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## **Abstract**

The use of solar energy for drying shelled corn was investigated. In a three-year field study, energy requirements of a conventional low-temperature electric drying installation were compared with those of a similar system supplemented with the output of a simple, inexpensive solar collector.

## **Disciplines**

Agriculture | Bioresource and Agricultural Engineering

## **Comments**

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# Grain Drying With Supplemental Solar Heat

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## ABSTRACT

**T**HE use of solar energy for drying shelled corn was investigated. In a three-year field study, energy requirements of a conventional low-temperature electric drying installation were compared with those of a similar system supplemented with the output of a simple, inexpensive solar collector.

## INTRODUCTION

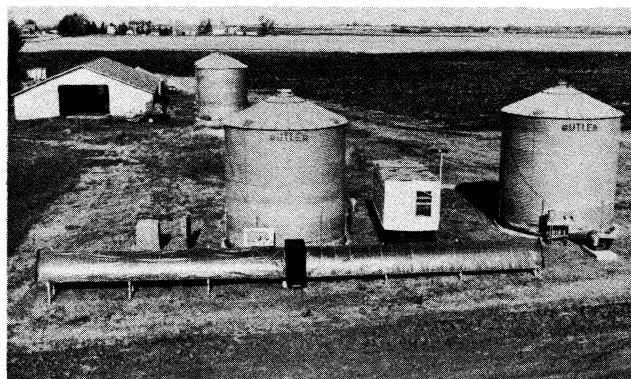
Recent concern regarding price and availability of conventional energy supplies has spurred interest in alternative sources for use in crop drying. From among the available options, increasing attention is being directed to the utilization of heat from solar radiation.

Although currently active, the notion of using sunlight for crop drying is hardly new. Since the beginning of agriculture, the solar drying of forages and grains has been practiced with varying degrees of sophistication and success. As recently as 15 yr ago, solar crop drying was the subject of extensive research activity (Buelow and Boyd, 1957; Buelow, 1958; Lipper and Davis, 1960; Löf, 1962; Peterson, 1963; Baily and Williamson, 1965). Much of this early solar work was subsequently obscured by the adoption of high-temperature grain-drying technology based on inexpensive and abundant fossil fuels.

Present-day energy realities have enhanced the appeal of low-temperature grain drying. Unlike the conventional high-temperature approach, low-temperature drying is not dependent on increasingly uncertain supplies of LP and natural gas. One-day bin filling and improved grain quality are other advantages cited (Shove, 1972).

Low-temperature drying appears well-suited to solar thermal supplementation. Because only low air-temperature rises are required, relatively simple and inexpensive solar collectors are adequate. Further, because constant temperatures are not required, low-temperature drying is compatible with the intermittent nature of solar radiation.

The objective of this Iowa State University solar grain-drying project was to compare the energy requirements of a conventional, low-temperature shelled-corn drying installation with those of an identical system sup-



**FIG. 1** Solar grain drying facility at Iowa State University Woodruff Farm southwest of Ames. Left bin is equipped for solar-supplemented low-temperature electric drying. Right bin is equipped for conventional low-temperature electric drying.

plemented with solar-heated air.

## FACILITIES

### Drying Equipment

Grain storage and drying facilities for the project were installed near Ames, IA (Fig. 1). We equipped two 5.5-m (18-ft) diameter, 5.2-m (17-ft) high steel grain bins for electric low-temperature shelled corn drying. Both were equipped with perforated floors, 3.7 kW (5 hp) axial-flow fans, electrical resistance heaters (4.8 kW for 1974, 2.4 kW for 1975 and 1976), and grain spreaders. We placed a solar collector south of one of the bins to provide supplemental heat for drying. The second bin served as the experimental control.

### Collector

We selected a free-standing, optimally tilted collector design to provide the desired supplemental solar heat. Important among the concept requirements was the utilization of standard-size, readily-available materials which would minimize complexity and cost. The collector design was based on a maximum desired temperature rise following previously published guidelines and data (Buelow, 1962; Close, 1963; Peterson, 1973a). Solar radiation information was drawn from generalized radiation data (Becker and Boyd, 1961; Buelow, 1967; ASHRAE, 1974) and from long-term solar records for Ames, IA (Waite and Shaw, 1961) (Fig. 2). Design criteria and specifications are summarized below:

- 1 Collector type: covered, suspended-plate
- 2 Design radiation level (max.): 3.5 MJ/m<sup>2</sup>-h (310 Btu/ft<sup>2</sup>-h)
- 3 Design temperature rise (max.): 5.6 °C (10 °F)
- 4 Design airflow (per section): 1.04 m<sup>3</sup>/s (2200 cfm)
- 5 Design efficiency (max.): 65 percent
- 6 Mounting angle: 55 deg from horizontal

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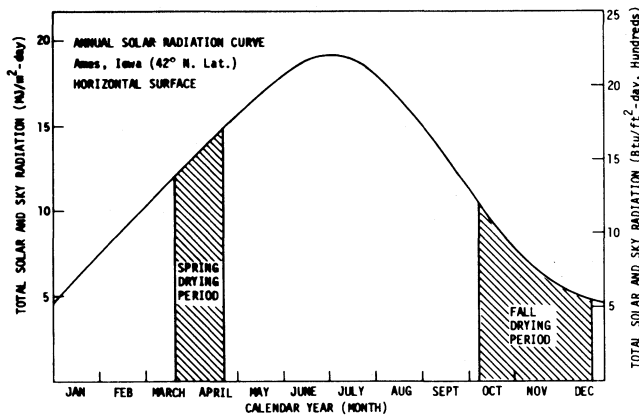


FIG. 2 Typical annual radiation curve for Ames, IA, horizontal surface. Drying periods employed in the study are indicated.

- 7 Absorber surface area: 23.2 m<sup>2</sup> (250 ft<sup>2</sup>)
- 8 Cross-sectional area: 0.21 m<sup>2</sup> (2.3 ft<sup>2</sup>)
- 9 Cost for material: \$150

The collector was constructed from 9.5-mm (3/8-in.) exterior plywood, dimension lumber, and 0.15-mm (6-mil) polyethylene plastic film (Fig. 3). The collector was fabricated in two sections, each 1.22 m (4 ft) wide and 9.75 m (32 ft) long. Black polyethylene was stretched over each trough-like section to provide a suspended-plate absorbing surface and form a lower air duct. A clear polyethylene cover was supported on arched wooden ribs and 15- by 15-mm (6- by 6-in.) concrete reinforcing screen made of 3-mm (1/8-in.) steel wire. This cover enclosed the upper air passage.

Because clear polyethylene is relatively transparent to long-wave reradiation from the absorber surface, it affords little of the "greenhouse effect" sometimes attributed to glass collector covers (Briston, 1974). We included the cover to reduce convective losses, particularly under windy ambient conditions. No insulation was applied to the back of the collector in view of the modest thermal gradients associated with a 5.6 °C (10 °F) maximum temperature rise.

Support frames were constructed and aligned on an east-west axis to provide south-facing collector mounts. The two collector sections were ducted to the dryer fan intake by means of a plywood junction box. In operation, drying air was drawn in at the ends of the collector and through the airspace on either side of the suspended ab-

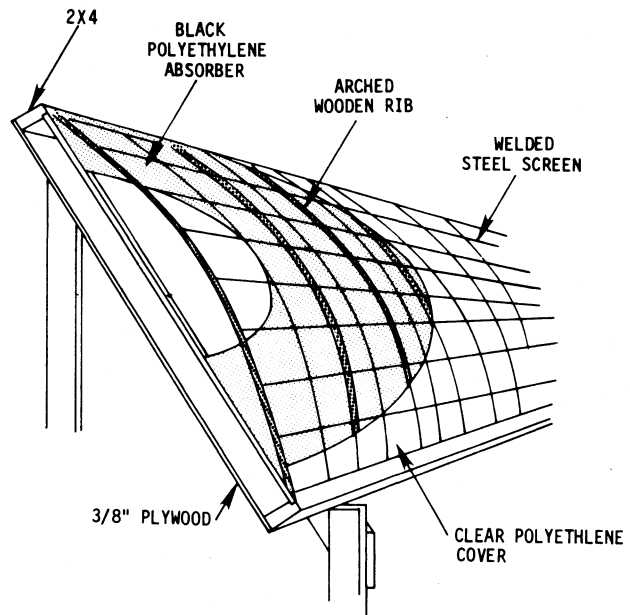


FIG. 3 Collector detail.

sorber film to the centrally located fan intake. A hinged inlet panel on the box front permitted the collector to be by-passed when desired.

#### Instrumentation

We provided thermocouples and a multipoint chart recorder to record ambient, collector, and transition air temperatures. Temperatures within the grain mass were monitored with thermocouples and a manual readout meter.

Watt-hour meters were installed to record energy consumed by the heaters and fans. A time clock permitted automatic cycling of the solar bin heater. We recorded the solar radiation using a dome solarimeter tilted at the collector angle.

#### PROCEDURE

##### Loading

Each year bins were loaded over a period of not more than 2 days, commencing on the starting date listed in Table 1. The corn was not cleaned prior to loading in the bins. Average initial moisture contents are listed in Table 1 for each year.

TABLE 1. COMPARATIVE DRYING RESULTS

	1974	Solar bin 1975	1976	1974	Control bin 1975	1976
Grain quantity, t drymatter (bu*)	70.2 (3265)	74.2 (3450)	66.9 (3109)	68.8 (3199)	73.3 (3407)	64.3 (2989)
Average initial moisture content, % w.b.	19.8	18.1	23.0	19.9	18.2	24.3
Average final moisture content, % w.b.	14.4	14.4	13.3	14.0	14.3	13.4
Starting date	Nov. 25	Oct. 25	Oct. 6	Nov. 25	Oct. 25	Oct. 6
Drying period, days	44 44	24 24	33 33	44 44	23 23	35 35
Airflow rate, m <sup>3</sup> /s·t dry matter (cfm/bu)	0.028 (1.3)	0.023 (1.0)	0.030 (1.4)	0.030 (1.4)	0.023 (1.0)	0.032 (1.5)
kWh used by fan and heater	8783	4475	6097	11,399	5369	7241
kWh/t dry matter · % point (kWh/bu · % point)	23 (0.50)	16 (0.35)	9.4 (0.20)	28 (0.60)	19 (0.40)	10.3 (0.22)
Electrical energy cost for drying† \$/t dry matter (¢/bu)	4.00 (8.6)	1.93 (4.2)	2.92 (6.3)	5.30 (11)	2.34 (5.0)	3.60 (7.8)

\* 1 BU = 47.32 LB Dry Matter

† Electrical energy cost: 3.2¢/kWh

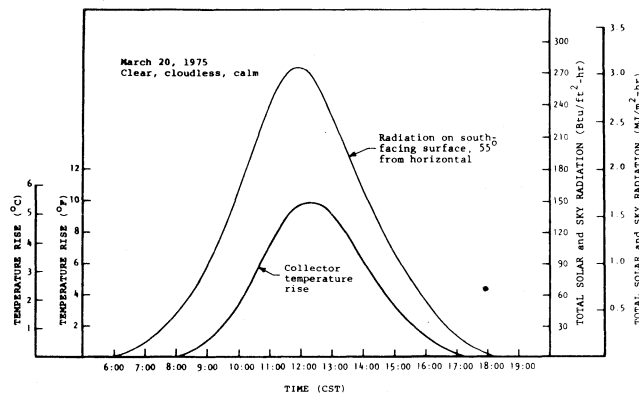


FIG. 4 Daytime collector air temperature rise and solar radiation received by collector.

### Drying

After analysis of long-term weather data we adopted the following management schedule:

	Operation of solar bin	Operation of control bin
Dryer fan, 3.7 kW (5 HP)	Continuous	Continuous
Heater (4.9 kW 1974, 2.4 kW 1975, 1976)	7 pm to 7 am	Continuous
Solar collector	Continuous	---

Drying was continued until corn at the top of the bin reached a moisture content of 15 percent. This occurred during November in 1975 and 1976. In 1974, drying was halted December 19 because of unfavorable daily weather conditions. From December 30 to March 18, 1975, we operated the drying fans 2 h daily to maintain grain quality. Drying was resumed March 19 and completed in both bins April 22, 1975.

## RESULTS AND DISCUSSION

### Collector

Collector performance compared favorably with that predicted from the design criteria. Fig. 4 shows a typical temperature-rise curve for a bright, sunny day, together with a curve of the radiation incident on the inclined collector surface. The maximum temperature rise is about 5.6 °C (10 °F). The maximum efficiency approaches 67 percent at solar noon. Average daytime efficiency exceeds 40 percent. Note that the temperature rise maximum lags slightly behind the insolation peak, indicating a "sink-source" heat exchange between the collector body and the air.

An extra 0.6 to 1.1 °C (1 to 2 °F) rise was observed on days when a reflective, snow ground cover coincided with bright sunlight. The maximum temperature rise recorded was 6.1 °C (11 °F).

The effect of long-wave radiation from the collector was noted during cloud-free nights. This loss produced a negative collector temperature change of 0.56 °C (1 °F).

Table 2 shows average temperature rises of the drying air stream on each bin during the 1974 drying season. The average temperature rise attributable to the solar collector was 0.61 °C (1.1 °F) for the entire drying period. The average total temperature rise for the solar bin is 0.3 °C (0.6 °F) lower than that of the control bin. The difference in the electric heater contribution between the two bins is due to the difference in the

TABLE 2. AVERAGE TEMPERATURE RISES OF DRYING AIR STREAM (1974 DRYING SEASON)

	Solar bin		Control bin	
Electric heater, °C (°F)	0.98	(1.8)	1.9	(3.5)
Motor and fan, °C (°F)	1.4	(2.5)	1.4	(2.5)
Solar collector, °C (°F)	0.61	(1.1)	---	---
Total, °C (°F)	3.0	(5.4)	3.3	(6.0)

operating schedule.

Airflow through each section of the collector was approximately 0.99 m<sup>3</sup>/s (2100 cfm), based on static pressure measurements and the fan characteristics. The static pressure drop through the collector was 100 Pa (0.4 in. water). This restriction caused a flow reduction of about 0.17 m<sup>3</sup>/s (350 cfm) in each collector section.

Outdoor exposure from November 1974 through April 1975 caused no significant deterioration of the collector. Before drying was resumed in mid-March, the transparency of the clear plastic covering was evaluated. Radiation attenuation through the cover was compared with that of new film. A transmission reduction of 3 to 4 percent was measured. We judged this degree of clouding insufficient to warrant replacement. Continued exposure into May produced accelerated transparency degradation. Cover and absorber surfaces had to be replaced prior to the 1975 drying season, and again prior to the 1976 drying season.

At the end of the 3-yr field study, the collector structure was still usable and with continued annual cover and absorber surface replacement, we estimated its life at two more years.

### Drying Results

Corn was unloaded from the bins at the average final moisture contents listed in Table 1. All grain was unloaded in excellent condition. The average final grain moisture content may be lower than desirable for some uses. This overdrying occurred before the top layer of corn reached the 15 percent moisture content shut down point.

The solar collector replaced 2616, 894, and 1144 kWh of electrical energy during the 1974, 1975, and 1976 drying seasons, respectively. This averages to 19 percent of the total electrical energy required by the control bin. Over the 3-yr test period, 4654 kWh of electrical energy, having a value of \$149\* was replaced.

The original cost for materials was \$150. Materials for collector maintenance required during the 3-yr study came to \$60, for a total cost of \$210. Projecting material costs and energy savings to the end of the 5-yr collector life, we estimate a total energy savings of 7757 kWh (worth about \$248) and a total materials cost of about \$270.

## CONCLUSIONS

1 Solar heat can be successfully used as a supplement to electrical resistance heat with a low-temperature drying system which adds heat to the air in addition to the heat supplied by the dryer fan and motor.

2 Under conditions similar to those of this investigation, solar energy can replace about 19 percent of the electrical requirements of drying (worth about \$0.70/t

\*Electrical energy cost: 3.2¢/kWh.

dry matter or 1.5 ¢/bu).

3 Under conditions similar to those of this investigation, polyethylene cover and absorber surfaces must be replaced after each drying season.

4 Under conditions similar to those of this investigation, the value of energy savings will not quite equal the total cost of materials for the collector.

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