questions. Therefore, I believe that it may be of value to you to disclose how the vendor goes about finding out the information which he has to have before he can specify the equipment which you need and make certain that it is operating at maximum efficiency.

Economics is the name of the game we play and economics is the topic which is duscussed at kiln club meetings. This meeting has been typical. We started off with Ken Bassett telling us about the dollar value of minimizing moisture content spread in a charge of lumber. Bill Brubaker followed with a discussion of how to utilize energy more efficiently and thereby save money. Bob Hiller told us about the use of a particular type of in-kiln moisture meter and how such an instrument could reduce the amount of redry and minimize degrade due to overdrying. This morning Loren Hearst told us how lumber sawn from dead timber could be dried to produce useful products; Jim Ward and Charlie Kozlik shared their research results leading to recommendations for the optimum drying of second growth western hemlock and Paul Bois told us about the economic and processing problems associated with the drying of oak, which Praise Allah, we do not work with out in this part of the world. George Bramhall appropriately anchored the session with a discussion of his research studies on the most effective and economical building of kiln schedules.

We have continued the same refrain this afternoon. Bob Erickson reminded us again that we must be extremely careful and smart in the drying of redwood in order to minimize damaging and costly shrinkage; Harvey Oster hit the energy problem again; Bill Moore established values on mill residues as energy and I have the privilege of singing the twelfth chorus of the same song--Drying Economics.

How Much Lumber to be Dried?

It is necessary to know the answer to this question in order to estimate the number of kilns which will be required and to determine the amount of water which must be removed during the drying process. It will be necessary to know the quantity of lumber both in terms of its volume and its weight. There is a temptation to use the board foot as a unit of volume since this term is commonly used by lumber manufacturers. However, it must be recognized that the board foot has become simply a convenience term and no longer represents a true volume unit. For example, one board foot by definition is that volume of lumber contained in a piece one inch thick, twelve inches wide and twelve inches long--in other words, one-twelfth of a cubic foot. A true 2" x 4" x 8' (stud) contains 5.33 board feet of volume. However, a stud 1.5" x 3.5" x 8' is still considered to contain 5.33 board feet of volume despite the fact that it contains only 66% as much material as the full dimension piece.

The mill manager probably estimates his production in terms of board feet per year. In order to transform this quantity into cubic feet it is necessary to know the target size of the sawmill. For simplicity, assume that the mill produces 150 million board feet of hemlock studs per year with each stud having dimensions of 3.75" wide, 1.875 inches thick and 8.25 feet long. Each green board therefore contains 0.4028 cubic feet of wood but is assumed to be 5.33 board feet, which in terms of full dimensions would contain 0.442 cubic feet. Therefore the actual volume of the annual production is 90.68% of that which would be assumed from the board footage. The 150MM board feet per year then becomes

$$0.9068 \times 150000000/12 = 11335000 \text{ cubic feet}$$

It will be necessary in many calculations to know the weight of lumber being dried. This requires knowledge of the density of the material. The desired value may be determined experimentally or found in tables such as those contained in the Wood Handbook published by the United States Forest Products Laboratory. The following values are taken from the Handbook.

DENSITIES OF SELECTED LUMBER ITEMS
Pounds of dry wood per cubic
foot of green volume

Species	Density
Cedar, Incense	21.840
Cedar, Port Orford	24.840
Cedar, Western red	19.344
Douglas Fir, Coast	28.080
Douglas Fir, Inland	28.704
Fir, Balsam	31.216
Fir, California Red	22.464
Fir, Grand	21.840
Fir, Noble	23.088
Fir, Pacific Silver	24.960
Fir, White	23.088
Hemlock, Western	26.208
Larch, Western	29.952
Pine, Ponderosa	23.712

Species	Density
Pine, Sugar	31.216
Redwood, Old	23.712
Redwood, Young	31.216
Spruce, Engelmann	20.592
Spruce, Sitka	23.058
Alder ******	23.089
Tan Oak	36.192

NOTE THAT THESE VALUES ARE FOR THE WEIGHTS PER CUBIC FOOT OF OVEN DRY WOOD.

The 11335000 cubic feet of lumber calculated above therefore contains

(11335000 cu. ft.)x(26.208 pounds/cu. ft) = 297,068,000 pounds of DRY WOOD SUBSTANCE.

How Much Water Must be Removed from the Lumber?

This important value requires knowledge of the average moisture contents of the green and kiln dried lumber. Both of these require measurement of enough samples to insure that the average values are typical of the material. Kiln dry lumber moisture contents are measured by use of electrical meters such as the so-called resistance (needle probes) meters or the capacitance type. (The type of meter used by the grading association should be used in the individual mill). These meters, while yielding individual board readings which may be in considerable error give average readings from a large number of samples which are reasonably trustworthy.

Green moisture content represents a different problem.

I am not aware of any meter that will indicate green moisture content of lumber with precision. Therefore the most satisfactory method is the slow and tedious oven drying method. At least one hundred and preferably two hundred random samples of the material to be dried are collected at the trim saw and trimmed to 1/2-inch wide strips which are immediately weighed. The procedure is greatly simplified if the sample weights are recorded directly on the pieces. The weighed specimens are then stacked loosely (for good circulation) in an oven maintained at a temperature of 215-220^{o}F and kept there until there is no further change in weight. This will require at least twelve hours and many people routinely allow the samples to remain in the oven for twenty four hours. The dried pieces are reweighed and the dry weights recorded on the specimens. When weighing is completed, green moisture contents of the specimens are calculated. Either a calculator or a slide rule may be used conveniently. The equation for the calculation is

$$100 \text{ X } \frac{\text{Green weight}}{\text{Dry weight}} - 1 = \% \text{ moisture content}$$

For example, if the green weight of a specimen was 27.43 grams and the oven dry weight was 18.65 grams the moisture content is

$$100 \frac{27.43}{18.65} - 1 = (100)(1.471 - 1) = (100)(0.471) = 47.1\%$$

Mechanically, simply divide the green weight by the dry weight, mentally subtract 1 and mentally multiply by 100.

Many samples of green wood will contain more than 100% moisture because moisture content in the lumber field is defined as the number of pounds (or other weight units) of water in 100 pounds (or other weight units) of dry wood. Thus, if there is more water than wood in a green specimen the result will be more than 100%. The calculation is the same as above, however. For example, if the green weight of the sample is 86.21 grams and the dry weight is 20.46 grams the moisture content is

$$100 \frac{86.21}{20.46} - 1 = (100)(4.214-1) = (100)(3.214) = 321.4\%$$

After the values have all been calculated an average value is obtained by adding all of the values together and dividing by the number of samples.

When the green and kiln dry moisture contents are known with sufficient confidence, the amount of water which must be removed during drying may be calculated. For example let us assume that the average green moisture content of the hemlock studs we have been using in the example is 83.6% and that the average kiln dry moisture content is 12.5%. The change in moisture content which takes place during drying is therefore 71.1%. (Remember that in the lumber manufacturing industry moisture content is expressed as pounds of water per pound of dry wood.) A change in moisture content of 71.1% means that each pound of dry wood loses 0.711 pounds of water. Therefore, the annual flow of 297068000 pounds of dry wood in our example would require the removal of

$$0.711 \times 297068000 = 21221500 \text{ pounds of water per year.}$$

Armed with the above information we are prepared to size the kiln or kilns and the heating system---almost, at least. There are several other bits of important information which you must supply or concerning which you add your vendor must agree or compromise. For example, if you use a crib stacker you may be set up to stack 25 studs per course. Perhaps you can stack a crib no higher than 12 feet. The amount of lumber which you can put into a crib will depend on the size of the sticks which you use. Your vendor will probably recommend that you use thick sticks--not because their use will decrease kiln holding capacity and therefore more or larger kilns necessary, but rather because uniformity of drying is improved. You will want to reduce stick thickness in order to increase kiln holding capacity. So--you compromise on, in our hypothetical example, on 5/8" sticks. You have definitely limited crib size to 56 courses of 25 boards per course with a crib height of 139.5" which leaves room for a small amount of error in sizing to a maximum of twelve feet.

You must also agree on a drying time which fits your operating schedule and which your experience and/or your vendor's performance warranty indicates that your schedule is conservative and capable of being achieved. For example, since you man your kilns around the clock seven days per week, you need not fit your kiln residence into a multiple of 24 hours or twelve hours. Your vendor tells you that he will guarantee that his facility will be capable of drying your product in 33-36 hours. To be conservative, you decide on a schedule of 38 hours of drying plus one hour each for loading and unloading--a total of forty hours per charge.

Now we may begin. The calculations go like this: (obviously the steps may be taken in different orders).

One course of lumber contains 25 boards and a crib consists of 56 courses for a total of

$$56 \times 25 = 1400 \text{ boards per crib.}$$

Each board has a volume of 0.4028 cubic foot. Therefore a crib contains

1400 x 0.4028 = 563.9 cubic feet of lumber.

It was established earlier that the annual production is 11,335,000 cubic feet. Therefore

11,335,000/563.9 = 20100 cribs per year.

If it is assumed that the kilns will operate 350 days or 8400 hours per year and since kiln residence has been specified at 40 hours

8400 hours/year/40 hours/cycle = 210 cycles/year.

Therefore, to meet the production schedule

20100 cribs/year/210 cycles/year = 96 cribs.

In words, 96 cribs of lumber must be processed at all times.

You are therefore concerned with the provision of kiln capacity for 96 cribs of studs. (It must be remembered that this number was arrived at on the basis of the specifications which have been inserted: board thickness, stick thickness, kiln residence time).

Most vendors furnish kilns in standard lengths of 68, 88, 104 and 120 feet. For board lengths of 8.25 feet, a 68 foot kiln will accommodate 8 cribs per track; an 88 foot kiln will hold 10, a 104 will hold 12 and a 120 foot kiln will hold 14 cribs per track. Therefore to accommodate 96 cribs of lumber simultaneously:

Kiln Length (ft)	Cribs/Track	Tracks Required for 96 Cribs
68	8	12
88	10	10
104	12	8
120	14	7

The conservative decision, under the circumstances described, will probably be to provide four 120' double track kilns. These will provide a holding capacity which is 17% greater than minimum requirements and thus allows some flexibility in operation and scheduling. The table above indicates that four 104's would provide the estimated required holding capacity but this arrangement would not allow for any flexibility other than that which has been carried along with the various estimates.

Heat Energy Required

The amount of heat energy which is required to dry a charge of lumber depends on the amount of water which must be removed from the charge; and the rate at which energy must be applied depends upon the kiln residence time.

Referring again to the example which has been carried along, a crib of lumber contains 563.9 cubic feet, or

(563.9 cuft) x (26.208 lb/cuft) = 14780 lb dry wood/crib.

The kiln which was selected holds 14 cribs per track or 28 cribs per charge. Therefore,

(14780 lb/crib) x (28 cribs/charge) = 413800 lb dry wood/charge.

An average of 71.1% change in moisture content is to be removed in the kiln. Therefore,

(.711) x 413800 = 294240 lb water removed/charge.

A well-constructed and engineered kiln should be capable of evaporating one pound of water with a total expenditure of 1800 BTU. Therefore, the removal of 294240 pounds of water will require

294240 x 1800 = 530,000,000 BTU

It must be emphasized that this quantity of heat energy is substantially independent of drying time--substantially the same amount of heat is required if the lumber is dried in 20 hours as in 200 hours.

If a schedule such as CRT which yields substantially constant drying rate is used the rate of heat application will be approximately constant. Therefore, provision for

526,000,000 BTU/ 38 hour = 13,800,000 BTU/hour

or approximately 15MM BTU per kiln hour is required. Thus a total of 60MM BTU/hour is needed for the four kilns.

If the schedule used yields falling rate drying staring at higher temperatures, much higher rate of energy usage must be provided to take care of the fast rate of drying and the heating up of the system during the early hours of the schedule. In this case substantially more than the average 60MM BTU/hour will be required during parts of the drying period.

It should be noted that the above calculations have no relation to the type of heating system which is used. A BTU is a BTU regardless of its source. However, if the kiln is steam heated an approximate rule of thumb which says that condensation of one pound of steam releases 1000 BTU of latent heat indicates that for the job described boiler capacity of 60000 pounds of steam per hour must be provided. Obviously if the required heating capacity is not available or cannot be provided the only recourse is to retreat to longer drying schedules.

The vendor sizes the kiln fans and the air circulation in terms of the quantity of air flow that will result in a reasonable dry bulb temperature drop across the load--that is, one that will allow the desired drying rate and at the same time require a wet bulb temperature depression which will neither subject the lumber to a ruinous equilibrium moisture content atmosphere nor require excessive quantities of dilution air.

The details of this highly important procedure would greatly over-expand the time allowed for this presentation. Hopefully, it may become the topic of a future paper before this group.

Testing the Kiln Operation

Once the kiln is installed and debugged it is ready for performance testing. By this time it is assumed that the materials and construction are suitable and according to specifications; that the vents operate properly; the baffles completely enclose the charges; the fans rotate in the right direction; and that all of the myriad of tormenting details which plague start-ups have been recognized and corrected.

The purpose of testing is to insure that the kiln provides specified conditions uniformly and that it does a uniform job of moisture removal. However, uniform kiln conditions and uniform drying cannot be obtained in any facility if uniform stacking of the lumber is not practiced. Therefore, for testing as well as for routine operation, care is taken that the cribs are stacked to the same heights; that the lumber in a crib is all of the same length; that there is no appreciable gap between the ends of the loads; that the baffles completely enclose the lumber; that the sticks are accurately placed; (if package loaded) there is sufficient space between the packages to insure that air may circulate freely across the crib; and that other details relating to kiln charging have been taken care of.

The philosophy which applies is that if identical raw materials are treated identically, identical products will result. It is desirable to produce as nearly uniform kiln dry lumber as possible. This cannot be completely achieved because the green lumber which is charged into the kiln is not completely uniform. And of course, if the processing conditions are not uniform, the finished product cannot be uniform. There is a great tendency in the industry to put the blame for non-uniform kiln-dry lumber entirely on the variations of raw materials when in reality the non-uniform conditions in the kiln, many of which are the result of careless stacking and baffling, are the culprits.

Air Flow Quantity and Uniformity: The quantity of air moving through the load of lumber in unit time is important because of its relation to the quantity of heat being delivered, the wet bulb temperature depression required for a given drying rate and the sizing of fans.

Two sets of information are required for the determination of delivered air quantity, namely: the cross-sectional area of the open spaces through the load and the mean air velocity.

The total slot area is simply the product of the area of a single slot and the number of slots. Slot thickness is determined by measuring several randomly chosen (one hundred is a reasonable number) slots midway between sticks on the leaving air side of the load. The values are averaged and the value expressed in terms of feet. Slot length is the effective value--total load length less the total width of the stickers. Thus if the charge on a track consists of 12 cribs each 8.25 feet in length (99.0 feet) with 5 1/2 sticks per crib (7.50 feet) the effective slot length is 91.5 feet. If the average slot width is 0.720 inches (0.060 feet) and there are 58 slots in the load, the cross-sectional area is

$$58 \times 0.06 \times 91.5 = 318.4 \text{ square feet}$$

The kiln operator knows from experience that the value of slot area calculated as described is an approximation at best because the assumptions are made that the boards are perfectly straight and that deviations in board thickness and other abnormalities have no effect on the effective slot area--in other words that every slot is a perfectly uniform rectangular duct across the entire load.

Note that in the typical double track kiln the same air goes through the lumber on both tracks in series so that the quantity of air being circulated is that calculated from a single track. However, if the kiln is of the type in which the air is pumped into the central plenum and thence flows outwardly through both tracks of lumber (parallel flow) the slot area of both tracks must be used--twice as much air is circulated as passes through a single track.

The most precise method of measuring air velocity is by means of a Pitot tube by means of which velocity pressure is read directly on a precision manometer (such as a Hooke gauge) which allows differences in height of the liquid in the two areas to be read to 0.001" or less. The equation

$$V = 1096 \, (P_v/P)^{1/2}$$

in which V is the air velocity expressed in feet per minute, P_v is the velocity pressure in inches of water and P is the density of the "air" at the temperature and humidity existing during measurement expressed in pounds per cubic foot.

Because of the care which must be used in the precise measurement of air velocity with the Pitot tube, other devices are generally used. Among these are hot wire meters, rotating cup or turning vane anemometers and others. Whatever instrument is used must be carefully and frequently calibrated, preferably in a good wind tunnel or against a standard instrument which is kept in calibration by frequent tests in a standard tunnel.

Measurements should be made on the leaving air sides of the loads. It is recommended that one vertical traverse in each slot in each crib should be taken. A convenient method of depicting the level and uniformity of air velocity is by means of a chart such as the one in Figure 1.

When the velocity data for each crib have been gathered, the average velocity may be calculated. Although there are no hard and fast specifications, many operators say that they consider that the spread of values is acceptable if two-thirds of the measured values are within $\pm$ 10% of the mean. For example, if the average of 500 readings is 600 feet per minute, 2/3 of the readings (333) should fall between 540 and 660 feet per minute. The mean and $\pm$ 10% lines are shown in Figure 1.

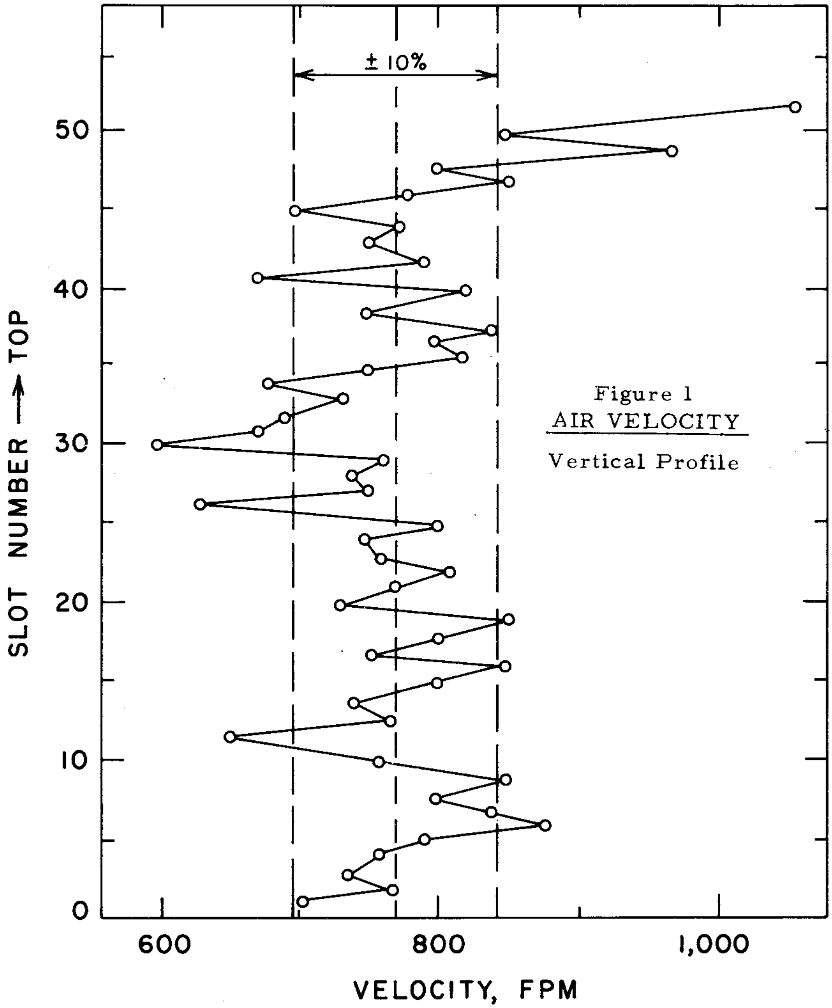
The uninitiated may be shocked with the variations in air velocity which are obtained. However, it must be remembered that the slots through which the air must travel are not aerodynamically designed ducts. There may be a gradient in velocity from top to bottom. The driving force which forces the air through the slots is a difference in static pressure between the entering and leaving air sides caused by the action of the fans. If the air is moving very fast in the plenums, the static pressure may be low and the result will be a low velocity through the load.

The velocities are expressed in feet per minute. When the average velocity is multiplied by the slot area in square feet the product is a rate of flow with units of cubic feet per minute (cfm).

Obviously, if the load is well baffled, the total rate of air flow should be the same through the loads on both tracks of a double track kiln. Frequently it is noted that this does not occur. Often there is more air flow measured through the second load than through the first. One reason for this highly unexpected phenomenon is that air moving through the first load may find that there is less resistance to flow vertically through cracks between boards than through the slots. So some of the air goes out through the top or bottom until it hits the baffles on the leaving air side of the load where it is forced back into the lumber pile to exit through the slots of the second load.

Temperature Level and Uniformity in Kiln: Most kilns have no more than four (and oftentimes fewer) dry bulb temperature sensors. So few recorded data cannot serve to describe the temperature profiles in a kiln. Furthermore, for some unexplained reason an important temperature value is not indicated or recorded--the dry bulb temperature on the leaving air sides of the loads. When this value is known:

a. the temperature drop across the load is known
b. whether or not drying can take place across the entire load is indicated
c. the rate of drying is calculatable when the air flow rate is known
d. the adequacy of the wet bulb temperature depression is immediately seen.


± 10%
Figure 1
AIR VELOCITY
Vertical Profile
SLOT NUMBER ⟶ TOP
0
10
20
30
40
50
600
800
1,000
VELOCITY, FPM

e. uniformity of energy application to the lumber can be deduced

f. performance of primary and secondary heaters is indicated

The only logical excuse for not obtaining this important bit of information is that the recorder-controller would require more pens and would therefore be somewhat more expensive. However, even leaving air side dry bulb temperature sensors would not provide the detailed profile data necessary for the identification of profiles.

The temperature performance analysis of a kiln therefore involves use of instrumentation which is not a part of regular kiln equipment. A typical set-up involves the installation of a minimum of twelve thermocouples on each side of the load on each track. Thermocouples are placed in groups of four with each group arranged along a vertical line. Thus, twelve couples can measure temperatures at four different heights at three different lengthwise positions. The couples in one plane are spaced longitudinally exactly as the couples in the other planes.

The readings may be taken by means of different types of equipment. The most sophisticated and also the most satisfactory is a multipoint recorder with switches which make possible the recording of as many temperatures as desired. If a multipoint recorder is not available a sensitive potentiometer which is calibrated in Fahrenheit temperature units or in millivolts (0 - 10 mv full scale). Readings should be taken at approximately hourly intervals throughout a full drying cycle. The data may then be analyzed in different ways to determine degree of temperature uniformity in different planes at different temperature levels.

Care must be taken to place all thermocouples in positions where they are not affected by bypass air or by dilution air.

A typical temperature analysis of a kiln is shown in Figure 2 a, b and c. Significant temperatures are shown as they existed at a particular time in a kiln that was being tested to find out the reason for non-uniform moisture contents in the dried lumber.

In Figure 2a, it is seen that the air from the primary heater enters load 1 at a quite uniform temperature of about 180° at this particular position lengthwise in the kiln. The air comes out of load 1 at a quite uniform 145°F level--a temperature drop across the load of 35°.

In Figure 2b, the spent air from load 1 is very unevenly heated by the booster coils. Most of the air is raised to the 190-200° level while one region about seven feet from the kiln floor is heated to only about 160°F and the air near the floor is heated only a small amount. When this air is passed through load 2 the temperature drops across the load were extremely variable, indicating non-uniform drying at different heights. In Figure 3 the effects of the primary and booster coils are shown.

These data pointed out problem areas. The lack of heating at the seven foot level was found to be due to the fact that there was a gap in the booster coil assembly which allowed air at that level to pass through without contacting coils. The inadequate heating near the bottom of the kiln was found to be due to a series of faulty coils which required replacement. The fact that the booster coil tended to heat the air to a higher temperature level than the primary heaters was noted and the recommendation made to modify the balance between primary and secondary heater assemblies.

Tests for temperature uniformity in a kiln are as important to the kiln operator in the maintenance of his kilns as they are for the vendor when he tests a new installation for performance.

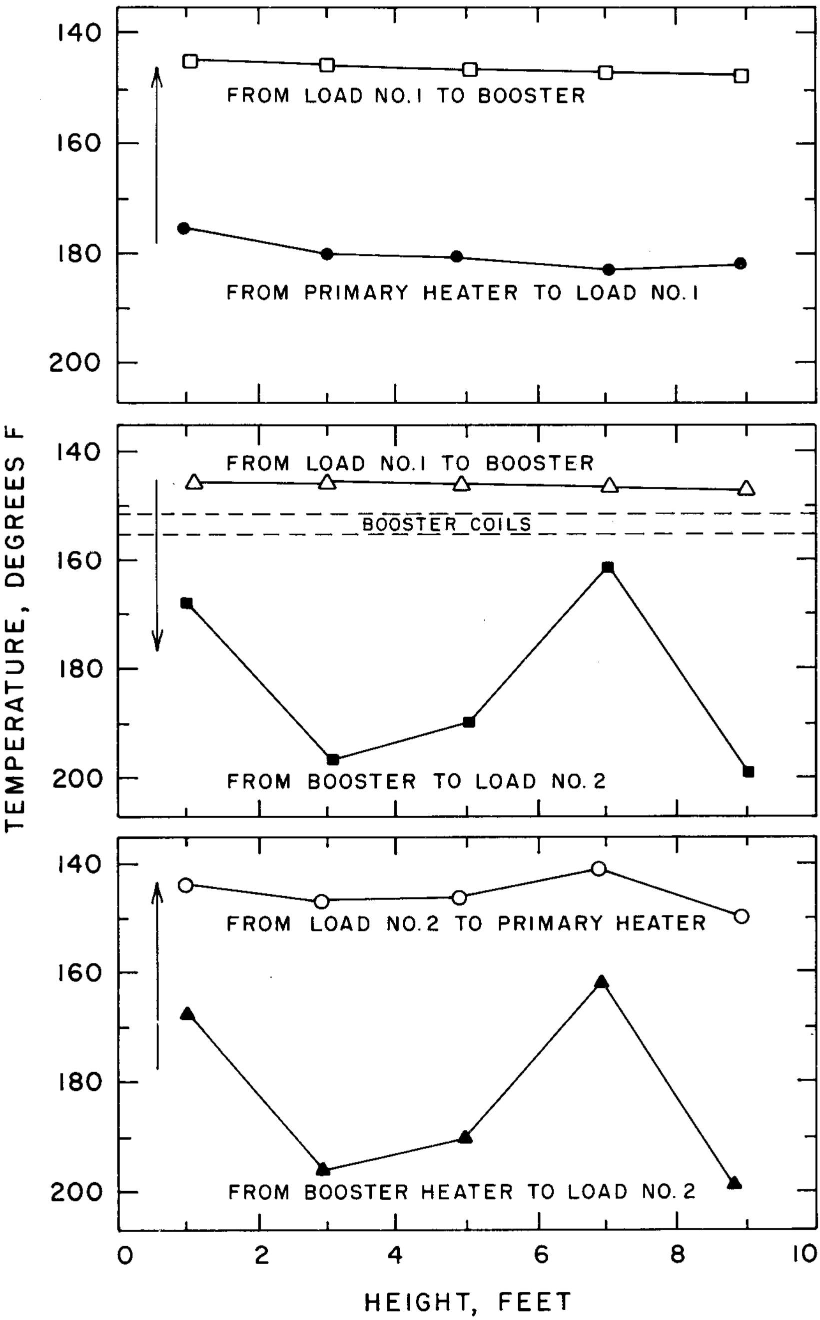
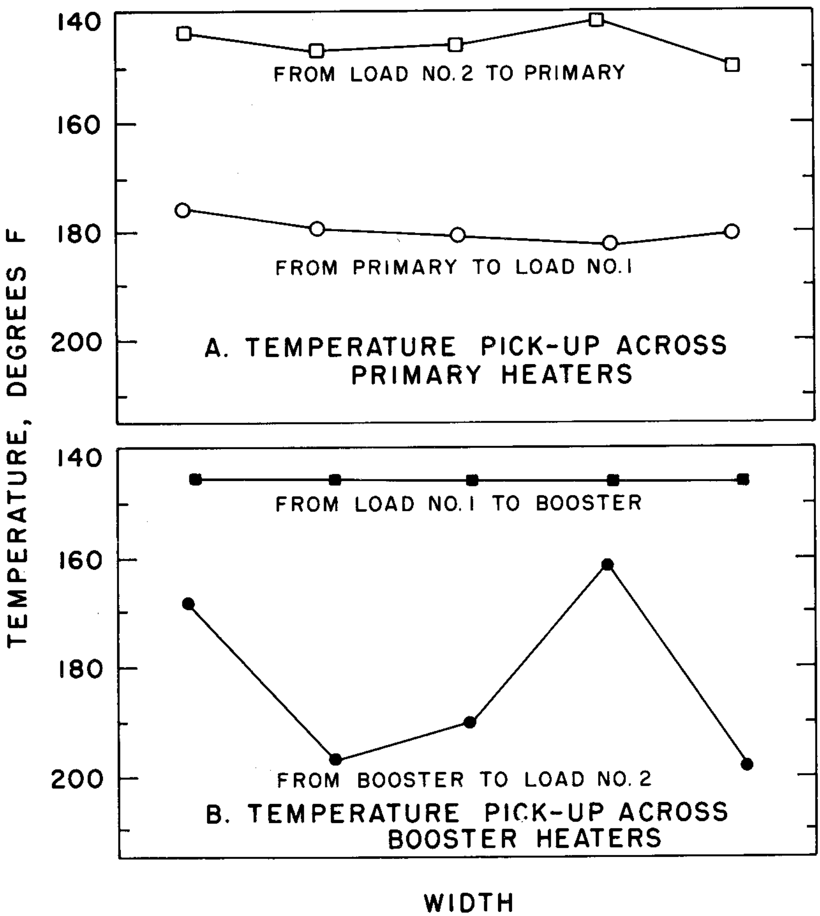


Figure 2(a)

Figure 2(b)

Figure 2(c)



TEMPERATURE, DEGREES F
140
160
180
200
FROM LOAD NO. 2 TO PRIMARY
FROM PRIMARY TO LOAD NO. 1
A. TEMPERATURE PICK-UP ACROSS PRIMARY HEATERS
140
160
180
200
FROM LOAD NO. 1 TO BOOSTER
FROM BOOSTER TO LOAD NO. 2
B. TEMPERATURE PICK-UP ACROSS BOOSTER HEATERS
WIDTH

Figure 3

Moisture Content Level and Distribution: The two basic objectives of kiln drying are (a) produce a product having specified moisture content; and (b) produce a product with maximum net product value (that is, the yield and grade distribution are maximum and processing costs are minimum).

Moisture content of kiln dried lumber is measured preferably at the time the cribs are unstacked but before surfacing so that any wet boards which are found may be redried without danger of producing scant dimensions. Measurements are made with the type of instrument which is approved by the grading association or inspection bureau related to the species. Most West Coast dimension lumber is metered by means of the so-called resistance or needle-probe meter.

Many mills use unstacker meters which operate on the capacitance principle but which are kept in calibration by comparison with the probe meters. The unstacker meters have obvious advantages of evaluating every board and of marking wet boards with minimum operator involvement.

Constant surveillance of the kiln-dry moisture content is of great economic importance to the mill. Wet boards in shipments often result in costly customer rejects. Lumber that is overdried will have lower grade and lower value. The loss is value of more than $1/Mbf for every percentage of moisture content below 17% has been demonstrated so many times that there is no question of its validity.

A most informative and effective manner of handling moisture content data is by means of a chart called a histogram. It consists simply of tallying the number of pieces in the population for each moisture content value. A typical histogram is shown in Figure 4. In this case it will be noted that the moisture content distribution is quite broad. Only 85.8% of the population is 15% or less--14.2% would be classed as "wet" since these data were randomly selected from an example with specifications of moisture content at a 15% maximum. Furthermore 24.2% of the specimens were dried to below 10%, leaving only 61.6% of the population in the desired 10-15% range.

However, a histogram does not tell the entire story of moisture content distribution. It may well serve the needs of marketing but it does not provide information concerning the uniformity of drying which takes place in a kiln. Wet boards will normally occur in a completely random distribution if the kiln is operating uniformly. Sometimes it will be found that the wet boards (or the over-dried boards) tend to be concentrated in certain regions of the kiln. This is a signal that causes are to be sought and corrective measures applied. Figure 5 shows the moisture distribution in an entire crib of kiln dry lumber obtained by metering seven boards in each course at the unstacker. Although the distribution is not extremely bad it definitely demonstrates some commonly encountered drying characteristics. The table illustrates trends:

	Top 1/3	Middle 1/3	Bottom 1/3
"Wets"	7	12	19
"Drys"	19	3	7

Note that almost two-thirds of the "drys" appear in the top 1/3 of the charge and the one-half of the "wets" are in the bottom 1/3 of the crib. Also note that almost three-fourths of the "drys" but only 3% of the "wets" are in the two left hand columns whereas 14% of the "drys" and 26% of the "wets" are in the corresponding two columns on the right. These numbers show that the charge is drying non-uniformly from top to bottom and from side to side. Probably because of too low wet bulb temperature depression, the drying is not taking place across the entire charge and the moisture removal is more effective when the air is travelling from left to right than in the opposite direction.

Figure 5 relates vertical and across-the-load non-uniformity of moisture content within a single crib. Another example of geographical non-uniformity is given in Figure 6 which shows the result of monitoring the moisture contents of an entire kiln charge of lumber and displaying the results crib-by-crib as they were placed in the kiln during drying. Note the large variation of moisture content lengthwise of the kiln and also across the booster coil. These data were taken from a kiln which was being considered for modification and were the basis for making drastic changes in the geometry of the kiln heating system.

There is no substitute for data and data collection is laborious and time consuming. Data analysis requires experience and acquaintance with kiln operation and drying mechanism. But they are critical to both the vendor and to the kiln operator.

Figure 4. Moisture Content Histogram

MC%	Number	No.	Cum.	%
4	x	4	4	0.3
5	xxxxxxx	35	39	3.0
6	xxxxxxxxx	46	85	6.4
7	xxxxxxxxxxxxxxxxx	85	170	12.9
8	xxxxxxxxxx	48	218	16.5
9	xxxxxxxxxxxxxxxxxxxx	101	319	24.2
10	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	186	505	38.3
11	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	156	661	50.1
12	xxxxxxxxxxxxxxxxxxxxxxx	115	776	58.8
13	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	150	926	70.2
14	xxxxxxxxxxxxxxxxxxxxx	105	1031	78.1
15	xxxxxxxxxxxxxxxxxxxx	101	1132	85.8
16	xxxxxxxxxxxx	58	1190	90.2
17	xxxxxxxx	41	1231	93.3
18	xxxx	18	1249	94.6
19	xxxx	19	1268	96.1
20	xx	8	1276	96.7
21	xx	12	1288	97.6
22	x	4	1292	97.9
23	x	3	1295	98.1
24	x	7	1302	98.6
25	xxxx	18	1320	100.0

Figure 5. Moisture Content

Slot	1	2	3	4	5	6	7	ave	
Top	9-	10	10	21+	11	11	9-	11.6	
2	10	14	25+	24+	25+	12	11	17.3	
3	10	11	14	14	16+	16+	14	13.6	
4	9-	9-	9-	14	14	12	12	11.4	
5	9-	7-	12	8-	11	13	14	10.6	
6	10	9-	8-	12	12	9-	12	10.3	
7	10	11	10	10	11	12	10	10.6	
8	7-	11	10	13	11	11	12	10.7	
9	10	10	12	9-	11	12	11	10.7	- dry
10	9-	10	10	10	10	12	12	10.4	+ wet
11	10	11	9-	13	11	13	14	11.6	
12	9-	8-	12	14	11	13	14	11.6	
13	9-	9-	10	12	13	12	11	10.6	
14	11	11	12	10	11	13	13	11.6	
15	11	15	15	14	14	15	13	13.9	
16	10	12	11	15	14	14	12	12.6	
17	6-	12	15	16+	14	14	14	13.0	
18	10	13	15	13	15	14	9-	12.7	
19	10	13	15	15	15	14	12	13.4	
20	10	10	12	15	17+	15	12	13.0	
21	11	10	13	15	14	15	12	12.9	
22	12	15	17+	12	15	11	13	13.6	
23	12	14	18+	15	13	12	13	13.9	
24	12	13	14	17+	16+	15	15	14.6	
25	10	13	20+	14	12	15	11	13.6	
26	11	11	16+	11	12	14	13	12.6	
27	9-	11	10	12	14	15	13	12.0	
28	11	10	15	11	14	12	14	12.4	
29	12	12	14	14	11	12	11	12.3	
30	11	9-	15	11	11	17+	13	12.4	
31	11	14	14	16+	14	15	13	13.9	
32	10	11	15	16+	15	10	13	12.9	
33	12	13	11	13	16+	14	15	13.4	
34	10	10	12	12	13	15	12	12.0	
35	9-	11	13	15	12	12	13	12.1	
36	11	15	14	14	15	16+	14	14.1	
37	10	15	17+	12	12	11	15	13.1	
38	13	15	15	16+	13	18+	15	15.0	
39	10	15	16+	15	15	16+	13	14.3	
40	11	13	12	15	17+	16+	14	14.0	
41	9-	12	16+	18+	15	14	14	14.0	
42	9-	13	13	15	14	14	14	13.1	
43	9-	11	13	15	14	16+	14	13.1	
44	12	13	14	15	13	15	13	13.1	
45	13	12	12	14	16+	15	12	13.4	
46	7-	14	14	15	10	17+	10	12.4	
47	10	12	11	16+	11	15	15	12.9	
48	9-	15	14	14	14	18+	10	12.9	
49	12	10	12	11	13	14	12	12.0	
50	11	12	12	13	15	16+	8-	12.4	
51	14	10	13	12	10	13	9-	11.6	
52	11	12	10	11	15	10	11	11.4	
53	11	14	10	25+	21+	14	14	15.6	
54	15	16+	11	9-	17+	13	13	13.4	
	10.4%	11.9%	13.2%	13.9%	13.7%	13.7%	12.7%		

MEAN CRIB MOISTURE CONTENTS

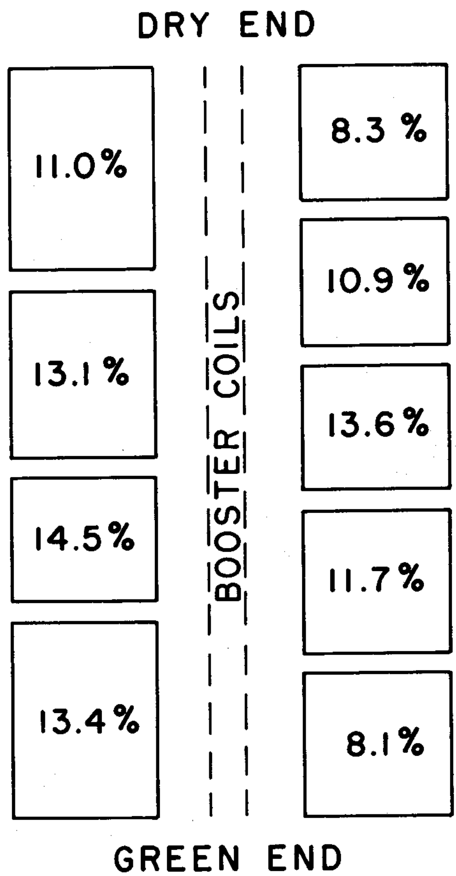


Figure 6