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IMPROVEMENTS IN SOLAR DRY KILN DESIGN[1]

By

EUGENE M. WENGERT, Forest Products Technologist

Forest Products Laboratory,[2] Forest Service
U.S. Department of Agriculture

Interest in solar drying of lumber has increased in recent years because previous results had indicated that: Drying times are shorter and final moisture contents are lower in solar drying than in air drying; much less lumber degrade occurs in solar drying when compared to air drying; and the cost of energy is less in solar drying than in kiln drying.

Work in the field of solar drying has reached the point at which dryer designs are being modified or need to be modified to provide more efficient dryers. In order that these modifications can be made intelligently, it is necessary to identify the weak areas (such as excessive solar reflectance from the walls) in the present dryer designs.

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[2]The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

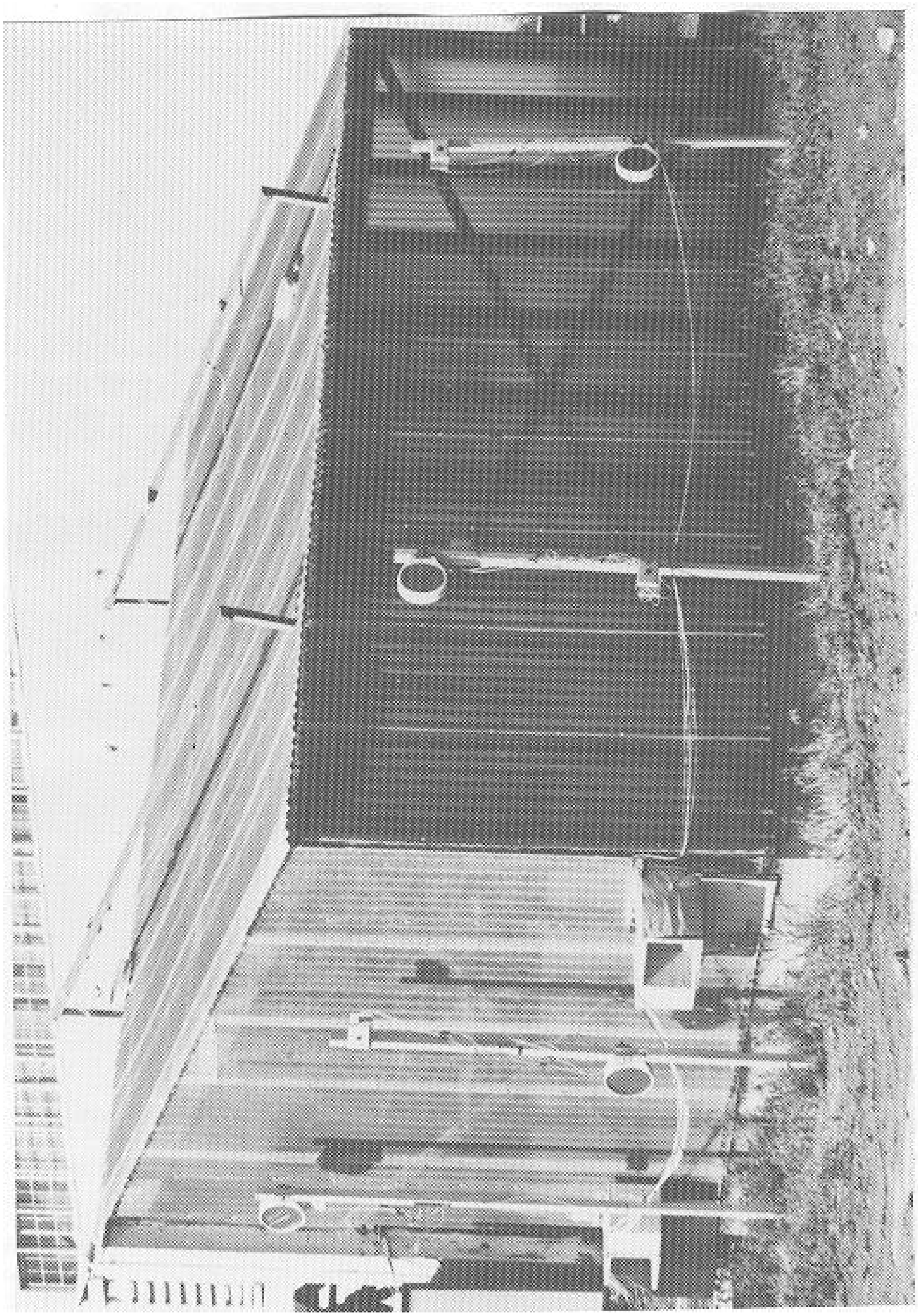

Figure 1.--The solar dryer at Colorado State University (looking NE) (M 136045-19)
with the instruments used for measuring energy gains and losses.

The objective of this study was to identify the major energy losses in the solar dryer at Colorado State University, and then to suggest various design changes, based on theoretical considerations, to reduce these losses to leave more energy for the primary task of drying wood.

Previous Solar Drying Research

Early work on solar drying of wood was done by C. L. Johnson[3] in 1961 at the U.S. Forest Products Laboratory, although the idea of using solar energy for drying wood was mentioned several years earlier by M. L. Ghai.[4] Since Johnson's early work, studies have been conducted at the U.S. Forest Products Laboratory (Madison, Wis.); Colorado State University and the Rocky Mountain Forest and Range Experiment Station (Fort Collins, Colo.); the Institute of Tropical Forestry (Puerto Rico); the Forest Products Research Institute (Philippines); the Division of Forest Products, Commonwealth Scientific and Industrial Research Organization (Australia); the Forest Research Institute (India); the Government Forest Experiment Station (Japan); South African Timber Research Unit (South Africa); Centre Technique Forestier Tropical (Madagascar); and the Uganda Forest Department (Uganda). Results of much of this research are included in the additional references at the end of this report.

Most of the solar kilns used by these organizations in their studies have been constructed of a wood frame covered with a transparent or translucent material such as glass, plastic, or fiberglass. Often one wall was not transparent but had a solid door to permit easy loading or unloading. In most studies the advantages of solar drying over air drying are reported as (1) less lumber degrade, (2) shorter drying times, and (3) lower final moisture contents.

The solar dryer at Colorado State University (fig. 1) is a typical solar dryer. It is a frame structure, 18 feet (east to west) by 10 feet (north to south), with translucent fiberglass walls and roof. The roof is at an angle of 17°, facing south, making the south wall about 7 feet high and the north wall 10 feet. A sliding plywood door is the north wall. The floor is concrete several inches thick. Two electric fans in the dryer circulate air though the load at about 250 feet per minute. Four small openings, two on the east wall and two on the west wall, are used for venting.

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[3] C. Johnson. 1961. Wind-Powered Solar-Heated Lumber Dryer. So. Lumberman 203(2532): 41-42, 44.

[4] M.L. Ghai. 1955. Seasoning of Timber with Solar Energy. In Solar Energy Research Eds. F. Daniels and J. A. Duffie, Univ. of Wisconsin Press, Madison.

Solar Dryer Theory

A solar dryer with transparent or translucent walls is designed to transmit the largest practical percentage of the incident solar energy into the dryer. Surfaces inside the dryer are painted dull or flat black so that as much of the transmitted energy as possible is then absorbed. When this energy is absorbed, the absorbing surfaces are heated. Energy is then transferred from the heated surfaces to the air in the dryer, primarily by convection. The air, circulated by fans, then transfers energy to the lumber where it evaporates and moves water from the wood.

However, this process of converting solar energy into energy for evaporating and moving water is not very efficient. As an example, about 1 million B.t.u.'s are required to dry 1,200 board feet of lumber from 50 percent to 12 percent moisture content. At Fort Collins, Colo., a horizontal solar energy collector or solar dryer roof with an efficiency of 100 percent and an area of 20.0 square feet could collect 1 million B.t.u.'s in two typical summer days or five typical winter days.' On the other hand, it is estimated that the solar dryer at Fort Collins, with a roof area of about 200 square feet, would take almost a week in summer and over 2 weeks in winter to dry 1,200 board feet from 50 to 12 percent. The major question is, "Where is the incoming solar energy going if it isn't being used to dry the lumber?'

Experimental Approach--Theory

To define the system to be studied, an imaginary boundary was considered as completely around the kiln. Any energy passing into the volume enclosed by the boundary was an energy gain; any energy passing out, an energy loss. As a result of this definition, the following energy changes were considered:

Gains.--(1) incident solar energy, (2) incident longwave or infrared energy, and (3) "drying power" or internal energy of the air entering through the vents.

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[5] It should be noted that the calculations, when considered in terms of a solar dryer, should also include such other sources of energy input as energy from the fans and solar energy input through the walls. This would mean that an ideal dryer could dry lumber in even less time than the times indicated.

Losses.--(l) outgoing solar energy, (2) outgoing longwave energy, (3) internal energy of the air exiting from the vents, and (4) sensible heat loss.

Storage or chances.--(1) changes in temperature of material (water, wood, air, etc.) in the enclosed volume, and (2) changes of state of water (e.g., liquid to vapor).

By using the imaginary boundary or energy balance approach, the energy gains must equal the energy losses plus the increase in energy of the material in the enclosed volume. If the measurements do not confirm this equality, then either a significant energy term has been omitted or an energy term has not been measured accurately.

To simplify this experiment, the imaginary boundary around the solar kiln was moved slightly so that the north wall (a sliding door) and the floor contained the boundary, while the boundary remained outside the other three walls and roof. This repositioning meant that the only term that had to be measured for the north wall and the floor was energy conduction because these surfaces were opaque.

Experimental Approach--Instrumentation

One simplification was necessary due to the instrumentation used--the longwave energy terms (incoming and outgoing) were not measured separately; rather a net radiation term was measured (incoming minus outgoing). Solar irradiation values were measured with silicon solar cells located in various positions around the dryer. Sensible heat or convection losses from the walls were determined by measuring the temperature difference between the air and the wall, and multiplying this difference by an empirically determined convection coefficient. Conduction in the north wall and floor was determined by multiplying the temperature gradient by a conduction coefficient for that material. Energy storage was determined by multiplying the change in temperature of a material over a period of time by the material's density and specific heat. The energy utilized in changing water from a liquid to a gas was determined by measuring the weight of water lost from the lumber in the dryer and multiplying this weight loss by the latent heat of evaporation.

Results and Discussion

Data were taken during, the morning hours of clear days during the summer of 1967. The data are summarized in table 1 in terms of the amount of energy gained or lost as a percentage of the incoming solar radiation. Five energy losses account for about 84 percent of the incoming solar energy: losses by convection (sensible heat loss), 29 percent; outgoing solar energy, 17 percent: ventilation, 14 percent; net longwave radiation, 13 percent; and conduction through the floor, 11 percent. The remaining 16 percent of solar energy was utilized for drying the wood and for minor losses.

Table 1.--Summary of energy distribution in the solar dryer

Source		Energy as a percent of incoming solar energy[1]
Conducted through north wall		1.5
Conducted through floor		11.4
Convected from walls	17.3	29.1
Convected from roof	11.8	
Storage inside dryer		7.4
Solar, outgoing		17.5
Longwave, net		13.2
Ventilation		14.4
Water evap. (latent heat)		15.4

[1]Total of column exceeds 100 percent due to experimental error and due to other energy input (e.g., from the fans) which was not considered.

Although these results are subject to a 2 to 5 percent experimental error due to the instrumentation used, they do indicate that five energy-loss terms are relatively large and must be reduced to utilize more of the incoming solar energy for drying wood

Reducing the Losses

The following section discusses each of the five losses and indicates methods of reducing them These methods apply, in general, to any solar dryer design with translucent or transparent walls.

Convection

The easiest method of reducing the convective loss would be to reduce the temperature difference between the walls and the outside air. This could be accomplished by using two layers of translucent material with a dead air space between them for the walls. If this modification is made to the existing solar dryer, the second layer should be as transparent as possible to solar radiation so that solar reflection losses do not increase. In addition, by using two layers of wall material, the amount of longwave radiation lost through the walls will decrease because of the lower temperature of the exterior wall.

Reflection and Transmission of Solar Energy

The wall material must be transparent or translucent to permit the solar energy to enter the dryer, but the more transparent the material, the larger the amount of energy transmitted out again through the walls. The translucent wall material works very well because it permits a high percentage of solar radiation to enter the dryer and does reduce the transmission loss.

As an improvement to the present dryer design, several baffles, vertically oriented and running north to south, could be placed in the dryer. These baffles should be painted black to absorb the maximum amount of solar radiation. This would reduce the amount of solar energy that enters the dryer, but then passes directly out again.

Ventilation Losses

Ventilation (the exchange of air in the dryer with the outside air) is necessary to keep the humidity inside the dryer at a moderate level so drying can take place. However, the ventilation in the present dryer can be improved. The present design results in fresh air being brought into the dryer at a rate of 600 cubic feet per minute. The air, once in the dryer, moves into the upper section where, with air previously in the dryer, it is heated. Some of this heated air is then exhausted to the outside. The remaining air is passed through the lumber. The major drawback to this design is that some of the heated air is exhausted before it does any work or supplies any heat to the lumber.

A better ventilation design would be to exhaust some of the air in the kiln immediately after it passed through the lumber pile. This can be accomplished by power venting with a small fan installed on the “low-pressure” side of the kiln. The fresh air intake vent would also be on the low-pressure side. In addition to obtaining more work and heat from the air, this method would also reduce the temperature difference between the entering and leaving air through the vents and further reduce the energy lost by ventilation.

Losses by Longwave Radiation

The losses by longwave radiation are difficult to reduce. Their magnitude is affected by the temperature inside the dryer and by the ability of the walls to transmit longwave radiation. Decreasing the temperature inside the dryer would defeat the major purpose of the dryer. However, decreasing the transmission of longwave radiation through the walls would decrease the longwave loss. This reflection could be accomplished, in part, by using two layers of wall material. Also, it could be accomplished by coating the wall surfaces with infrared reflecting chemicals (such as titanium dioxide).

Losses Through the Floor

Concrete is a relatively poor thermal insulator and therefore is not a suitable material to be used for a floor in a solar dryer. A wood floor would be much better. An excellent floor design would be a composite floor with wood as an underlayment and concrete or asphalt as a covering material.

Conclusions

This study has shown five major areas where energy losses exist in the present solar dryer design. These losses account for nearly all of the energy lost in this dryer:

1. Convection losses from the walls and roof;
2. Reflection and transmission of solar energy;
3. Ventilation losses through the vents;
4. Longwave radiation losses;
5. Conduction losses through the floor.

Corrective design procedures are available which will reduce each of these losses.

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