STEAM AND ELECTRICAL CONSUMPTION IN A COMMERCIAL SCALE LUMBER DRY KILN

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INTRODUCTION

Kiln drying of lumber is the most energy intensive phase of the lumber manufacturing operation. It has been estimated that 60-70% of the energy used to manufacture lumber is used in the drying process (Comstock, 1975). During the 1970s and early 1980s the cost for that energy soared, and while energy costs have recently fallen, continued increases can be expected in the coming years. The trend in the lumber industry toward cogeneration of electric power further increases the potential value of energy the industry consumes.

While energy is a major cost component of the drying operation, until recently little information on the actual energy consumption of commercial dry kilns has been available. The trend toward computer based kiln control systems should make this type of information more readily available in the future. Currently, some kiln instrumentation vendors are making energy quantification part of their control systems.

Historically three methods have been used to quantify energy consumption. These include the use of theoretical models, the measurement of energy consumption on laboratory kilns and the measurement of energy consumption on full sized commercial kilns.

Theoretical methods for calculating energy consumption are essential for engineering kilns and boilers. Their accuracy is limited by the accuracy with which vent losses and heat transfer coefficients for structure components can be estimated. While heat transfer coefficients for large homogeneous components can be accurately determined, losses near joints, doors and other openings are difficult to determine and can be significant (Laytner and Arganbright, 1984). Excess venting losses can range from 5 to 25%.

Measurement of energy consumption using laboratory kilns has limited value due to the scale effect on transmission heat losses. Rosen (1980) has calculated that when all factors, including details of kiln design, were kept constant, and only kiln size was varied, energy consumption for drying southern pine varied from 1600 BTU/pound of water evaporated in a 100 thousand board feet (MBF) kiln to 18,000 BTU/pound of water evaporated in a 10 board foot kiln.

The measurement of energy consumption on full sized commercial kilns, while most representative of real world conditions, also has limitations, as it may be difficult to apply results obtained from one kiln to another kiln. Factors that can greatly influence such measured data include the kiln's construction, the integrity of the structure with regard to its ability to seal against air and heat losses and migration of moisture into the structural components, the status of kiln maintenance, ambient environmental conditions, and green and final moisture content of the lumber being dried.

PREVIOUS WORK

The data that has been published on energy consumption in commercial scale kilns is summarized in Table 1. Data which applies to work done on laboratory kilns is not included in the table, but is reviewed in an earlier article (Breiner, et al., 1984).

OBJECTIVES

The primary objective of this study was to measure, using multiple replications, the energy required to kiln dry commercial California softwood species. Secondary objectives included:

1. To determine the variability in energy requirements.
2. To compare commercial California softwood species with respect to the energy required in kiln drying.
3. To determine how heat and humidification requirements vary during various stages of the drying schedule.
4. To determine how energy requirements vary with seasonal changes in environmental conditions.
5. To determine if the total energy requirement for air circulation and electrical power demand varies in response to changes air density (measured by dry bulb temperature and humidity conditions).

MATERIALS AND EQUIPMENT

A 50 MBF, 88 foot long, single track steam heated kiln was instrumented so that energy consumption could be measured by a microcomputer based data acquisition system. The kiln was the eighteenth kiln in a bank of 34 masonry kilns. The circulation system was a line shaft type driven by a 40 horsepower motor. The kiln had both pneumatic instrument controlled vents and manual vents that were used only when drying sugar pine. The kiln was located at a mill in the Sierra foothills southeast of Sacramento, California.

A Rockwell AIM-65 microcomputer was expanded to serve as a data acquisition computer. Data on energy consumption and related parameters were logged on a continuous basis, and automatically transferred daily over phone lines to a computer at the University of California Forest Products Laboratory for storage and subsequent analysis. Instrumentation for energy monitoring included vortex shedding flow meters and pressure transducers on both the heat and spray steam supply lines, and watt and current transducers for monitoring electrical consumption. In addition, temperatures and humidity both inside and outside the kiln, and control action of the pneumatic controller were monitored. The computer, instrumentation, and software was described in detail in an earlier article (Breiner, et al., 1984).

The species dried during this study were Douglas-fir, white fir, ponderosa pine, and sugar pine.

RESULTS AND DISCUSSION

Total energy consumption is presented in Tables 2 through 5 for charges of Douglas-fir, white fir, ponderosa pine, and sugar pine, respectively. Generally, energy consumption in the kiln monitored appeared to be higher than would be expected based on data reported in the literature.

Total energy consumption for Douglas-fir was over twice that measured by Davis (1954), while that for ponderosa pine was 31% greater than that reported in the literature (Anon., 1956). While no data is available in the literature on energy consumption for drying white fir, data is available for Western Hemlock, a species that is very similar to white fir. Total energy consumption for drying white fir was 38% higher than that reported by Davis (1954) for western hemlock clears.

Average energy consumption for heating for drying Douglas-fir, white fir, ponderosa fine, and sugar pine was 2.5, 4.5, 5.0, and 6.3 million BTU per thousand board feet (MMBTU/MBF) respectively. Humidity control required 1.2, 1.4, 1.2 and 0.1 MMBTU/MBF respectively. It should be noted that steam used for humidity control, while necessary for controlling degrade, contributes virtually no energy to the removal of water from the lumber. Conditioning required an additional 0.6, 0.7, 0.7, 0.4 MMBTU/MBF respectively.

Energy consumption for the two Douglas-fir charges is given in Table 2. Total steam energy for the two charges differed by 48%. The reason for this difference could not be determined. Average total steam energy consumption was 4.3 MMBTU/MBF. Of this, 58% was used for heating, 28% for humidity control and 14% for conditioning.

Energy consumption for white fir is given in Table 3. Drying time for each of the three charge was approximately six and one-half days. To dry each of two charges of 6/4 dimension, 6.0 MMBTU/MBF was required. The charge of 6/4 common required 28% more steam energy than did the 6/4 dimension. The average total steam consumption for the three charges was 6.6 MMBTU/MBF. This total can be broken down into 68% for heating, 21% for humidity control, and 11% for conditioning.

Energy consumption for nine charges of ponderosa pine is given in Table 4. Average total steam energy consumption was 6.9 MMBTU/MBF, of which 73% was used for heating, 17% for humidity control and 10% for conditioning. Generally, charges of shop or shop and select required more energy than those of common lumber. While charges of common lumber required an average of 6.4 million BTU/MBF, those of shop and shop and select required 7.6 million BTU/MBF. The difference can be explained by the fact that shop and select lumber tends to contain more clear material and therefore more sapwood, while common lumber is generally knotty and therefore tends to have a higher percentage of heartwood.

The six charges of sugar pine, for which energy consumption is given in Table 5, required very little of the steam energy for humidity control or conditioning. An average of 6.8 MMBTU/MBF was required, of which 92% was used for heating, 2% for humidity control and 6% for conditioning. Energy consumption varied widely between the six charges and ranged from 4.9 to 9.6 million BTU per MBF. The wide range is partially due to differences in ambient temperatures, which were low in December and January when data for sugar pine charges with high energy consumption were collected. The sugar pine was dried with the all vent open (including the manual ones if available) during the first one-half to two-thirds of the schedule in order to suppress the wet bulb temperature and consequently control brown stain. This practice can lead to high energy consumption, particularly when the ambient temperature is low.

As noted, overall energy consumption for both drying and conditioning varied significantly between charges. This variability was thought to be due to one or more of the factors listed below.

1. Differences between schedules used for different grades and thicknesses.
2. Differences in drying time.
3. Effect of seasonal changes in ambient environmental conditions on transmission heat losses and the temperature of incoming vent air.
4. Possible variation in initial moisture content (this parameter was not monitored).
5. Variation in drying time due to periodic lack of sufficient steam supply with the resultant extension of drying times.

Cumulative energy consumption for typical charges of Douglas-fir, white fir, ponderosa pine and sugar pine are shown in Figures 1 through 4, respectively. All figures showed that, in the early stages of drying, heat was required at a constant rate. Steam for humidity control generally was not required until at least half way through the schedule, except perhaps for a short period during start up. In the case of sugar pine, a species that is permeable and has a high initial moisture content, the spray was rarely used until the conditioning period.

Figure 4 also illustrates a pattern observed in several of the sugar pine charges. The heat demand rate (heat demand/unit time) was steady for several days and then dropped to a lower, constant demand rate. With all four species a pattern was observed where heat demand was almost constant for several days and then at some identifiable point began to fall off. What was unique in some of the sugar pine charges, however, was how abrupt the change in heat demand was. Heat demand for the charge illustrated was virtually constant at .036 MMBTU/hr for the first 3 days of drying and then fell to .008 MMBTU/hr for the remainder of the schedule. It appeared that this change was due to the partial closing of the manual vents. As previously noted, the manual vents were opened during the early and middle stages of the schedule to maximize the wet bulb depression in order to minimize the occurrence of brown stain.

Cumulative electrical consumption is also illustrated in Figures 1 through 4. In all cases, electrical consumption remained steady irrespective of dry bulb and wet bulb temperatures and averaged .088 MMBTU/hour (26 kilowatts-hours/hour[1]). Electrical energy for air circulation represented 3.4% to 9.8% of the total energy (steam and electrical) required to dry a charge, and averaged 6.9% of the total energy for the twenty charges monitored. Average total electrical consumption for the 20 charges monitored was 16.6 MMBTU (4860 kilowatt-hours) per charge. While electricity only represented 6.9% of the total energy consumed, it must be noted that electrical energy costs two to three times as much as energy generated from gas or oil. As a result, with respect to cost, electrical energy represents 14%-21% of the total energy cost. This suggests that significant savings would be realized if energy for air circulation were reduced. One method for realizing such reductions is slowing fans down during the middle and later stages of the schedule. Fan speed reduction has reduced electrical consumption 40-50% (Anon., 1986).

SUMMARY

Heat and electrical consumption for twenty charges of California softwood was measured. Values for heat consumption were higher than would be suggested by previous studies, and varied significantly between charges. Total steam energy for heating, humidity control, and conditioning was 4.3, 6.6, 6.9 and 6.8 for Douglas-fir, white fir, ponderosa pine and sugar pine, respectively. Six to fourteen percent of the energy used to dry the charges monitored was used for conditioning.

Generally, in the first half of the schedule, no steam was required for humidity control. Except for sugar pine, during the second half of the schedule significant amounts of steam were required for humidity control. In the case of sugar pine virtually no steam was required for humidity control except during conditioning.

Energy consumption during winter months was higher than during other seasons. Due to the limited number of replications, however, the extent of the effect of season, i.e., ambient temperature, could not be determined.

Electrical consumption for air circulation was constant, irrespective of kiln temperature or humidity and represented 6.9% of the total energy consumption.

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[1] One kilowatt-hour = 3409.52 BTU.

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Table 1. Estimates[1] of energy required to kiln dry softwood lumber

Source of Data	Specie/Grade	MMBTU/ MBF	BTU/Lb. Water Evaporated	Lbs. Steam/MBF	Lbs. Steam/Lb. Water Evaporated
Davis (1954)	Douglas-fir Clears	----	----	2064	2.58
Davis (1954)	Douglas-fir Commons	----	----	1254	2.44
Comstock (1975)	Douglas-fir	1.2-1.8	2600-3000	----	----
Schotter & Schuler (1974)	Eastern White Pine	4.24	2122	----	----
Anon. (1956)	Longleaf Pine	----	----	4000-5500	2.0-2.75
Anon. (1956)	Ponderosa Pine	----	----	3600-5000	2.0-2.75
Kininmonth (1980)	Radiata Pine	3.2-3.7	----	----	----
Anon. (1956)	Shortleaf Pine	----	----	5100-7000	2.0-2.75
Comstock (1975)	Southern Yellow Pine	3.0-4.0	1600-2200	----	----
Taylor (1979)	Southern Pine	----	1602-2062	----	----
Davis (1954)	Western Hemlock Clears	----	----	5025	2.59
Davis (1954)	Western Hemlock Commons	----	----	4353	2.55

[1]Does not include data derived for small-scale laboratory kilns.

Table 2. Energy consumption for Douglas-fir charges

Month	Approximate Running Time (days)	Thickness and Grade	Footage (MBF)	Energy Consumption per MBF				
				Heating (MMBTU)	Drying Humidity (MMBTU)	Conditioning Humidity (MMBTU)	Total Steam (MMBTU)	Electrical (MMBTU)
Sept.	6.3	5/4 Shop	42.8	2.0	1.1	0.4	3.5	0.3
Sept.	5.7	5/4 Shop	46.1	3.0	1.3	0.8	5.2	0.3
			Average	**2.5** (58%)	**1.2** (28%)	**0.6** (14%)	**4.3**	**0.3**

Table 3. Energy consumption for white fir charges

Month	Approximate Running Time (days)	Thickness and Grade	Footage (MBF)	Energy Consumption per MBF				
				Heating (MMBTU)	Drying Humidity (MMBTU)	Conditioning Humidity (MMBTU)	Total Steam (MMBTU)	Electrical (MMBTU
Dec.	6.4	6/4 Dimension	48.2	4.2	1.3	0.5	6.0	0.3
July	6.7	6/4 Dimension	52.8	3.6	1.6	0.8	6.0	0.2
Dec.	6.5	6/4 Commons	50.2	5.7	1.2	0.8	7.7	0.3
			Average	**4.5** (68%)	**1.4** (21%)	**0.7** (10%)	**6.6**	**0.3**

Table 4. Energy consumption for ponderosa pine charges

Month	Approximate Running Time (days)	Thickness and Grade	Footage (MBF)	Energy Consumption per MBF: Heating (MMBTU)	Drying Humidity (MMBTU)	Conditioning Humidity (MMBTU)	Total Steam (MMBTU)	Electrical (KWH)
Dec.	7.7	5/4 Shops and Selects	43.8	5.8	1.6	0.7	8.1	0.4
Jan.	5.9	5/4 Shop	45.6	6.1	1.0	0.8	7.9	0.3
May	7.6	5/4 Commons	41.9	6.9	1.9	0.9	9.7	0.4
Jan.	7.0	6/4 Shops and Selects	47.4	5.3	1.2	0.5	7.0	0.3
Nov.	6.8	6/4 Shop	51.5	6.2	0.9	0.6	7.7	0.3
Jan.	6.5	6/4 Commons	51.9	4.0	1.0	0.5	5.5	0.3
July	5.9	6/4 Commons	51.7	3.6	1.0	0.8	5.4	0.2
Sept.	5.3	6/4 Commons	48.9	4.4	0.4	0.8	5.6	0.2
Aug.	10.2	10/4 Commons	55.2	3.1	2.2	0.6	5.9	0.4
			Average	**5.0** (73%)	**1.2** (17%)	**0.7** (10%)	**6.9**	**0.3**

Table 5. Energy consumption for sugar pine charges

				Energy Consumption per MBF				
Month	Approximate Running Time (days)	Thickness and Grade	Footage (MBF)	Heating (MMBTU)	Drying Humidity (MMBTU)	Conditioning Humidity (MMBTU)	Total Steam (MMBTU)	Electrical (MMBTU)
Nov.	6.3	4/4 Commons	47.3	5.1	0.0	0.3	5.4	0.3
Dec.	4.7	4/4 Commons	44.0	5.8	0.0	0.2	6.0	0.2
Dec.	9.5	5/4 Shop	44.4	7.9	0.0	0.8	8.8	0.5
Jan.	10.8	6/4 Commons	46.4	9.6	0.0	0.0	9.6	0.5
Oct.	14.9	8/4 Commons	52.1	4.8	0.2	0.6	5.6	0.6
Oct.	15.0	8/4 Commons	55.7	4.3	0.1	0.5	4.9	0.5
			Average	**6.3** (92%)	**0.1** (2%)	**0.4** (6%)	**6.8**	**0.4**

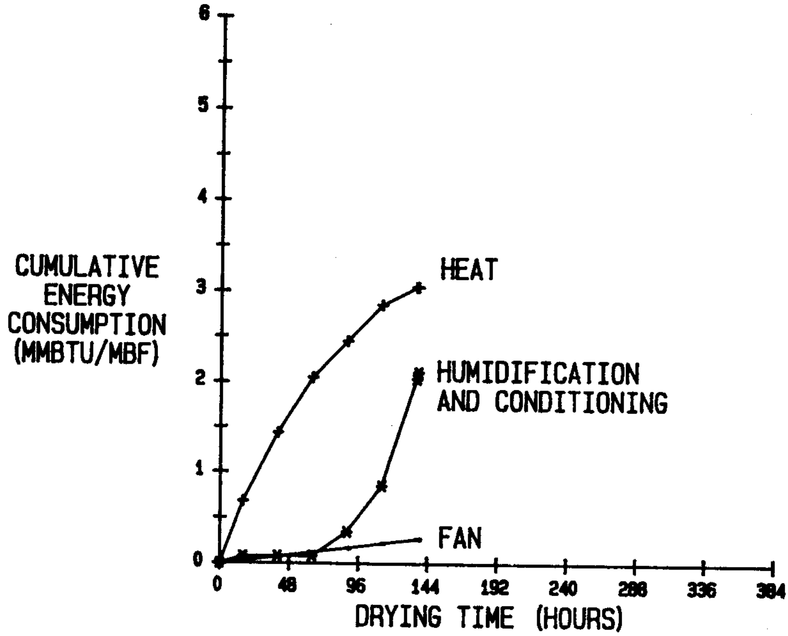

Figure 1. Energy consumption for 5/4 Douglas-fir

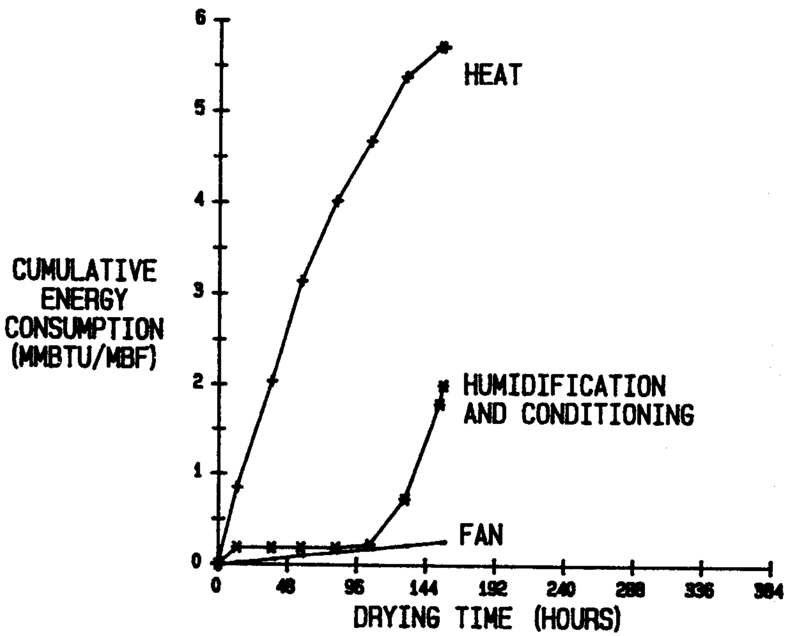

Figure 2. Energy consumption for 6/4 white fir commons

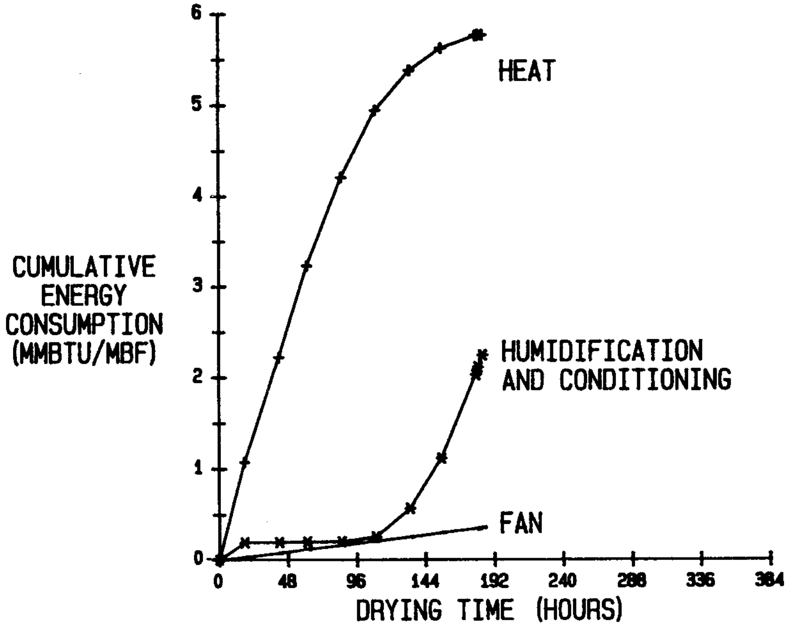

Figure 3. Energy consumption for 5/4 ponderosa pine shop and selects

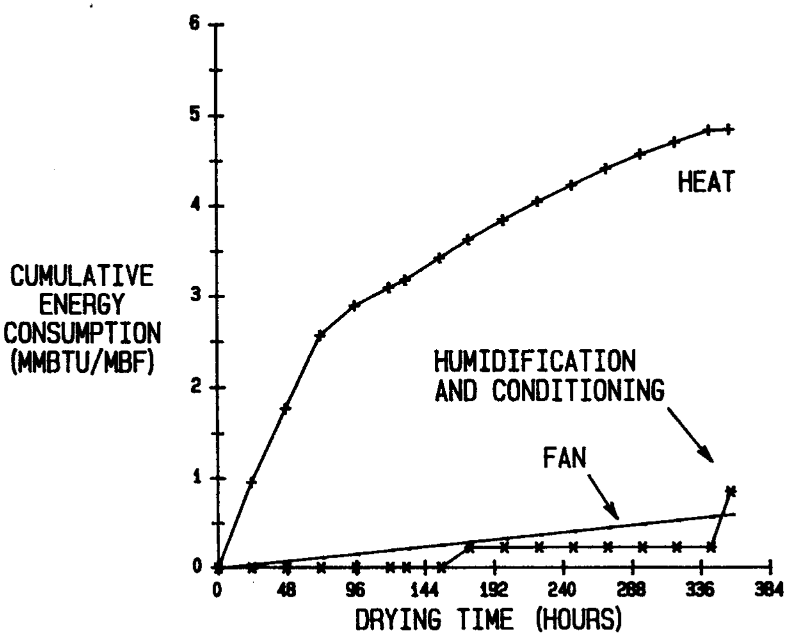

Figure 4. Energy consumption for 8/4 sugar pine commons