Potential for Energy Recovery From Lumber Dry Kilns

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Abstract

Total energy consumed in kiln-drying exceeds 1.4×10^{13} Btu per year, but energy recovery from vent exhausts could reduce the consumption. Energy consumption and recovery from vent exhausts were determined for a conventional kiln, and heat requirements were estimated for two low-temperature (below 120°F) systems: batch and progressive. Calculations showed that passing vent air through a heat exchanger and cooling to 100°, 120°, or 140°F had less effect on energy consumed at 230°F than at 180°F.

Efficiency of a recovery system is optimum when all vent air is recovered. The low-temperature recovery kilns, which have longer drying times but lower construction costs, could be used in conjunction with conventional kilns. Depending on production requirements and species, the recovery system could serve as a predryer to reduce total drying time in a conventional kiln.

WITH THE DECREASING SUPPLY and increasing price of energy, energy savings become more important. Comstock (3) estimated that drying consumes 60 to 70 percent of all the energy used in wood-products manufacture. Thus, a small savings in lumber drying could mean a large savings in energy use.

Although some dimension lumber is used green or is air-dried, the amount of lumber kiln-dried in the West has steadily increased over the last years (Fig. 1). On the basis of an annual production of 10.8 billion board feet of kiln-dried lumber, an average green specific gravity (SG) of wood of 0.40, Comstock's minimum 1,500 British thermal units (Btu) per pound of water evaporated, and a change in moisture content (MC) of 40 percent (dry basis), we can calculate that 1.4×10^{13} Btu were consumed in kiln-drying. That is the energy equivalent of 2.3 million barrels of No. 6 fuel oil — at a price of $26 per barrel in early 1980, an amount equal to about $60 million.

The purpose of this paper is to describe how energy recovery from vent exhausts of a lumber dry kiln might reduce total energy used in lumber drying. I examined a conventional batch dry kiln and calculated total energy consumption and energy recovered from the vent exhaust. I also estimated the heat requirements of two low-temperature (below 120°F) recovery systems — batch and progressive—and the expected energy consumption of a conventional dry kiln operating in conjunction with a low-temperature recovery system.

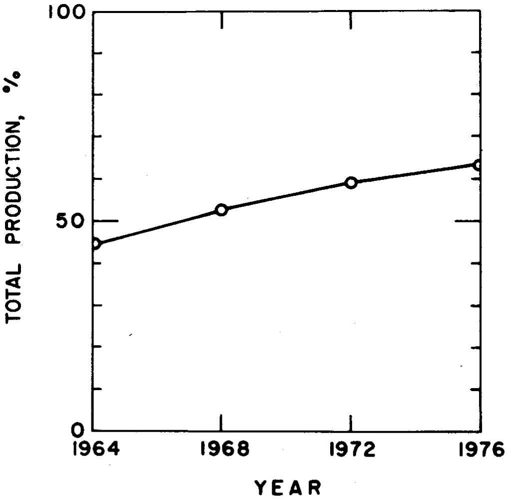

Figure 1. — The percentage of softwood lumber produced west of the Great Plains that was kiln-dried (9). Total production in 1976 was 10.8 billion board feet.

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TABLE 1. — *Values assumed for calculating energy consumption in a conventional batch kiln.*

Item	Value	Literature source
Outside temperature	52°F	(8)
Outside RH	74%	(8)
SG		
Douglas-fir	0.45	(3)
Hemlock	0.38	(3)
Initial MC (dry basis)		
Douglas-fir	55%	(3)
Western hemlock	100%	(3)
Final MC	15%	(6)
Water removed during schedule:		
First third	43%	
Second third	37%	
Last third	20%	
Kiln size	18 ft. wide by 27 ft. high by 33 ft. long	(7)
Building coefficients of heat transmission (Btu/hr./ft.^{2})		
Walls	0.118	(7)
Roof	0.116	(7)
Doors	0.220	(7)
Floor	0.900	(7)
Capacity	25,000 fbm/charge	(7)
Vent air	No excess	

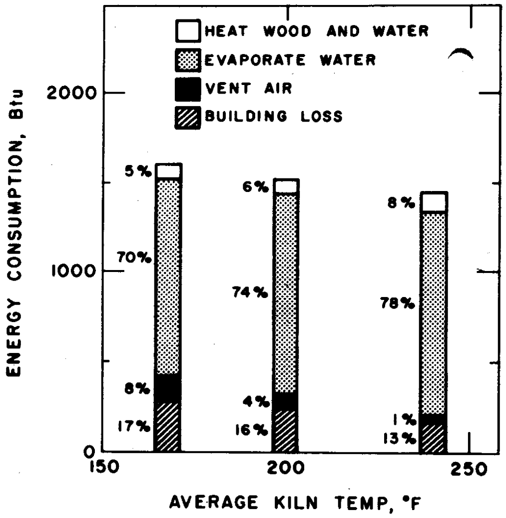

Figure 3. — Total calculated energy consumption in removing 1 pound of water for drying western hemlock lumber with three different drying schedules.

Energy for Lumber Drying

Looking for possible energy saving in kiln-drying means looking at present energy use. Shottafer and Shuler (7) break down dry kiln heat consumption into six categories:

1) Energy required to heat the wood substance
2) Energy required to overcome hygroscopic forces (heat of wetting)
3) Energy to raise the temperature of the residual water
4) Energy of evaporation
5) Energy to raise the temperature of the exhausted vent air
6) Energy lost by heat transmission through the kiln structure

The energy lost in initial heating of the kiln structure is not considered in this study.

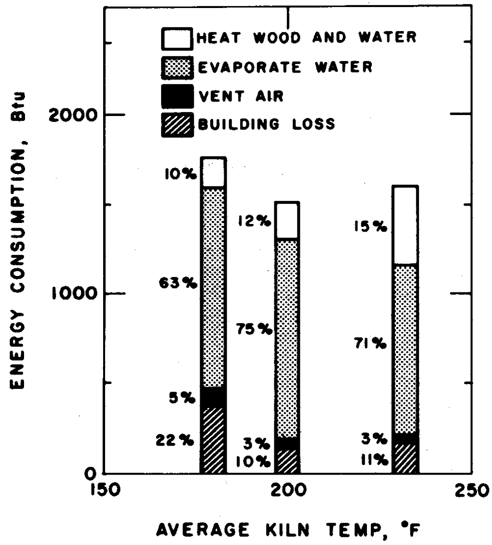

Figure 2. — Total calculated energy consumption in removing 1 pound of water for drying Douglas-fir lumber with three different drying schedules.

To estimate energy consumption for different kiln conditions, calculations were made for three Douglas-fir (dimension) schedules and three western hemlock (dimension) schedules. These calculations indicate the influence of kiln temperature on the components of kiln energy consumption. The results for a batch kiln with the values in Table 1 are shown in Figures 2 and 3. Assumed energy requirements are for a progressive kiln (Table 2). Most of the energy in a dry kiln is consumed by evaporating water. The energy in heat-consumption categories 1, 2, 3, 4, and 5 defined by Shottafer and Shuler (7) represent so-called latent and sensible heats of the exhaust gases. Thus, a large proportion of energy in kiln-drying is concentrated into the flow from the exhaust vents.

Estimation of Drying Rates

Evaporation efficiency of a dry kiln varies during a schedule. For example, with a constant dry-bulb temperature, the relative humidity (RH) decreases as the schedule progresses, increasing the amount of vent air,

TABLE 2. — *Values assumed for calculating energy consumption in a progressive kiln.*

Item	Value	Literature source
Outside temperature	52°F	(8)
Outside RH	74%	(8)
SG		
Douglas-fir	0.45	(3)
Hemlock	0.38	(3)
Initial MC (dry basis)		
Douglas-fir	55%	(3)
Western hemlock	100%	(3)
Final MC	15%	(6)
Entering RH	40%	(5)
Final RH	80%	(5)
Kiln size	24 ft. wide by 10 ft. high by 110 ft. long	(5)
Building coefficients of heat transmission (Btu/hr./ft.^{2})		
Walls	0.118	(7)
Roof	0.116	(7)
Doors	0.220	(7)
Floor	0.900	(7)
Kiln Capacity		
Douglas-fir	13,000 fbm/24 hr.	(5)
Western hemlock	6,500 fbm/24 hr.	(5)

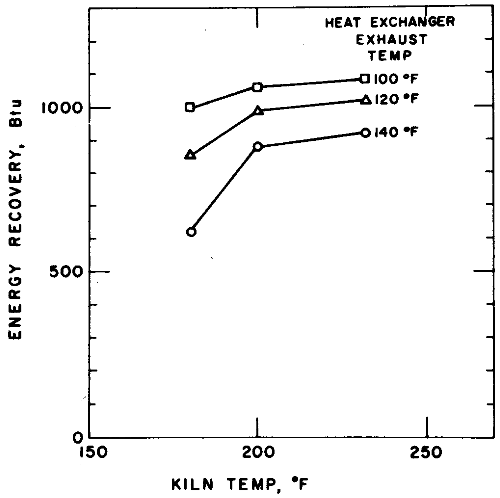

Figure 4. — Calculated energy recovery in removing 1 pound of water for drying Douglas-fir lumber when kiln vent exhaust is cooled to three temperatures.

and therefore heat, required to evaporate each unit of water. In all schedules, the evaporation rate decreases as the wood dries, thus the transmission loss through the kiln structure increases per unit of water.

Because kiln efficiency changes during a schedule, calculation of kiln energy requirements must approximate the drying rate of the lumber. I used drying curves given by Anderson, Knauss, and Frashour (1) for second-growth Douglas-fir using 10 schedules. To quantify the shape of these curves, I divided the kiln schedule into thirds and determined the fraction of the total moisture removed for each. Because the original schedules represented extremes of kiln-drying (1), I assumed that the confidence interval would reasonably approximate a randomly selected commercial kiln schedule. I partitioned the mean values of moisture loss

TABLE 3. — *Schedules used in conventional kiln calculations for energy recovery.*

Time(hr.)	Dry-bulb temperature(°F)	Wet-bulb temperature(°F)	MC(%)
Douglas-fir dimension schedules			
0-24	175	165	55.0→37.8
24-48	180	165	37.8→23.0
48-72	185	165	23.0→15.0
0-8	200	190	55.0→37.8
8-16	200	185	37.8→23.0
16-24	200	180	23.0→15.0
0-12	225	190	55.0→30.4
12-21	240	190	30.4→18.0
21-24	205	180	18.0→15.0
Western hemlock dimension schedules			
0-24	170	155	100.0→72.6
24-48	175	155	72.6→47.7
48-72	180	155	47.7→27.7
72-96	185	155	27.7→15.0
0-18	200	190	100.0→72.6
18-36	200	180	72.6→47.7
36-72	200	170	47.7→15.0
0-42	240	205	100.0→15.0

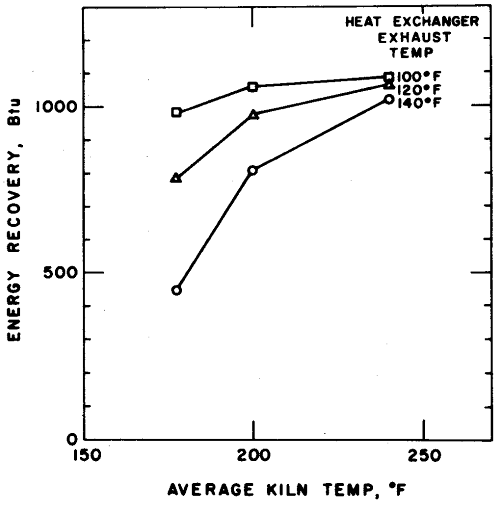

Figure 5. — Calculated energy recovery in removing 1 pound of water for drying western hemlock lumber when kiln vent exhaust is cooled to three temperatures.

TABLE 4. — *Calculated values of drying energy for a conventional dry kiln and potential for additional water removal in a low-temperature heat-recovery kiln.*

Conventional kiln			Heat recovery kiln			
Avg. kiln temperature (°F)	Water removed (lb.)	Drying energy (Btu[a])	Heat-exchanger exhaust temperature (°F)	Recovered-heat energy (Btu[a])	Added water removal (lb.)	
180	1.0	1,760	140	625	0.27[b]	0.33[c]
			120	865	.37	.46
			100	1,010	—	.54
200	1.0	1,510	140	882	.38	.47
			120	991	.43	.53
			100	1,060	—	.56
232	1.0	1,600	140	924	.40	.49
			120	1,020	.44	.54
			100	1,080	—	.57

[a] Btu per pound of water removed.
[b] Batch kiln using Douglas-fir schedule shown in Figure 1, with an energy requirement of 2,320 Btu per pound of water removed.
[c] Progressive kiln using no recirculation, with an energy requirement of 1,880 Btu per pound of water removed.

appropriately among the steps of the three Douglas-fir schedules shown in Table 3.

Unfortunately, drying curves were not available for any species other than Douglas-fir. For hemlock calculations, I assumed the slope of the drying curve to be the same as for Douglas-fir, and moisture loss for the three hemlock schedules was determined with the same values and procedures.

Low-temperature kiln schedules (below 120°F) for Douglas-fir or hemlock were not available. Two conventional schedules, BS7-AK4 (Douglas-fir) and BS11-BK6 (western hemlock) (6), were adjusted to a 100°F dry-bulb temperature maintaining the original wet-bulb depressions. The drying-rate curve for Douglas-fir with changes in dry-bulb temperature should parallel that of hemlock. The several schedules I examined for hemlock batch kilns were approximately twice as long at drying temperatures of 200°F and higher as comparable Douglas-fir schedules (2, 4, 6). The progressive kiln capacity for drying hemlock was therefore assumed to be half that for drying Douglas-fir. The small transmission loss, the only calculated value dependent on kiln capacity, indicated that such a rough approximation was sufficient.

Energy-Recovery Potential From Vent Exhaust

To calculate the potential recovery from vents, I assumed that all vent air was passed into a heat exchanger and cooled to 100°, 120°, or 140°F. Figures 4 and 5 indicate more heat is available for recovery as kiln temperatures increase. Also, recovery from cooling exhaust to 140°F is almost the same as recovery from cooling to 100°F for the high-temperature schedule (240°F). At 120°F heat-exchanger temperature, 95 percent of recovery from the lowest temperature Douglas-fir schedule and 97 percent of recovery from the high-temperature schedule is from condensation (latent heat). Thus, a high-temperature schedule means a greater proportion of condensation due to the higher absolute humidity (weight of water per unit dry air) of air leaving the kiln. This increased condensation makes the final temperature of the vent air heat exchanger less important than in kilns operated at lower temperature schedules.

Recovered-Heat Drying Systems

Although energy recovered from a dry kiln has many possible uses, it is logical to use it for drying additional lumber. A low-temperature batch kiln could function like a conventional batch kiln—with the lower temperatures implying lower construction costs and longer drying times.

A low-temperature, recovered-heat kiln will have higher thermal efficiency than a conventional kiln. If all recoverable heat is used in the low-temperature kiln, the maximum recoveries may be calculated (Table 4). Deviation from the assumed operating conditions or heat loss in the recovery system itself would significantly reduce evaporation efficiency. The designer of a recovered-heat drying system is thus faced with a

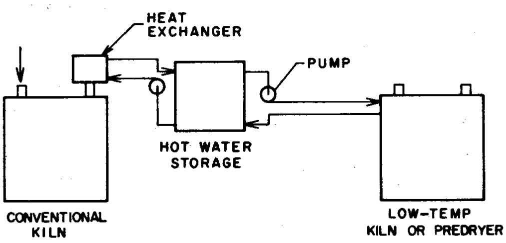

Figure 6. — Schematic sketch of how recovered energy from a high-temperature kiln might be used in a low-temperature kiln.

TABLE 5. — *Schedules used for calculating energy use in a Douglas-fir predryer.*

Time(hr.)	Dry-bulb temperature(°F)	Wet-bulb temperature(°F)	MC(%)
Predry schedule			
0-57	100	90	55.0→44.2
Shortened conventional schedule			
0-9	175	165	44.2→37.8
9-23	180	165	37.8→23.0
33-57	185	165	23.0→15.0

TABLE 6. — *Calculated values of drying energy and recovered-heat energy for a conventional dry kiln, and potential for additional water removal in a low-temperature predryer.*

Conventional kiln			Predryer[a]		
Kiln temperature (°F)	Water removal (lb.)	Drying energy (Btu[b])	Heat-exchanger exhaust temperature (°F)	Added water removal (lb.)	Recovered heat energy (Btu[b])
181	1.0	1,865	120	0.37	870

[a] Batch predryer with an energy requirement of 2,350 Btu per pound of water removed.
[b] Btu per pound of water removed.

tradeoff: a low-temperature kiln will have much available energy with minimum heat-exchange surface, yet will be slow and inefficient; a kiln at temperatures of 200°F and higher will use vent air more efficiently, yet will have less available energy and will require larger heat-exchange surfaces.

Low-temperature predrying would be another method for recovered-heat drying. A predryer can operate at higher RH with lower heat requirements than other kilns because most of the moisture in the lumber is free water and is readily evaporated.

The expected performance of a predryer system was calculated for the batch kiln of Figure 6 with the predry and conventional schedules shown in Table 5. Lumber would remain in a predryer using recovered heat, until lumber in a conventional kiln was dried to the desired final MC. The predried lumber would be dried in a conventional kiln that would again supply recovered heat for the next predryer load.

The increased efficiency of the predryer would be somewhat offset by the decreased efficiency of the conventional kiln resulting from cutting back the high-humidity, high evaporation stages of a conventional schedule. Also, a long predry schedule can result in larger transmission loss than in an independent, low-temperature kiln. The increase in evaporation efficiency is shown in Table 6.

A progressive kiln would offer another possibility for drying with recovered energy. Although uncommon in the United States, this type of kiln provides several advantages when using recovered heat. It is better adapted to using large volumes of low-temperature drying air, has a continuous heat requirement (also a possible disadvantage), and may have discharged air of high humidity even for drying lumber to a low MC. However, since drying conditions at any point in the kiln depend on the drying rate of "up-stream" material, progressive kilns lack flexibility for changing the type of material to be dried.

Energy Requirements for Low-Temperature Kiln-Drying

To estimate energy requirements, calculations were made using ambient conditions in Corvallis, Oregon (8), for all recovery systems except the predryer system I have described. The results are shown in Figure 7.

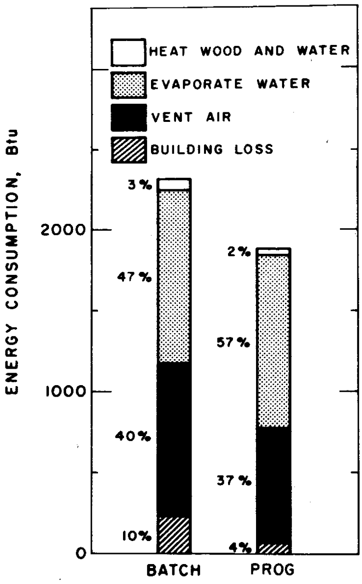

Figure 7. — Total calculated energy in removing 1 pound of water for drying Douglas-fir lumber in low-temperature batch and progressive kilns. Assumed conditions given in Tables 3 and 4.

Ambient conditions have a significant effect on the total drying energy of a low-temperature kiln. For moisture to be added to the kiln vent air, the absolute humidity must be higher inside than outside the kiln. If the ambient absolute humidity reached the absolute humidity in the kiln, no drying could take place. In effect, the vent loss would become infinite, since air would be drawn into the kiln, heated, and discharged without drying taking place.

This undesirable venting effect can be avoided by a schedule using as small a wet-bulb depression as practical. A small wet-bulb depression means a longer drying time and increased transmission loss through the kiln structure. Because changes in transmission loss are small compared to the changes in vent loss, comparisons among various wet-bulb depressions can be made (Figs. 8, 9) for a given time schedule (Table 7).

Potential Problems and Disadvantages

Two potential problems in heat-recovery systems are leaks in the kiln structure and scheduling for energy recovery and usage.

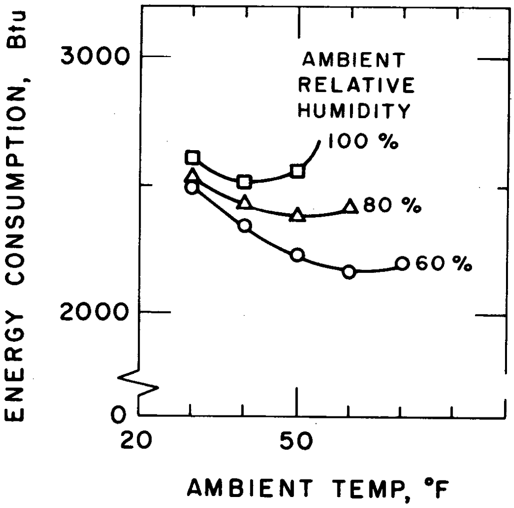

Figure 8. — Total calculated energy consumption in removing 1 pound of water for drying Douglas-fir lumber in a low-temperature batch-type kiln. Assumed schedule in Table 4.

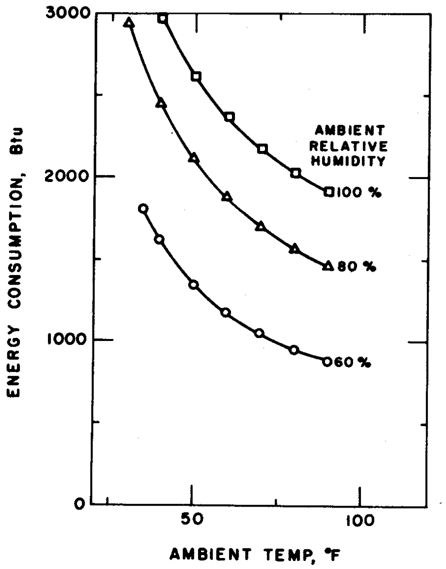

Figure 9. — Total calculated energy consumption in removing 1 pound of water for drying Douglas-fir lumber in a low-temperature progressive kiln. Assumptions in Table 3.

TABLE 7. — *Schedules used for calculating energy use in low-temperature batch kilns with heat recovery.*

Time(hr.)	Dry-bulb temperature(°F)	Wet-bulb temperature(°F)	MC(%)
Douglas-fir			
0-37	100	90	55.0
37-55	100	85	38.5
55-74	100	80	31.3
74-115 or to 15% MC	100	75	24.2
Western hemlock			
0-36	100	85	100.0
36-75	100	80	75.9
75-116	100	75	53.4
116-178 or to 15% MC	100	70	32.6

During a high-temperature kiln run, only a small amount of air is vented with the evaporated moisture. Thus, leakage in the kiln could reduce the efficiency of heat recovery. Most kilns today have some leakage (7).

Scheduling problems between the source and use of recovered energy could be partially alleviated by a hot-water storage tank (Fig. 6). Drying rates in the kilns and heat-transfer capabilities of the heat exchangers in a particular system would need careful examination to determine if such hot water storage would be adequate.

Other problems that might be expected in a heat-recovery system would be less critical than these. For example, a low-temperature kiln requires more moving air per unit of water evaporated. Thus, higher fan energy (from expensive electric power) would be required for drying a given volume of lumber than in a strictly high-temperature kiln.

Implementing a heat-recovery system on an existing kiln would require altering the conventional vent arrangement of a batch kiln with vent openings functioning as either intakes or exhausts. These would have to be connected by, or replaced with, ducts allowing collection of all of the exhaust, yet still permitting periodic fan reversal.

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