United States
Department of
Agriculture

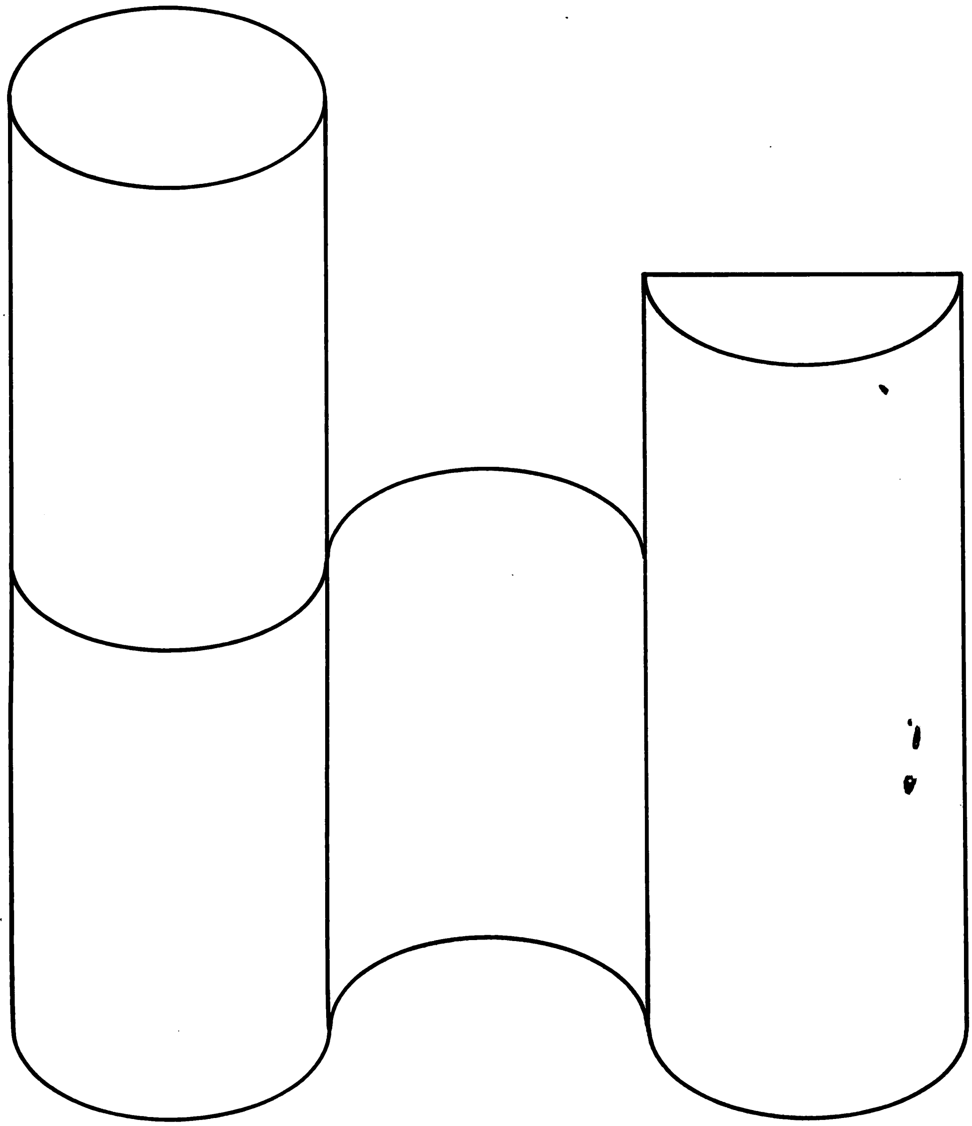
Forest
Service

North Central
Forest Experiment
Station

General Technical
Report **NC-92**

A Thermal Comparison Among Several Beverage Can Solar Collectors

Peter Y. S. Chen



North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication September 26, 1983
March 1984

A THERMAL COMPARISON AMONG SEVERAL BEVERAGE CAN SOLAR COLLECTORS

Peter Y. S. Chen, *Forest Products Technologist,*
Forestry Sciences Laboratory,
Carbondale, Illinois

One of the simplest and most efficient applications of solar energy is heating air for space heating or for drying applications. In 1977 we built an air-heated solar collector from aluminum beverage cans (Chen *et al.* 1978) and tested for its effectiveness in drying lumber in a solar kiln (Chen 1981), and in a solar-dehumidifier kiln (Chen *et al.* 1982). This solar collector was highly efficient and the solar kiln was able to dry 4/4 yellow-poplar from green to 15 percent moisture content (MC) in 8 days and the solar-dehumidifier kiln was able to dry 4/4 yellow poplar from green to 8 percent MC in less than 6 days during the summers of 1978 and 1980.

We were encouraged by this performance and wanted to know more about this type of solar collector. Therefore, we designed and built four air-heated solar collectors from aluminum beverage cans, each with a different configuration of cans. We tested these collectors for four consecutive seasons from summer 1981 to spring 1982 for their daily efficiencies. One of the collectors was also evaluated for one season for the effect of air velocity across the collector on efficiency, temperature rise, and power consumption rate of the collector.

DESIGN AND CONSTRUCTION

Our collectors differ from the common flat tray collectors in one essential aspect; ours contain numerous sectioned beverage cans behind two layers of transparent fiberglass covers. These cans, sprayed with two coats of flat black paint, act as both the black absorber surface of the collector and the heat transfer surface to the passing air. The amount of air that comes into close contact with the absorber surface is greatly increased in this way as compared to a standard flat tray collector while the total external collector area remains essentially unchanged. Two panes of fiberglass reinforced polyester ("Sunlite" from Kalwall Corp.[1]) were used as the collector cover and provided a stagnant air space that reduced heat loss from the collector back to the atmosphere. Air flowing through the collector was in contact with the heated can halves and also the inner layer of collector cover. The configurations for the four 2- by 8-foot test collectors are as follows (fig. 1).

All cans were tacked to ½-inch plywood.

Collector A—crosscut can halves tacked with ½-inch space between cans,

Collector B—crosscut can halves tacked side-by-side in contact,

Collector C—lengthwise cut can halves tacked parallel to air flow, and

Collector D—lengthwise cut can halves tacked perpendicular to air flow.

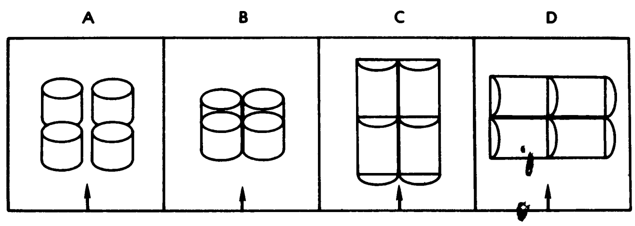


Figure 1.—*Different configurations of can halves used in the four test collectors. Arrows indicate the air-flow direction. A = crosscut can halves tacked with ½-inch space between cans, B = crosscut can halves tacked side-by-side in contact, C = lengthwise cut can halves tacked parallel to air flow, and D = lengthwise cut can halves tacked perpendicular to air flow.*

[1]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

A reflector measuring 6 feet by 15½ feet was built by gluing a layer of 5 mills foil of Mylar cover on top of ½-inch exterior plywood to reflect more solar radiation (therefore more heat) to the collectors (fig. 2).

TEST FACILITY AND METHODS

The variables measured were insolation, air velocity flowing through collectors, blower power consumption, and temperature rise of the heated air with respect to the inlet air temperature.

Insolation was continuously measured by a precision spectral pyranometer and recorded by a strip-chart recorder. A hot wire anemometer was employed to measure different air velocities flowing through collectors with 20 points at each cross section (table 1). Inlet and outlet temperatures in the collectors were measured and recorded by means of thermocouples and a multi-channel recorder.

Daily efficiencies of the four collectors were tested on four mostly clear days per season (two days with the reflector and two days without) for four seasons at the second highest air velocity (V_2). The second highest air velocity was chosen because it was the highest air velocity the four blowers can produce without reaching their limit. When the reflector was tested, we visually adjusted it to reflect solar radiation to the full length (8 feet) of test collectors (fig. 2). The effect of air velocity on temperature rise, collector efficiency, and power consumption rate was tested on two mostly clear days in the spring of 1981 without the reflector on Collector B (crosscut can halves tacked side-by-side in contact). Six different air velocities were tested (table 1). Tests were conducted for 2 hours in the middle of the day to minimize the nonsteady state effects of insolation.

Figure 2.—*The four test collectors with the common reflector.*

COLLECTOR PERFORMANCE

A measure of collector performance is the instantaneous collector efficiency, η_c, defined by Duffie and Beckman (1980) as the ratio of the useful heat gain to the incident solar energy.

$$\eta_c = \frac{Q}{AI} \qquad (1)$$

where

Q = the useful heat transferred to the working fluid in the solar collector (Btu/hr),

A = the collector area (ft^2), and

I = the insolation measured on the collector surface (Btu/ft^2/hr).

For our system with air as the working fluid,

$$Q = \dot{m} c_p \Delta T \qquad (2)$$

where

$\dot{m}$ = the mass flow rate of air (lb/hr),

c_p = the specific heat of air at constant pressure (Btu/lb/°F),

Table 1.—*The effect of air velocity on instantaneous collector efficiency (η_c), temperature rise, and power consumption rate of collector*

Air velocity CF/SF/m[1]	Rank	Outlet temperature	Temperature rise	η_c	Power consumption rate
		°F	°F	Percent	kW
11.0	V_1	88.5	21.0	75	0.155
9.9	V_2	90.5	22.5	72	.081
8.7	V_3	93.0	24.5	68	.064
6.4	V_4	97.5	28.5	57	.054
4.7	V_5	102.0	31.5	48	.043
2.3	V_6	116.0	45.5	33	.020

[1]CF/SF/m = cubic foot of air/square foot of collector area/minute.

ΔT = the temperature rise (measured by thermocouples) of the air through the collectors. (°F)

Thus,

$$\eta_c = \frac{\dot{m} c_p \Delta T}{AI} \quad (3)$$

For daily efficiency, η_d, the sum of the useful heat collected (ΣQ) was divided by the total unreflected solar radiation (ΣI) arriving at the solar collector. Thus,

$$\eta_d = \frac{\Sigma Q}{A \Sigma I} \quad (4)$$

RESULTS AND DISCUSSION

The effect of can half configuration on daily efficiency of collectors was statistically significant. Duncan's multiple range test showed that Collectors D and B were not different from each other and that Collectors B and A were not different from each other. However, Collector D was superior to Collectors A and C, and Collector B was superior to Collector C (table 2). Even though Collector D (lengthwise cut can halves) requires only slightly more than one-half of the aluminum cans per square foot of collector area compared to Collector B (crosscut can halves), it is much more time-consuming and difficult to cut aluminum cans in half lengthwise than crosswise. Thus, the extra labor costs can easily overshadow the potential material savings of Collector D.

To show how the reflector affected insolation and heat collection, Collector D was monitored with and without the reflector during two consecutive days of almost identical daily insolation (2,008 Btu/ft² of September 20, 1981, vs. 1,986 Btu/ft² of September 21, 1981) (fig. 3). Both insolation and useful heat curves indicated that the fixed reflector was effective for 4 to 6 hours around noon. The fluctuation of the insolation of September 20, 1981 (with the reflector), was caused by the bumpy surface of the reflector. A heavier reflective material would probably provide a flatter reflector surface.

Table 2.—*Mean daily efficiencies (η_d) of the four test collectors*

Duncan's grouping[1]		Mean η_d	Days	Collector[2]
		Percent	*Number*	
	a	73	16	D
b	a	71	16	B
b		69	16	A
	c	67	16	C

[1]Means with the same letter are not significantly different.

[2]Collector A—crosscut can halves tacked with ½-inch space between cans,

Collector B—crosscut can halves tacked side-by-side in contact,

Collector C—lengthwise cut can halves tacked parallel to air flow, and

Collector D—lengthwise cut can halves tacked perpendicular to air flow.

The mean daily efficiency of the four collectors tested with the reflector was significantly higher than that of the same collectors tested without the reflector throughout the year (table 3). Collectors tested with the reflector averaged 73 percent daily efficiency compared to 67 percent daily efficiency without the reflector. Although the difference in mean daily efficiency between tests with and without the reflector was significant, the 6 percent increase in daily efficiency may not be enough to offset the extra costs for installing and maintaining the reflector.

The seasonal effect on the mean daily efficiency of the collectors was not statistically significant. Although the mean daily efficiencies among the four seasons appeared to increase with decreasing temperature of the season, the variation in daily efficiency between the 2 days tested within each season was as great as the difference shown among the four seasons.

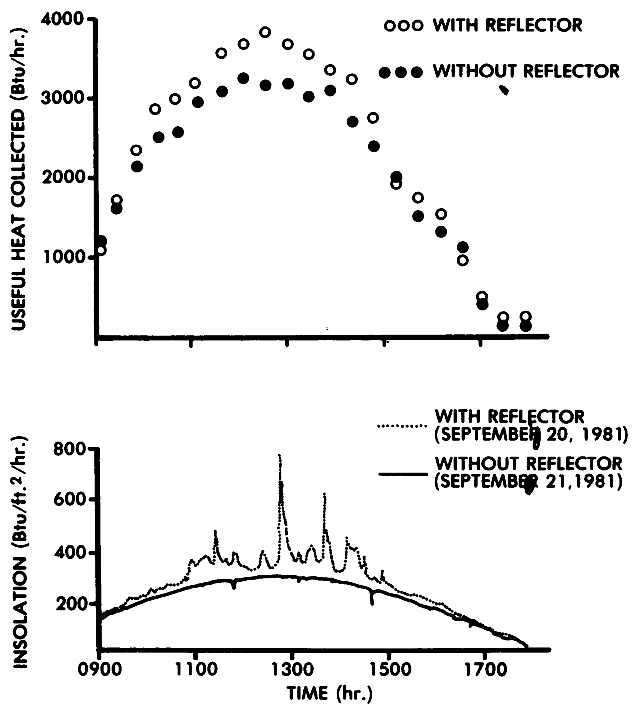


Figure 3.—*Effect of reflector on useful heat collection and insolation of Collector D during two consecutive days of almost identical daily insolation.*

Table 3.—*Mean daily efficiencies (η_d) of collectors with and without reflector*

Duncan's grouping[1]	Mean η_d	Days	Reflector
	Percent	*Number*	
a	73	32	Yes
b	67	32	No

[1]Means with the same letter are not significantly different from each other.

The interaction between the reflector and the season was significant (fig. 4). As expected, the mean daily efficiency curve without the reflector showed a trend of increasing efficiency with decreasing temperature of the season. However, the mean daily efficiency curve with the reflector did not show a corresponding increase in mean daily efficiency with decreasing temperature of the season. The fact was that all seasons, except summer, showed a mean daily efficiency of nearly 75 percent. It is possible that 75 percent daily efficiency is the maximum limit that this type of solar collector can reach.

Tests on the effects of six different air velocities showed that collector instantaneous efficiency varied proportionally to the air velocity across the collector and power consumption rate but inversely proportionally to the collector outlet temperature and temperature rise (outlet temperature - inlet temperature) (table 1). This information is useful to a solar kiln operator in maximizing collector efficiency and minimizing power consumption. For example, during the early stages of lumber drying, the kiln operator should use a high air velocity (V_2 or V_3) to collect solar energy at relatively higher efficiency but at relatively lower outlet temperature and at a moderate electrical energy cost. V_2 is approximately four times faster than the air velocity used in residential space heating. However, toward the end of drying, the kiln operator should raise kiln temperature by reducing air velocity in order to increase the outlet temperature of the collector and simultaneously reduce power consumption.

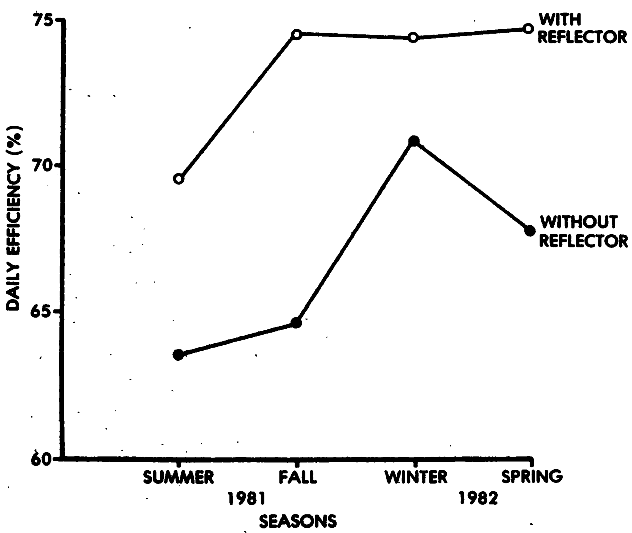


Figure 4.—*Demonstration of reflector-season interaction.*

CONCLUSIONS

1. Collector B (crosscut can halves tacked side-by-side in contact) was deemed to be the best among the four collectors tested when collector efficiency and collector cost were considered.
2. A reflector can increase collector efficiency, especially during noon hours.
3. Collector efficiency varies proportionally to the air velocity across the collector and power consumption rate but inversely proportionally to the collector outlet temperature and temperature rise.

LITERATURE CITED

Chen, P. Y. S. Design and tests of a 500 BF solar kiln. For. Prod. J. 31(3): 33-38; 1981.

Chen, P. Y. S.; Helmer, W. A.; Rosen, H. N.; Barton, D. J. Experimental solar-dehumidifier kiln for drying lumber. For. Prod. J. 32(9): 35-41; 1982.

Chen, P. Y. S.; Workman, E. C., Jr.; Helton, C. E. How to build a collector for a solar kiln with aluminum cans. FPRS News-Digest, Processes: Drying and Storage, G-1.14; 1978. 4 p.

Duffie, J. A.; Beckman, W. A. Solar engineering of thermal processes. New York, NY: John Wiley and Sons; 1980. 199 p.

Chen, Peter Y. S.
A thermal comparison among several beverage can solar collectors. Gen. Tech. Rep. NC-92. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 4 p.

Four air-heated solar collectors were built using four different configurations of aluminum beverage cans. The collectors were then tested for four consecutive seasons for their daily efficiencies. One of the collectors was also evaluated for one season for the effect of air velocity on efficiency, temperature rise, and power consumption of the collector.

KEY WORDS: Efficiency, configuration, reflector, insolation, temperature rise, power consumption.

U.S. GOVERNMENT PRINTING OFFICE:1984-765-802/5162