ENERGY CONSUMPTION IN LUMBER DRYING OPERATIONS

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The drying of lumber is known to be the most energy intensive process in the sawmilling industry (Comstock, 1976). The total amount consumed depends on a number of factors which may be generally placed in two major groups; those affecting consumption of energy by the material being dried and those affecting consumption by external components. Material influences include species density, initial and final moisture contents, and actual drying schedule used. External influences include kiln size, kiln type, building materials, environmental conditions, and type of heating, air circulation, venting, and control systems.

The overall objective of this paper is to provide some insight into the critical factors affecting kiln energy demand. The information used in this discussion was derived from a kiln energy computerized program located at the University of Washington. It was developed during a tenure at the Centre Technique du Bois, Paris, France in 1977. This type of program will allow a single variable to be examined while all others are held constant. Another computerized program also exists at the University of California Products Laboratory (Gorvad and Arganbright, 1983) based on work done by Shottafer and Shuler (1974). It is the purpose of both of these programs to provide a better understanding to these influences so that energy consumption may be maintained at a minimum.

An infinite number of situations can exist for lumber drying operations, therefore an initial base case will be set up and changes from this base case analyzed. The material assumed is 8/4 clear coastal Douglas-fir with an initial moisture content of 65 percent (ovendry basis) dried to a final moisture content of 15 percent (ovendry basis). It has an average specific gravity (green weight, ovendry volume) of .45. The drying schedule, listed in Kiln-drying Western Softwoods by E. Knight (1970), has a 6.5 day drying time including equalization, with a temperature range of 170 to 180 degrees Fahrenheit. Wet bulb depressions range from 5 to 50 degrees Fahrenheit and have a weighted average relative humidity of 57 percent.

The kiln is double track with aluminum panel construction on a concrete slab. Venting losses average 5 percent; i.e. excess air over that theoretically required. Assuming a majority of the humidity needed to humidify incoming air will be supplied by moisture evaporated from the lumber, only 5 percent humidity supplied by steam spray was assumed. The actual amount used will certainly affect the total energy values as will be discussed. Three kiln sizes are compared; 65 MBF, 100 MBF and 170 MBF, all in nominal footages.

The power plant consists of a hog fuel boiler operated at 40 percent excess air and a 350 degree Fahrenheit stack temperature. The hog fuel used has a higher heating value of 8000 Btu per pound with a moisture content of 100 percent (ovendry basis). Boiler and kiln heat transfer efficiency combined are assumed to be 65 percent. Therefore only 1925 Btu's per pound of fuel input are realized for heat delivered to the kiln system.

The environmental conditions surrounding the kiln are assumed to be 36 degrees Fahrenheit ambient temperature and 72 percent relative humidity.

When analyzing energy systems the exact amount of ovendry wood and water need to be known. It can become confusing when nominal values are used for board footage values, therefore, for calculations used in this paper actual values are assumed to be 65 percent of nominal values. Therefore, even though the first column of the tables give footage in nominal values, all calculations have been done using actual values. This is indicated in Table 1.

Tables 1 and 2 contain results for the base case kiln operation as described above. As can be seen, energy requirements vary with kiln size, the smaller kilns requiring more energy per MBF. This will be discussed more fully when discussing Table 2.

Column 2 of Table 1 contains the intrinsic energy required. Since this is the amount of energy required for heating only the wood and water and evaporating the water which is removed, kiln size will not affect it. It also means that approximately 1.4 million Btu's is "fixed" for this case and nothing can be done to the drying system to reduce it. It is affected, however, by density and moisture content as will be discussed later.

The warm-up energy requirements, given in column 2, are important for examining boiler requirements. The values presented are for total heat required to increase the kiln temperature from an ambient temperature of 35 degrees Fahrenheit to the initial schedule temperature, 170 degrees Fahrenheit. This value will change with changes in relative humidity, ambient temperature of the outside air and lumber, temperature of kiln components prior to the start of a charge, and lumber moisture content. Heat requirements on the boiler are the highest during this period than any other time during drying, therefore knowledge of warm-up time desired, warm-up temperature, ambient temperature, moisture content, and number of kilns starting up at the same time must be known to size the boiler correctly for a drying operation.

The values for average energy required per hour per MBF are contained in column 4 of Table 1. These average energy values will vary with differing kiln schedules, drying time, ambient temperature, relative humidities, moisture content, density, kiln structural components and humidification requirements. These values do not include warm-up energy required, therefore, once the kiln has been heated it will need an average of 14,600 to 15,400 Btu's per hour from the boiler to dry this material for this operation.

The total heat requirements for this operation given in column 5 is from 2.6 to 2.75 million Btu's per MBF depending on kiln size. The affects on these values caused by changing variables are shown in Table 3. These will be discussed later.

One method of comparing energy efficiencies for differing drying operations and proposed drying systems is to compare the energy required per pound of water evaporated. These values, given in column 6, range from 2224 Btu's per pound of water to 2330 per pound depending on kiln size. In this example, the 65 MBF kiln is approximately 5 percent less efficient than the 170 MBF kiln. It is expected, however, that lower efficiencies than presented actually exist due to leaks around kiln doors, vents and faulty steam valves. It should be possible though to increase the efficiency over that presented here by better insulation of the structure, especially the kiln floors.

The last column in Table 1 presents the total wood fuel requirement in pounds of fueld per MBF. This range of 1363 to 1428 pounds will not only vary with the variables mentioned above, but also with numerous wood fuel and boiler operating variables. It is beyond the scope of this paper to discuss the boiler variables but their values are presented here simply to provide a feeling for quantity requirements.

Table 2 contains energy requirements for each kiln size broken down by type of consumption. As can be seen, the intrinsic energy consumes over 50 percent, followed by heat loss through the structure (26 to 30 percent), heating all incoming air and vapor and increasing the humidity (18-20 percent), and finally heating all kiln components inside the kiln (less than 1 percent).

The basis for differences due to kiln size can also be analyzed using values in Table 2. As shown only 1) the energy required to heat the kiln components and 2) the energy lost through the kiln structure change with respect to kiln size. The intrinsic energy would not since these values are on a per unit volume basis. The energy required to heat and humidify the incoming air and water vapor also would not change for the same reason, i.e. the air and humidity requirement is based directly on the amount of water removed which is constant per MBF. (Actual differences may exist, but would be so slight that differences in values presented would not be significant.)

Differences in energy consumption for differing kiln sizes can therefore be attributed to the greater percentage of kiln components or weight per MBF which need to be heated up and to the greater surface areas present on a per unit lumber volume basis as kiln sizes decrease. The latter is obviously the more important due to its much higher percentage of the total energy consumed.

The overall affects of kiln size may be more clearly seen by comparing annual fuel intake for a 10 million board foot drying operation drying this material. A 65 MBF kiln would require $2.749 * 10^{10}$ Btu's per 10 MMBF whereas a 170 MBF kiln would require $2.624 * 10^{10}$ Btu's per MMBF per year. This is a difference of $1.249 * 10^{9}$ Btu's per year. If a conservative steam cost of $3.00 per million Btu's is assumed, a difference of $3748 per year per 10 million board feet is realized. Be careful though, this is assuming full kiln capacities. If charges are not full, cost figures would increase more rapidly for the larger kiln sizes since wood and air values per MBF do not change. Therefore, installing a larger kiln just because it is more energy efficient and not having the lumber production to keep it full would very quickly defeat the purpose.

Table 3 contains factors which indicate how changes in major material and operation variables affect energy consumption in a kiln. These values were determined only for the 65 MBF kiln to facilitate this discussion. Since these are based on the base case outlined, some of the system variables may be different when other bases are examined, however, the relative magnitudes should remain similar.

The values contained in Table 3 were derived by dividing the value after the indicated change in column 2 by the original value. The values, therefore are multiples of the base case. A 1.00 indicates no change took place, hence no influence, values greater than 1.00 indicate increases in energy consumption.

Some of the changes suggested in this table appear to be drastic, and they may be for the same species from the same area. However, if a global view is taken to include various species and different drying operations, then these changes are more realistic and variables can be better compared for importance.

The material variables have the greatest influence as seen by changes caused by different initial moisture content and density values. As each is doubled independently, total energy requirements increase by a factor of 1.82 and 1.61, respectively. This is primarily due to their effects on the intrinsic energy comprising more than 50 percent of the energy consumed and to the energy required to heat and humidify all air and vapor. The final moisture content also influences total energy consumption for the same reason. It's factor is not as large here as initial moisture content and density since only a 4 percent change is being examined, but a 5 percent difference is not insignificant.

These material influences again point out how important drying segregations are. Not much can normally be done about density variations as long as species segregations are made, but segregations can be made for widely varying moisture contents. Energy can be conserved here in one way by minimizing over drying. A number of mills with target moisture contents of 19 percent dry to an average of 10-12 percent moisture content to have 95 percent of the material less than or equal to 19 percent. As seen by increasing the final moisture content only 4 percent, from 15 percent to 19 percent, an energy savings of 5 percent can be realized. This amounts to a savings of $4124 per year per 10 MMBF in a 65 MBF kiln.

Energy consumption will also be minimized by keeping drying times to a minimum, the next most important variable. When drying time is doubled 1.3 times more energy is consumed, keeping everything else constant. This is attributable to its influence on structural losses, which are linear to changes in time. Moisture content segregations and thickness uniformity will help keep this influence to a minimum.

Kiln construction is obviously important in keeping structure losses to a minimum. Since structural losses comprise 25 percent to 30 percent of total energy consumed, thermal conductivity values for materials used should be maintained. As shown, energy consumption increases 1.17 times as flow of heat through the structure doubles. This could easily occur from wet insulation of leaks around vents, doors and through cracks in the structure.

Changes in ambient temperature influence each type of consumption. The greatest is on structural losses and warm-up requirements followed by heating and humidifying incoming air. An increase in ambient temperature from 35 to 68 degrees Fahrenheit reduces the total energy requirements to 88 percent of the original result. This indicates how drastically seasons of the year affect steam consumption. Changes in outside relative humidity by 50 percent altered the total outcome less than .5 percent.

Steam spray used to humidify incoming air increases the total energy requirements by a factor of 1.11 times when 25 percent of the incoming air is humidified instead of only 5 percent. This analysis does not include conditioning which would be expected to increase the effects of this variable even more significantly. Excess air shows the least affect for the range analyzed.

In conclusion, the energy consumed during the drying of lumber is very significant, but its total consumption can be minimized by good operating procedures. The material variables proved to be the most important variables. These should be carefully controlled through good segregation practices for species and moisture content and by keeping thickness variation to a minimum.

Good maintenance practices are the best solutions to keeping external influences to a minimum. Expense incurred by heat losses through a faulty structure far outweigh that incurred by a good regular maintenance program. The costs of poor maintenance have been shown to be exorbitant for just increased wear and tear on equipment. Increased energy costs should always be included on that list.

REFERENCES

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Table 1. Energy Consumption Results for The Base Case

Kiln Size[1]	Intrinsic Energy[2]	Warm-up Heat[2]	Average Heat per Hour[2]	Total Energy[2]	Total Heat per LB Water Removed[2]	Wood Fuel[2]
(MBF)	(Btu/MBF)	(Btu/MBF)	(Btu/MBF-HR)	(Btu/MBF)	(Btu/LB)	(LBS/MBF)
65	1408256	350854	15375	2749145	2330	1428
100	1408256	348039	15137	2709329	2296	1407
170	1408256	344064	14617	2624209	2224	1363

[1] Nominal Board Footage

[2] Actual Board Footage

Nominal (MBF)	Actual (MBF)
65	42
100	65
170	110

Table 2. Energy Requirements by Type of Consumption - Base Case

Kiln Size	Intrinsic Energy		Heat Kiln Components		Structural Losses		Heat & Humidify Air & Vapor	
(MBF)	(Btu/MBF)	(%)	(Btu/MBF)	(%)	(Btu/MBF)	(%)	(Btu/MBF)	(%)
65	1408256	51.2	14644	0.5	815419	29.7	510826	18.6
100	1408256	52.0	12674	0.5	777573	28.7	510826	18.9
170	1408256	53.7	10811	0.4	694316	26.5	510826	19.5

Table 3. Influences on Energy Consumption from Changes in Major Variables

Variable	Change	Warm-up Requirements	Intrinsic Energy	Structural Losses	Heat and Humidify Air and Vapor	Total Energy
Material						
Initial MC	Double	1.59	2.13	1.00	2.30	1.82
Density	Double	1.86	2.00	1.00	2.00	1.61
Final MC	15%-19%	1.00	.93	1.00	.92	.95
External						
Drying Time	Double	1.00	1.00	2.00	1.00	1.30
K Values	Double	1.01	1.00	2.00	1.00	1.17
Ambient Temp	36-68	.76	.97	.77	.80	.88
Steam Sprey	.05-.25	1.002	1.00	1.00	1.61	1.11
Excess Air	.05-.25	1.00	1.00	1.00	1.19	1.04