DRYING YELLOW-POPULAR IN A HIGHLY EFFICIENT SOLAR KILN

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Recent shortages and the soaring cost of fossil fuels have forced the wood processing industry to seek ways to conserve energy and alternative sources of energy. The largest potential energy savings is in the drying of lumber because 60 to 70 percent of the energy needed to process wood is used in this step (5).

Solar energy, a renewable and pollution-free source, is a promising energy alternative. During the past 20 years many solar kilns have been designed but they have all been the low efficiency greenhouse type--they incorporate the collector as an integral part of the kiln and they have little or no insulation (2,4,6). Wengert (7) found that only 15 percent of the total insolation (solar radiation) was used to evaporate water from the lumber. The rest of the insolation was lost either to the atmosphere or to the ground. Even with such poor efficiency, however, these kilns are capable of reducing energy costs compared to conventional kilns and of reducing drying time compared to air drying (2,4,6). Several solar kilns with external collectors have been built, but they are costly and elaborate (3).

We designed a highly efficient (60 to 80 percent) and low-cost solar kiln with external air-heating collectors that has the ability to dry hardwood lumber.

Solar Kiln Construction

Air-Heating Solar Collectors

The heat for the kiln is supplied by four 4- by 8-foot solar collectors. Each collector plate contains 336 recycled aluminum cans cut in half and mounted on a sheet of 1/2-inch exterior plywood that is covered with heavy aluminum foil (Fig. 1). The collector plate rests in a large wooden tray that is deep enough to allow air to flow over the top of the cans. Both the collector plate and tray are covered with two coats of velvet black paint and the collector tray has 6 inches of polyurethane foam insulation under it. A double-paned fiberglass solar collector cover is sealed over the collector plates leaving a 1-1/2-inch air space between the panel and the top of the cans.

Air is circulated through the solar collectors by two centrifugal blowers, each driven by a continuously variable 0.5 hp motor. Air flow rates are regulated by the variable speed motors. The shuttered vents and the fans are automatically turned on and off by temperature controllers that turn the fans on when the solar collectors are warm enough and turn them off when the collectors cool down.

The collectors were tested from spring through fall of 1977 in southern Illinois. Average daily efficiency in May was 74 percent. Efficiency decreased as the solar collector outlet temperature increased.

$$\text{Collector efficiency} = \frac{\text{BTU collected/ft}^2 \text{ of collector area}}{\text{Insolation available/ft}^2 \text{ of collector area}}$$

Drying Chamber

The kiln has a wooden frame and measures 8 feet by 8 feet by 6.5 feet high (Fig. 2). The walls, ceiling, and floor are insulated with 6 inches of fiberglass wool and 2 inches of styrene foam. The exterior of the kiln is covered with insulated aluminum siding with 1/2-inch exterior plywood underlayment. The interior of the kiln is covered with 5/16-inch exterior plywood, over which is a sealer coat.

Air is circulated in the kiln by a tubeaxial fan driven by a reversible, continuously variable 1 hp motor. Air flow rate is regulated by the variable speed motor and measured by an air velocity meter.

The relative humidity inside the kiln is controlled with a humidistat. The kiln is vented with two motorized shuttered vents. When the relative humidity becomes too high, a small blower automatically turns on and the two motorized vents open allowing humid air to be expelled and outside air to enter. When the relative humidity goes below the prescribed level, the venting blower shuts off and the vents close. At night the venting system is shut down to reduce heat loss, and to increase kiln efficiency.

$$\text{Overall kiln efficiency} = \frac{\text{Theoretical heat required to remove water in the wood}}{\text{Total insolation collected and sent to the kiln}}$$

Material and Methods

Yellow-poplar (*Liriodendron tulipifera*) boards were kiln dried and air dried in two runs--one in the summer and one in the fall. The boards for the summer run were 6 feet long, 4 inches wide, and 1-1/16 inches thick and for the fall run were 8 feet long, 4 or 6 inches wide, and 1-1/16 inches thick. For both runs, the boards were randomly divided into two equal stacks of 500 board feet each--one stack was solar kiln dried and the other was air dried in an open shed.

Kiln air velocity, solar collector air velocity, and the size of the kiln and air-dried charges were fixed for every drying run. Weights of the boards were taken to the nearest 0.01 pound before and after drying. Dimensions of the boards were taken at three different points for thickness and width before and after drying. Weight of sample boards were checked every 24 hours until 15 percent moisture content (MC) was reached. After the drying, the boards were measured for crook, bow, and twist and inspected for checking and collapse. In the fall run, boards were graded before and after drying to compare the grade drops between air- and kiln-dried lumber. The summer runs were not graded because the lumber used was not in standard lengths.

Results and Discussion

The time necessary to solar dry 4/4 yellow-poplar lumber from green to 15 percent MC was 8 days during the summer (compared to 16 days for air drying) and 11 days during the fall (compared to 41 days for air drying)(Figs. 3 and 4). Initially, solar kiln drying was slower than air drying due to the lack of venting capacity in the kiln but by day 4 to 6 had surpassed air drying. The difference between kiln and ambient temperature became greater toward the end of drying (Figs. 3 and 4) because less energy was needed to evaporate water in wood and more energy was available to heat the kiln.

No significant difference was found in average shrinkage and warpage between the solar kiln-dried and air-dried lumber (Table 1). A larger grade drop was found in the kiln-dried lumber than in the air-dried lumber of the fall run. However, 100 percent of the air-dried lumber developed end-checking on both summer and fall runs and only 60 percent of the solar kiln-dried lumber developed end-checking (Table 1). The surface of the air-dried lumber appeared slightly darker and weathered compared to that of the solar kiln-dried material. Both air- and solar kiln-dried lumber developed mild internal stresses after drying.

The solar kiln required much less energy to dry lumber than the conventional kiln described by Cech and Pfaff (1). For the summer and fall runs, the solar kiln used approximately 1/4 to 1/3 the energy required by the conventional kiln (Table 2).

From summer to fall the efficiency of the solar collector increased by 7 percent but the overall efficiency of the solar kiln decreased by more than 25 percent (Table 2). The reduction in kiln efficiency was probably due to the longer time required for drying in the fall run, which resulted in greater heat losses through walls, roof, floors, and vents. More time was required for drying in the fall run due to the lower average kiln temperature.

Summary

A solar kiln can dry green lumber to 15 percent moisture content 2 to 4 times faster than air drying. The solar kiln also used less energy than a conventional kiln. We will continue our efforts in Carbondale to evaluate solar kiln drying during other seasons of the year and to supplement solar drying with auxiliary heat and steam for conditioning so that hardwoods can be dried stress-free to 6 to 8 percent MC.

Literature Cited

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Table 1.--Comparison of shrinkage, warpage, grade drop, and end checking between solar kiln- and air-dried 4/4 yellow-poplar

Drying method	Average shrinkage		Average warp			No. of grades dropped			End-checking
	Width	Thickness	Twist	Bow	Crook	1	2	3	
	Percent		Inches			Percent			Percent
Solar kiln									
Summer	4	4	0.15	0.13	0.16	-	-	-	55
Fall	3	3	0.13	0.13	0.16	7	1	0	65
Air									
Summer	4	4	0.16	0.12	0.16	-	-	-	100
Fall[1]	4	3	0.19	0.10	0.15	1	1	0	100

[1] The fall run was dried with a 19 lb/ft^2 top load, whereas, the summer run was dried without top load.

Table 2.--Power consumption and efficiency of solar collector and solar kiln when drying 4/4 yellow-poplar lumber

Kiln	Green MC	Final MC	Electrical energy consumption	Collector efficiency	Kiln efficiency
	Percent		KWH	Percent	Percent
Solar					
Summer	95	15	258	57	89
Fall	92	15	341	64	62
Conventional[1]					
	64	16	1,090	-	-

[1]Data from Cech and Pfaff (1), reduced to 500 BF basis and corrected for moisture content for comparison with solar kiln data.

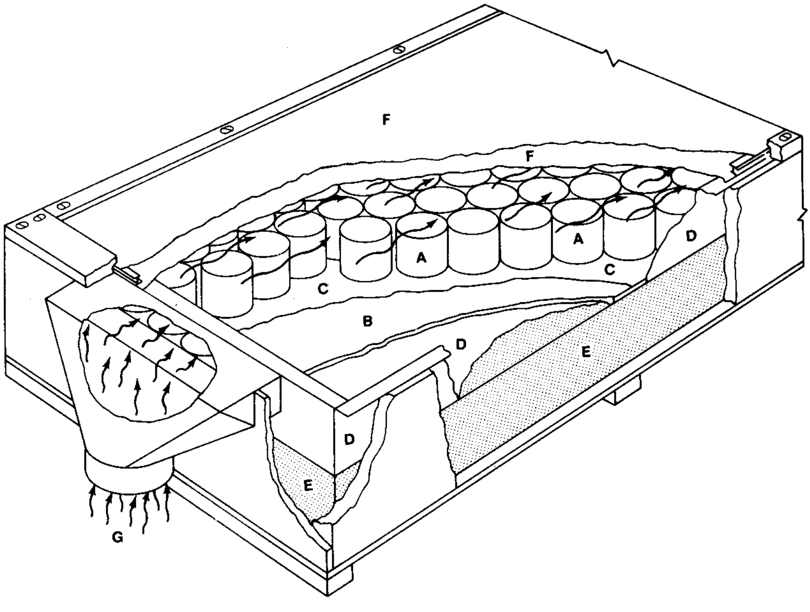

Figure 1.--Cutaway view of aluminum can solar collector. A--Aluminum cans cut in half, B--1/2-inch exterior plywood, C--heavy aluminum foil, D--wooden tray, E--polyurethane foam insulation, F--double paned fiberglas solar collector cover, and G--air flow.

Figure 2.--Solar collectors (left), solar kiln (middle), and instrument building (right).

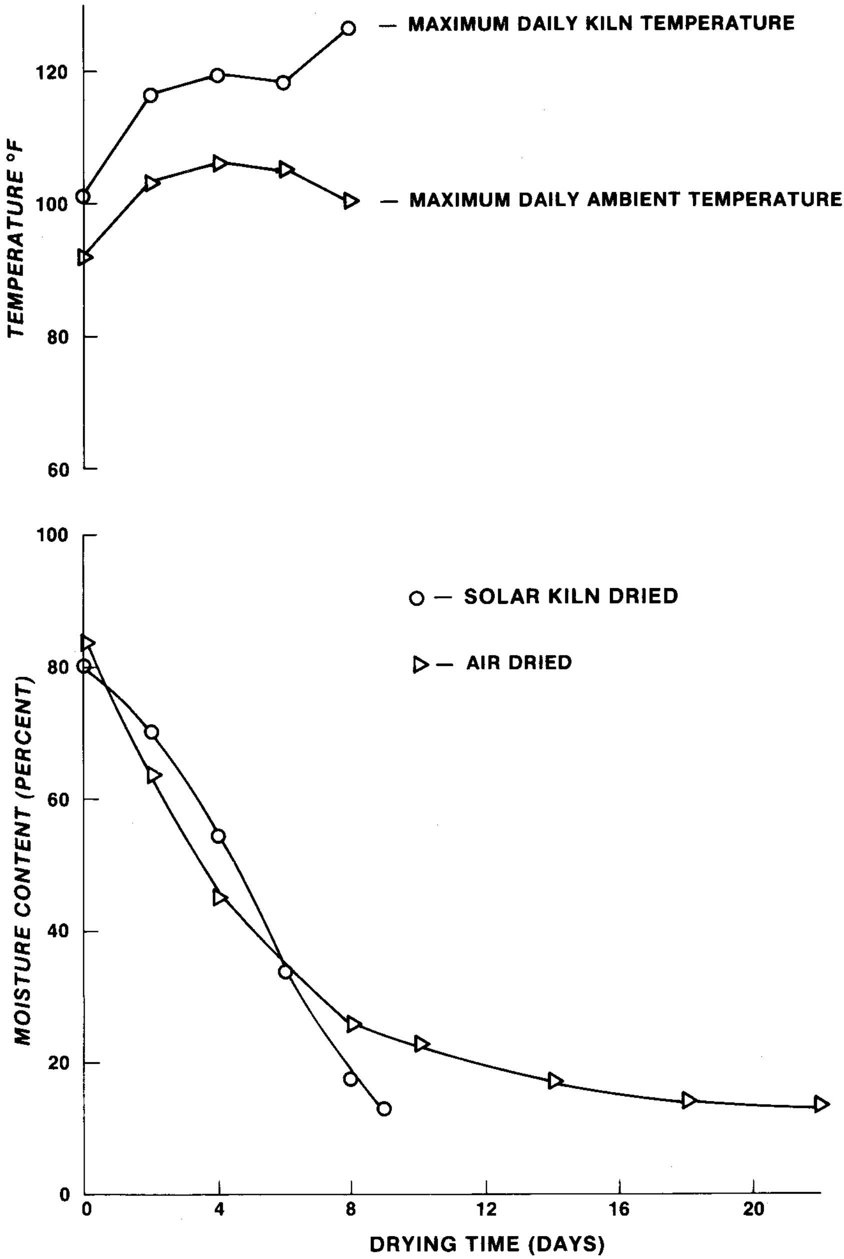

Figure 3.--Moisture content versus time for solar kiln- and air-dried yellow-poplar lumber during the summer.

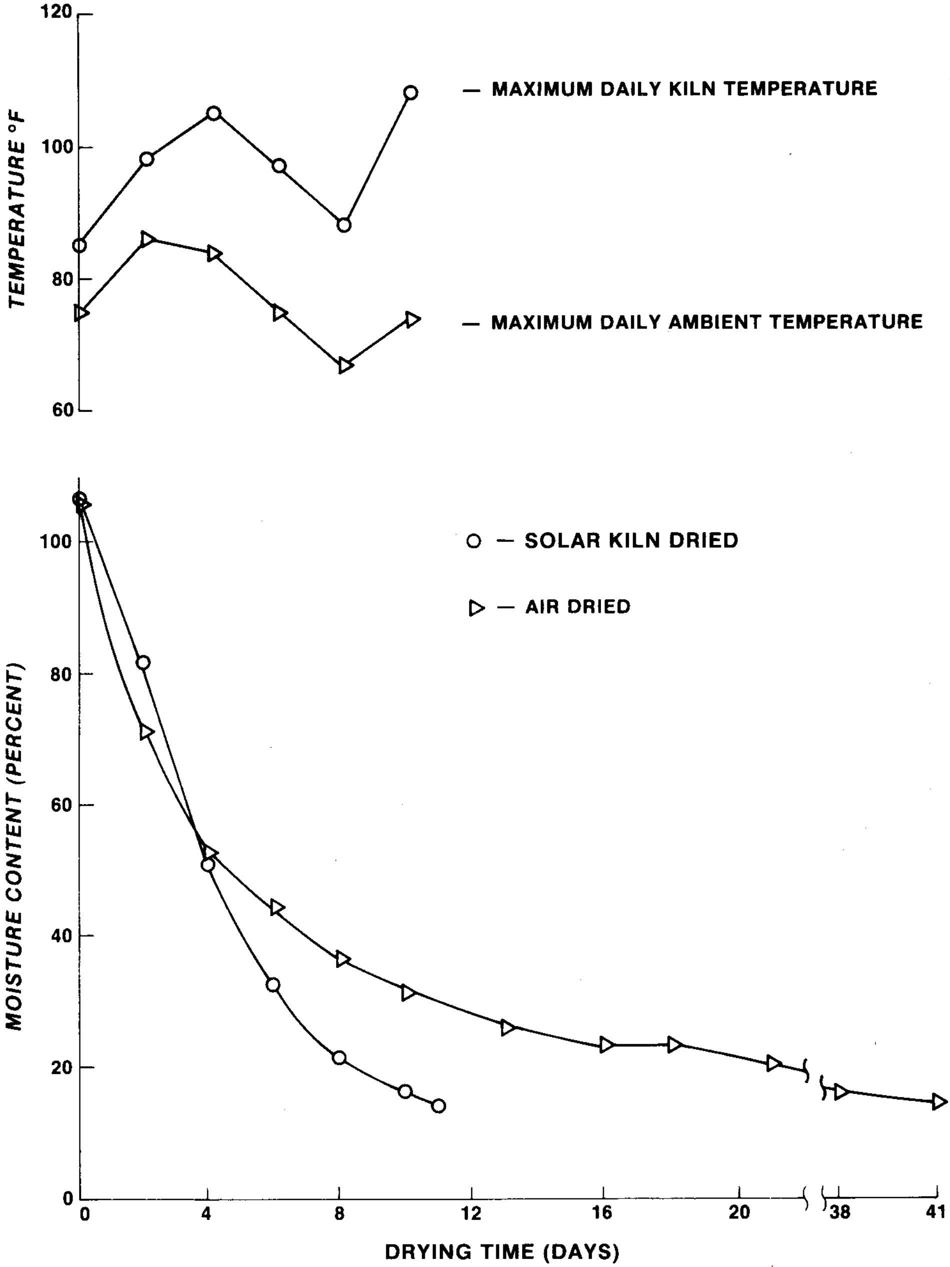

Figure 4.--Moisture content versus time for solar kiln- and air-dried yellow-poplar lumber during the fall.