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PERFORMANCE OF WOOD IN A DO-IT-YOURSELF SOLAR COLLECTOR.(U)
1979 G E SHERWOOD, W A GATZ
UNCLASSIFIED FSRN-FPL-0240 NL

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United States Department of Agriculture

Forest Service

Forest Products Laboratory

Research Note FPL-0240

1979

Performance of Wood in a Do-It-Yourself Solar Collector[1]

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Abstract

Six variations of a do-it-yourself solar collector design were constructed and exposed under stagnation conditions for 1 year; collectors were basically closed boxes without air circulation. Temperature in each collector was recorded throughout the test period and the effect of these temperatures on the wood framing and plywood in the collectors was estimated based on previous studies of effect of high temperature on properties of wood. Visual observations were also made on the wood, paint, insulation, and glazing.

Temperatures in the collectors could reduce strength properties of the wood if stagnation conditions were maintained for many years. The maximum stagnation temperatures could result in spontaneous ignition of wood if maintained continuously for long time periods (months, years). Operating temperatures are usually much lower than stagnation temperatures.

Introduction

The search for economical methods of collecting solar energy has led to a variety of systems with many of them employing wood as the basic construction material. One such system is a series of simple wooden boxes that could be built by the homeowner with few tools and limited skills. The collected heat energy would be distributed to the heating system by air circulation. However, if the air circulation system failed to function or if it were not operated during summer, temperatures in collectors could become quite high. The durability of wood and safety of using it at such temperatures as under stagnation conditions has caused some concern.

To determine temperature levels and effects of those temperatures on materials, six variations of a do-it-yourself collector were exposed under stagnation (no air flow) conditions for a period of 1 year near Madison, Wis. Temperatures were recorded at critical locations in each collector and the performance of all materials was observed. Long-term effects of high temperature on wood have been previously studied, so these effects were projected for the collectors tested.

[1]Research conducted in cooperation with the USDA, Farmers' Home Administration, Rural Development Service, Washington, D.C.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3]Millett, M.A., and C.C. Gerhards. 1972. Accelerated aging: Residual weight and flexural properties of wood heated in air at 115° to 175° C. For. Prod. J. 4(4):193-201.

[4]Holmes, Carlton, A. 1977. Effect of fire-retardant treatments on performance properties of wood. *In* Wood Technology: Chemical Aspects. ACS Symp. Ser. 43, Am. Chem. Soc., Washington, D.C.

[5]Matson, A.F., R.E. Dufour, and J.F. Breen. 1959. Survey of available information on ignition of wood exposed to moderately elevated temperatures. Underwriters Lab. Inc., Northbrook, Ill.

Background

Studies of temperature effects on wood have shown that temperature above 150° F results in immediate temporary reduction in mechanical properties, but prolonged heating may also cause permanent loss. Permanent reductions increase with time, but are not directly proportional to the length of time those temperatures are maintained. Although exact data are not available for the condition in this study, some extrapolation can be made from accelerated aging studies by Millett and Gerhards.

The immediate effect of 150° F conditions on wood at 5 percent moisture content is projected to be a reduction in strength of about 26 percent. If that condition occurs for only a brief time, strength will be recovered when the temperature is lowered. However, exposure to that temperature for a long duration would result in a permanent strength reduction. Projections of the data would indicate a 13 percent permanent reduction if 150° F were maintained constantly for 20 years. If that temperature occurred for only 4 hours per day, the same reduction in strength would occur in 120 years. Using the same accelerated aging data and extrapolating for 200° F for a short time period, the immediate reduction in strength is 40 percent. A 13 percent permanent reduction would occur in 1 year of continuous exposure at 200° F or in 6 years if that temperature occurred for only 4 hours per day.

Ignition of wood varies with the specimen and with duration and uniformity of exposure, heating rate, oxygen supply, air circulation and ventilation, degree of confinement or space geometry surrounding the exposed wood element, temperature and characteristics of adjacent or contacting material, and amount of radiant energy present. With convective heating of wood under laboratory conditions, spontaneous ignition has been reported at as low as 520° F and as high as 880° F after only minutes of exposure.

Although not proven by laboratory experiments, there have been many documented field reports on ignition of wood under long-term stagnation conditions at temperatures near 212° F. Consequently, to provide a safety factor, this temperature of 212° F has been given as the upper limiting temperature for wood exposure over long periods of time (months, years).

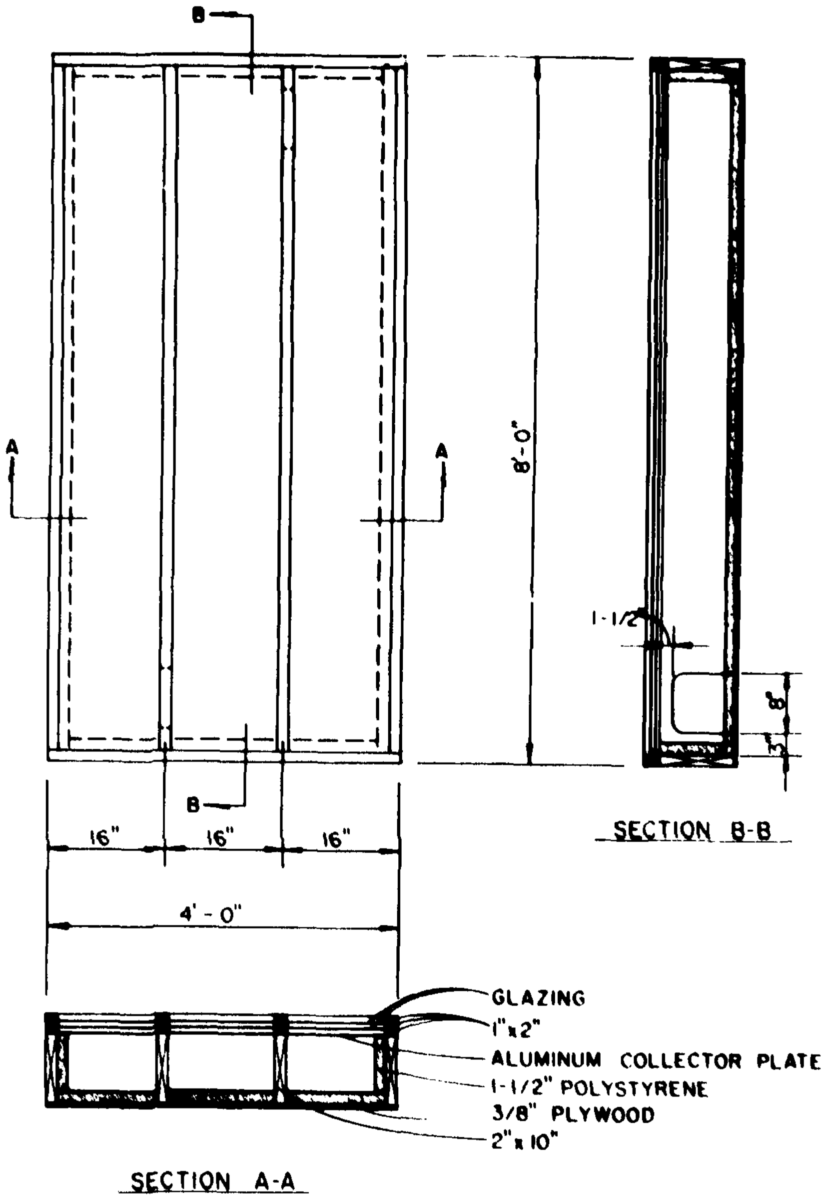

Figure 1 —Collector with 2 x 10 framing

(M 148 280)

Description of Collectors

Six variations of the collector design were fabricated in 4- by 8-foot panels (figs. 1 and 2, table 1). All had wood frames, plywood back, and double glazing on the front. Four were insulated on the sides and back, the other two had no insulation. A flat black paint was applied inside and out to all surfaces before collector plates or glazing were installed. All joints were caulked before members were screwed together.

Each panel was divided into three cavities about 16 inches by 8 feet by the depth of the framing members. All three cavities were interconnected by cutouts near alternate ends of framing members dividing the panel. In a functioning system, additional cavities with similar cutouts would be placed side by side to achieve the desired collector capacity. An exhaust fan on one end would draw air through all of the cavities.

For exposure, the 4- by 8-foot panels were mounted on a frame at 60° to horizontal and facing south so they would be nearly perpendicular to the sun's rays during the coldest time of the year (fig. 3).

Instrumentation

A thermocouple was placed near the center of the middle air space in each panel. Additional thermocouples were placed in Panels 1 and 5 to observe variations in temperature due to location within the panel. Panel 1 had thermocouples near the top of the center air space, on the metal collector, between the collector and the wood, between the collector and glazing, and between the two sheets of glazing. Panel 5 had thermocouples on the plywood collector, near the top of the center air space, between the two sheets of glazing, and on the surface of the outer glazing. Outdoor temperature was also measured by a thermocouple. A wind anemometer was used to measure wind speed, and a cadmium cell measured light. All of the data were recorded on a strip chart recorder with a timer that turned it on only during daylight hours.

Collector Temperatures

The collectors were placed at an exposure site near Madison, Wis., in January 1977, and stagnation temperatures were recorded continuously through December 1977. Temperatures at the center of the middle air space were selected as representative data for estimating the effect of heat on properties of wood. Other temperatures in the collectors were never more than about 15 degrees higher, and temperatures in some parts of the collector were much lower.

The uninsulated panels had frequent daily highs of about 160° F, but few that exceeded that temperature. Only one daily high in Panels 5 and 6 exceeded 180° F.

The insulated panels had temperatures above 200° F for about 4 hours a day in April. None of the panels had temperatures exceeding 200° F on the selected sunny day in August, and only one panel (No. 3) had temperatures exceeding 200° F on the selected sunny day in December. The highest temperatures were in Panel 3, which had temperatures above 200° F on 123 days or about one-third of the days of a year.

Temperature cycles for Panel 3 on selected sunny days in early spring, late summer and winter are shown in figure 4

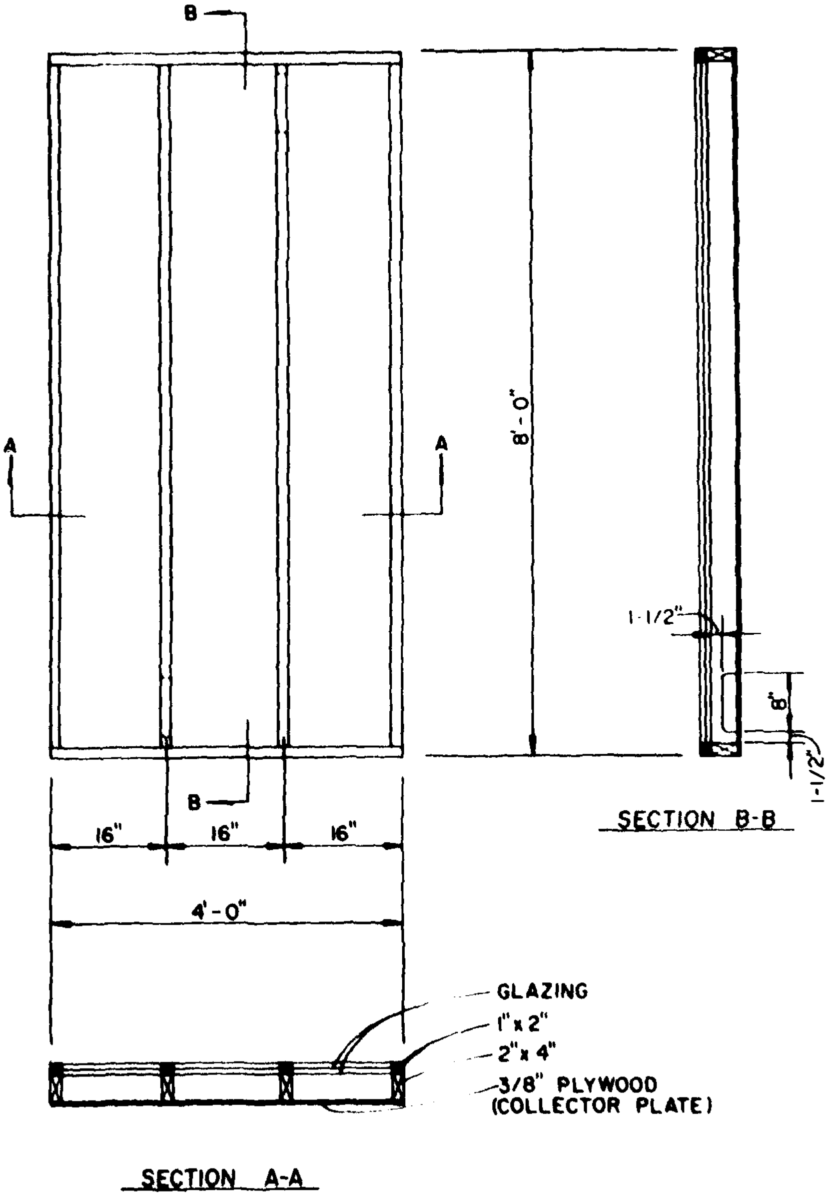

Figure 2.—Collector with 2 x 4 framing.

(M 148 281)

Estimated Effect of High Temperatures on Wood

As stated in the "Background" section, permanent reduction in strength of wood due to 1 year of exposure to a temperature of 200° F would be about 13 percent. In Panel 3, with such temperatures occurring for about 4 hours per day on about one-

Table 1.—Collector construction materials

Panel number	Framing	Back	Insulation	Collector	Collector paint	Glazing
1	2 x 10 Southern pine	3/8 CD Southern pine	1½ in extruded polystyrene	1/16 in aluminum	lacquer	Two 0.25 in glass sheets
2	2 x 10 Southern pine	3/8 CD Southern pine	1½ in extruded polystyrene	1/16 in aluminum	lacquer	Two 0.25 in fiberglass sheets
3	2 x 10 Douglas fir	3/8 CD Douglas fir	1½ in extruded polystyrene	1/16 in aluminum	flat	Two 0.25 in glass sheets
4	2 x 10 Douglas fir	3/8 CD Douglas fir	1½ in extruded polystyrene	1/16 in aluminum	flat	Two 0.025 in fiberglass sheets
5	2 x 4 Southern pine	3/8 CD Southern pine	None	Plywood back	lacquer	Two 0.25 in glass sheets
6	2 x 4 Douglas fir	3/8 CD Douglas fir	None	Plywood back	lacquer	One 0.025 in fiberglass and one corrugated fiberglass

third of the days of the year, the 13 percent reduction would occur in about 18 years. However, if 250° F occurred for about 2 hours per day, the 13 percent strength reduction would be estimated in 9 years. During the time this high temperature is maintained, a 40 percent immediate reduction in strength would also be expected to occur. It should be recognized that the above effects assume stagnation conditions in the collector. Under normal operating conditions, temperatures should be much lower.

Spontaneous ignition has occurred in wood heated above 212° F for long times, so the collector panels tested should not be maintained at stagnation conditions for long times. Under operating conditions, temperatures should be kept below 212° F.

Visual Observation of Materials

Although the primary objective of this study was to observe temperatures in the collectors under stagnation

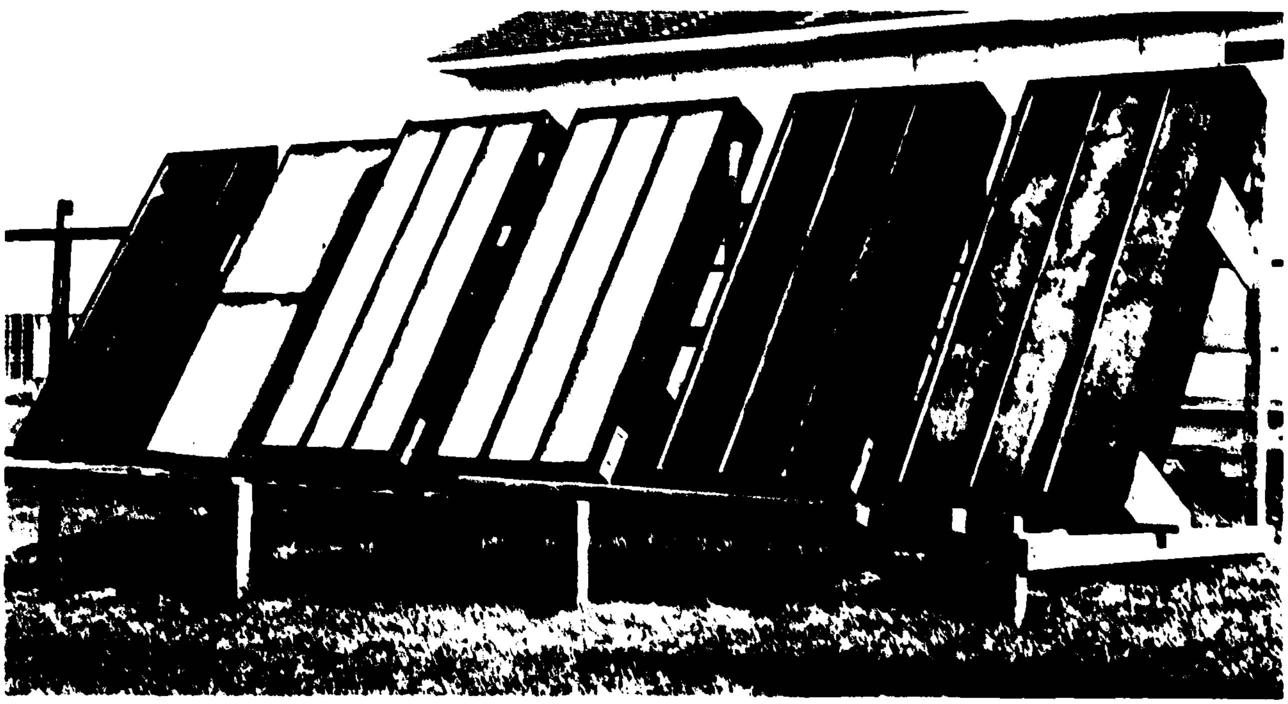

Figure 3.—All six solar collector panels mounted at the exposure site.

The mottling in the panel at the far right is the result of the black lacquer peeling off the metal collector plate and settling to the bottom of the panel.

In the second panel from the right, the arrow shows the crack in the glass of Panel 3.

(M 147 004-9)

U.S. Forest Products Laboratory.

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conditions and estimate their effect on wood, certain visual observations were made concerning materials in the collectors.

Wood

Solid wood in all of the collectors showed no visible signs of char or degradation of any type. Plywood on the backs of Panels 1, 2, 3, and 4 was insulated from the main cavity, and temperatures in Panels 5 and 6 were not high enough to have much effect on the plywood. However, plywood in all the panels was affected by condensation. Inside faces were water stained (fig. 5), and some delamination occurred. Screws used to attach the plywood were quite corroded. C-D grade plywood with an exterior glue was used as specified in the plans, but should not be used for continuous outdoor exposure. An exterior grade plywood should solve the delamination problem but moisture could eventually cause decay and the corroded screws would lose much of their holding power.

Paint

There appeared to be no major difference in the radiant heat collection ability of the two types of paint. The flat black paint used performed well with no peeling, blistering, or other signs of deterioration. The lacquer used did peel from the metal collector (fig. 3), and slightly lower temperatures were observed in the collector after peeling.

Insulation

The only insulation used was an extruded polystyrene, which the manufacturer recommends not be used where temperature exceeds 160° F. At temperatures over 200° F, the foam distorted severely (fig. 6). The least distortion occurred adjacent to the plywood because the average temperature was lower than where the 2- by 10- framing insulated the foam from outdoor temperature.

Under normal operating conditions, temperature in the collectors may not be high enough to damage the foam; however, if stagnation conditions are expected for even short periods, another type of insulation should be considered.

Glazing

Glazings included a clear glass, a translucent fiberglass, and a corrugated plastic. The translucent fiberglass

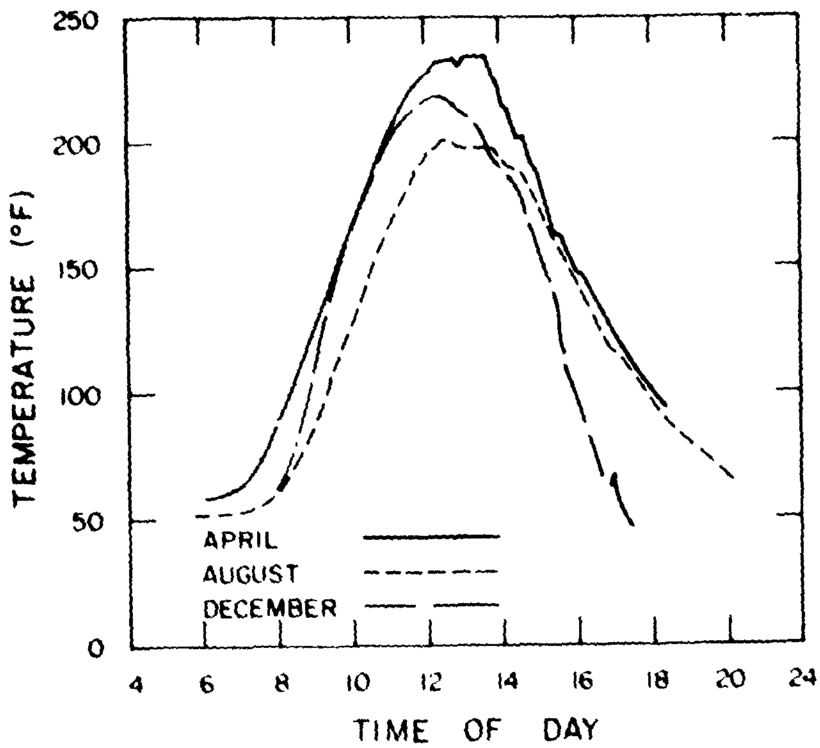

Figure 4.—Temperatures cycles in Panel 3 for a selected sunny day in each of three months.

Figure 5.—Plywood back of a collector panel badly water stained due to condensation.

produced slightly higher maximum temperatures than did glass. The flat fiberglass used in combination with corrugated plastic performed as well as two sheets of flat glass. A large crack occurred in one of the sheets of glass (fig. 3).

Following the test period, small pieces of glazing were cut from the collectors and light transmittance through them was measured with a spectrophotometer. Transmittance in the visible range (near infrared to near ultra violet) was the same as control specimens not used in the collectors.

Outgasing of wood could result in deposits on glazing that would reduce the transmission of solar energy to the collector plate. In Panels 1 through 4, most of the wood was separated from the glazing by the metal collector plate. In Panels 5 and 6, all of the wood was exposed to the glazing, but temperatures were never above 180° F There was no evidence of outgasing deposits on glazing in either case; however, this does not preclude outgasing problems where wood at higher temperatures is exposed to glazing.

Figure 6.—Rigid insulation severely distorted due to temperatures higher than manufacturer's recommendation.

(M 147 057-6)

Summary

The four insulated solar collector panels tested under stagnation conditions near Madison, Wis. frequently had temperatures above 200° F, which would reduce strength properties of wood over a long period of time. However, under operating conditions, temperatures should be considerably lower. Spontaneous ignition would not be expected under operating conditions when there is a flow of air over the wood members, but could occur if stagnation conditions were continuously maintained for long periods of time (months, years). Solid wood showed no visible signs of char or degradation of any type. Plywood backs on the panels were stained by condensation and slight delamination occurred. Screws used to attach the plywood to wood frames were badly corroded.

The flat paint performed well, but enamel used on metal collector plates peeled excessively. Polystyrene insulation distorted at high temperatures (manufacturer's literature recommended no use at temperatures above 160° F). The flat fiberglass sheets used resulted in slightly higher collector temperatures than did clear glass. There was no reduction in light transmittance in the visible range in any of the collectors. If there was outgasing from wood, gases did not reach the glazing and result in deposits that would have reduced collection of solar energy.