The Young Solar Collector:
An Evaluation of Its Multiple Farm Uses

Walter G. Heid, Jr.
**Abstract**

The homemade, low-cost Young flat-plate solar collector, well suited for multiple agricultural uses, was designed by a Nebraska farm couple and personnel from the Small Farm Energy Project. It is portable and tiltable, with a flexible airflow system. The collector satisfactorily dried grain and heated the Young farm home. Use of the collector in the fall and winter of 1979 saved 331 gallons of propane worth $179. Net energy savings yielded an 11.2-percent return on investment and, including allowable tax credits, gave a payback of 5.8 years, making this collector—with an expected 20-year life—an attractive investment for farmers and lending institutions.

Keywords: Solar energy, flat-plate collector, grain drying, home heating, payback.

**Note**

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Summary

An efficient solar collector designed for multiple uses on the farm, including grain drying and home heating, has been developed by a Nebraska farm couple and the Small Farm Energy Project of the Center for Rural Affairs in Hartington, Nebr. The Young collector, named after its farmer-designers, performed successfully in 1979 and appears to be an attractive farm investment.

The collector performed efficiently, drying corn from 18.5- to 15-percent moisture in the fall of 1979. Attached to the Young farm home in the winter of 1979/80 for 4 months, the collector provided 20 percent of the total heating. More than 330 gallons of propane valued at $179 were saved in drying and heating.

This solar collector is portable, can be tilted to receive the maximum available solar radiation, and features a flexible airflow system. This combination of features makes the Young collector ideal for several diverse farm uses. It is simple to construct with used lumber and other materials commonly found around the farmstead. There are no prefabricated parts.

For grain drying, the collector and fan system can produce an airflow of 3,000 cubic feet per minute at 1.2 inches of static pressure and produce a temperature rise of 12°F at noon. For home heating, the collector produces 19,700 Btu per hour at noon, with a temperature rise averaging about 40°F.

Investment in the Young collector, including the cost of a used four-wheel running gear, totaled $1,410, or $5.88 per square foot of collector surface. After deducting regular investment credit from this cost, net energy savings resulted in an 11.2-percent return on investment. Payback was estimated at 5.8 years for the collector, which has a 20-year expected lifespan. With such a short payback, the Young collector appears to be a safe system for lenders to finance and an attractive investment for farmers.
Plans Available

Construction plans for the Young collector may be purchased from the Small Farm Energy Project, P.O. Box 736, Hartington, Nebr. 68739. Specify “Portable Solar Collector Plans.” The cost is $2 per set. The charge covers expenses only; the Small Farm Energy Project is a U.S. Government-funded nonprofit organization. The collector and its plans are not copyrighted. Information and specifications relating to this collector are within the public domain.

Acknowledgments

Gary and Delores Young, farmers from McClean, Nebr., and Dennis L. Demmel, codirector, and Robert M. Aiken, research assistant, Small Farm Energy Project, Center for Rural Affairs, Hartington, Nebr., provided information used to describe and analyze this multiple-purpose solar collector.
The Young Solar Collector: An Evaluation of Its Multiple Farm Uses

Walter G. Heid, Jr.*

Introduction

The homemade, low-cost Young flat-plate solar collector, for multiple uses on the farm, was designed by a Nebraska farm couple and personnel of the Small Farm Energy Project.\(^1\)

Most commercially built air-type solar collectors are designed for one use: residential heating. With restricted airflow (small air channels), their applicability to farm uses is limited. Early designs for homemade collectors were also largely single-use oriented. Recently, however, flexible airflow has been designed into a few collectors. Two added features, portability and tiltability, were combined by the Small Farm Energy Project to produce an effective and economic homemade collector. The Young collector, designed and constructed in 1978, is the first flat-plate collector design that incorporates all three features. It is especially effective for grain drying and home heating.

This study describes the features of the Young collector and reports on its physical and economic performance on the Gary and Delores Young farm near McClean, Nebr. They found it an economical investment, saving both conventional fuels and cost of operation.

The Youngs originally considered two vertical wall collectors to dry their grain and heat their home. However, after learning more about multiple-use collectors, they decided that one collector could be used for both purposes. Mr. and Mrs. Young designed and constructed the solar collector, receiving some technical assistance from personnel of the Small Farm Energy Project.

\*Agricultural economist stationed at the U.S. Grain Marketing Research Laboratory, Manhattan, Kans.

\(^1\)The Small Farm Energy Project, administered by the Center for Rural Affairs, is a nonprofit corporation largely funded by the Community Services Administration. The project demonstrates that farm technology can be tailored to help small farm owners use resources available on their farms, thus reducing their dependence on purchased inputs. Personnel of the project work with farmers by providing information on energy-saving devices. Farmers select innovations that they wish to install; technical information and assistance is provided.
Investment Costs

The Young collector cost about $1,310 excluding labor, or $5.46 per square foot of collector surface (table 1). Valuing a used running gear—an integral part of the collector—at $100, the total investment increased to $1,410, or $5.88 per square foot. (A new four-wheel running gear is valued at $525.) Approximately 84 hours of labor were used to construct this collector. Extra time was required to plan the collector; a set of plans will allow future collectors to be constructed in less time.

The investment cost would have been approximately $2,065 (1980 dollars) if all new materials had been used. Thus, substantial savings from using the Youngs’ own labor and used materials were realized. However, given allowable tax credits on homemade collectors, the savings in labor and materials cost may not be as great as expected because of the use of these resources. If a collector is built of all used materials, it does not qualify for regular investment credit, energy investment credit, or residential energy tax credit. Neither can the value of labor be used as a tax credit if it is the taxpayer’s own labor. However, if part of a homemade collector is made of new materials and if any labor is hired to construct it, then that portion of the collector cost (value) qualifies for tax credits.

Table 1—Investment costs for the Young collector, 1979

<table>
<thead>
<tr>
<th>Item</th>
<th>Investment</th>
<th>Dollars</th>
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<tbody>
<tr>
<td>Collector, with frame</td>
<td></td>
<td>610</td>
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<tr>
<td>Fiberglass cover with seals</td>
<td></td>
<td>140</td>
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<tr>
<td>Ducts and adapters</td>
<td></td>
<td>260</td>
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<tr>
<td>House fan and controls</td>
<td></td>
<td>135</td>
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<tr>
<td>Transport and lift equipment</td>
<td></td>
<td>140</td>
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<tr>
<td>Anchors and miscellaneous</td>
<td></td>
<td>25</td>
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<tr>
<td>Total cost</td>
<td></td>
<td>1,310</td>
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<tr>
<td>Investment per square foot</td>
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<td>5.46</td>
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This means, for example, that instead of being able to write off $800 (40 percent), assuming a collector used for residential heating and valued at $2,000, the 40-percent tax credit can be claimed only on the value of the new materials used. If only $500 of the total value is for new materials, the residential energy tax credit would be only $200. The entire purchase price of commercially built collectors can be used to compute tax credits.

The type of tax credit allowed also depends on the type and the use of the collector. The Young collector, not being a structural component of a building, qualifies for investment credit. If collector use must be prorated between farm and residential use, then the farm portion (new materials and hired labor only) should qualify for the 10-percent investment credit, plus a 15-percent business energy credit and normal depreciation. The residential portion qualifies for a special residential energy tax credit.

Farmers may wish to consult with their local Internal Revenue Service office on how to handle tax credits, focusing closely on homemade systems and allocations between agricultural and residential uses.

Performance

All performance tests on the Young collector were made onsite since no official or centralized test sites are available for evaluating homemade collectors. However, all tests performed on this collector are believed to be reasonably accurate and appropriate since recognized instrumentation and procedures were used by the Small Farm Energy Project engineers.

The Youngs kept detailed records on the collector's performance throughout the 1979/80 grain drying and home heating season. In addition to the temperature of ambient air going into the collector and warm air coming out, they monitored the amount of solar energy reaching the collector, the number of hours the collector operated each day, and weather conditions including temperature.

Homemade collectors are more system dependent than manufactured collectors. Panels cannot be removed and transported to centralized testing sites. Although onsite engineering tests are more limited than those conducted at central testing centers, sufficient tests can be made to establish collector value.
wind velocity, and the cloud cover. From this daily journal, the Small Farm Energy Project engineers prepared a summary of collector operation throughout the season of grain drying and space heating.

**Efficiency**

Using an instantaneous collector efficiency calculation,

\[
\text{Efficiency} = \frac{\text{Energy produced}}{\text{Energy available}} = \frac{(\Delta T)(1.08)(\text{Airflow in cfm})}{(\text{Insolation})(\text{Collector area})},
\]

the collector's efficiency while drying grain was estimated for six different operating periods. At an airflow of 2,000 cubic feet per minute (cfm) and grain depths of 3 to 6 feet, the collector's efficiencies ranged from 58 to 80 percent, a reasonable range considering optimal operating conditions. At grain depths of 7 feet and 1,500 cfm of air, the efficiency rating measured 65 percent.

The Youngs dried 2,000 bushels of shelled corn from 18.5-percent moisture to 15 percent. The collector delivered air to the bin at 2,000 cfm with an average temperature rise ($\Delta T$) of 17°F on the calm, clear October days. Relative humidity typically dropped from 62 percent for the ambient air to 27 percent for the solar heated air. Collector efficiency averaged 65 percent on the clear days of the drying season.

The Youngs operated the 1.5-hp grain drying fan for 516 hours at a cost of nearly $20 (3.4 cents/kWh) and a savings of 190 gallons of propane gas. The value of the savings was $102.60, given a propane gas cost of 54 cents per gallon. Net savings, deducting the cost of operating the drying fan, were about $83.

The collector produced a $\Delta T$ of over 40°F at noon on calm, clear days when the outside temperatures ranged from 30°F to 40°F (fig. 1). On cold, windy days, between -6°F and 20°F, with more than 10-mph wind velocity, the collector typically produced a $\Delta T$ of 24°F at noon.

The collector was next moved to the Young home for space heating after the grain drying period in the fall of 1979. From late November to early May 1980, the system produced 9,470,000 Btu of heat for the home, an equivalent of 141 gallons of propane. Throughout the

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$^5$Temperature rise ($\Delta T$) is the difference between the temperature of the heated air coming out of the collector and the outside air (ambient) temperature.
mild winter of 1979/80, the collector fan operated 727 hours, drawing 137 kWh at a cost of $4.65. With a propane cost of 54 cents per gallon, the fuel saving was $76.14. Thus, the net saving was $71.49. (Performance data collected for the final 4 months of the 1978/79 home heating season suggest that the solar collector may save considerably more propane in hard winters.) The solar collector provided 20 percent of the home heating needs during the winter of 1979/80 according to the Youngs’ records (fig. 2).

Payback

Simple payback is the time, measured in years, required for the cumulative value of energy cost savings to equal the investment costs of the solar collection system. Simple payback does not consider escalating fuel prices and inflation. Although recognized as only a rough estimate of payback, the results of this measurement are probably as accurate as estimates that are based on tenuous assumptions about inflation, interest rates, and fuel escalation rates. Simple payback provides a useful and easily computed estimate for
farmers and lenders who desire to know if a system is cost effective (is the payback time less than the useful life of the system?).

The formula used to compute simple payback is:

\[ P = \frac{I - TC_i - TC_e - TC_r}{E - P_f} \]

where

- \( P \) = Payback
- \( I \) = Initial investment
- \( TC_i \) = Regular investment tax credit
- \( TC_e \) = Special energy tax credit
- \( TC_r \) = Residential energy tax credit
- \( E \) = Value of usable Btu produced
- \( P_f \) = Parasitic fuel costs (for electricity to run the fans on the collector)

Figure 2

**Solar Contribution to Young Home Space Heating**

Heat units in gallons of propane

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1979-80 heating season
The out-of-pocket investment cost of the Young collector is estimated at $1,410, including the value of the used running gear. Allowable tax credits must be considered to figure payback. These credits are computed on the presumption that approximately 25 percent of the collector's use is allocated to grain drying and 75 percent to home heating. Tax credits allowable for the grain drying portion include the 10-percent regular investment credit, $35, and the 15-percent energy investment credit, $53. The residential portion of the collector's value qualifies it for the special 40-percent incentive tax credit, $423. To compute payback, each of these three one-time tax credits are deducted from the initial investment cost.

The value of energy produced for grain drying in 1979 was $103. The value of energy produced for home heating was $76, bringing the total value of usable Btu produced to $179. Parasitic power costs totaling about $25 are subtracted, leaving a positive annual value of $154.

The payback formula, using these values, produces this result:

\[
    P = \frac{1,410 - 35 - 53 - 423}{179 - 25} = \frac{899}{154} = 5.8 \text{ years}
\]

This payback, 5.8 years, is a conservative estimate since it does not take into account State tax credit allowances and tax deductions for depreciation. Payback in less than 6 years is considered very good since the collector's life is estimated at 20 years.

Energy credits are important as shown in the preceding analysis. Payback for the Young collector would have been 8.9 years without them. Because the Youngs did not have to purchase all new materials and used their own talents, a lower value could be placed on the collector. This, of course, reduced the payback. Payback on the collector, assuming an investment of $2,590 for all new materials and a new running gear, would have increased to 10.7 years. It would have been increased to 12.6 years if the value of the Youngs' labor had been included.

Finally, using the same value of energy produced by the collector and assuming the purchase of a commercially built collector for $3,600 ($15 per square foot), the payback is estimated at 14.9 years. Payback for a commercially built collector costing $10 per square
foot would be 9.9 years. Without special energy credits, the payback for these commercial collectors would be 22.8 and 15.2 years, respectively.

These payback estimates show the importance of keeping initial investment costs as low as possible. If farmers can use lumber and other materials from existing farm supplies, the total investment cost may be kept low enough to produce a payback well below the collector's life. This type of solar collection system, with its payback shorter than its life, should be a reasonably safe loan risk for lenders. Farmers can afford to replace their systems after a few years if they become obsolete.

Design

The Young flat-plate solar collector's flexible air system gives it the capacity to perform either as a low temperature/high airflow system for grain drying or as a high temperature/low airflow system for space heating. Because it is portable, a collector of this type can be used on any farm without regard to farmstead layout. The collector's tilt feature allows it to be positioned to receive maximum sunlight.

Air System

For grain drying, a 3,000-cfm fan was selected to provide an airflow of 1 cfm per bushel. This decision was based on several factors, including bin capacity, anticipated grain depth, maximum moisture content at harvest, and weather data for northeastern Nebraska. Maximum grain depths of 12 feet and maximum corn moisture content of 22 percent were used to estimate an expected maximum S.P. (static pressure) of 1.2 inches. Given this information, the next step was to study manufacturer specifications to select a fan that could deliver 3,000 cfm at 1.2 inches S.P. A 1.5-hp fan was selected. This design produced a 12°F temperature rise at noon.

A 700-cfm fan (rated at %-inch S.P.) was selected for home heating. Engineering data suggested the need for 2.5 to 3 cfm per square foot of collector surface to heat homes at the northeastern Nebraska elevation. At 3 cfm per square foot, a 240-square foot collector had the capacity to produce 720 cfm. This estimate was cross-checked
using the Peterson formula.\textsuperscript{4} Solar gain at noon in northeastern Nebraska is known to be 300 Btu per hour per square foot. Thus, total noon collection is 300 Btu $\times$ 55 percent efficiency $\times$ 240 square feet of collector surface, or 39,600 Btu per hour. Using the Peterson equation,

$$\frac{39,600 \text{ Btu/hr}}{50^\circ \text{F heat rise} \times 1.1} = 720 \text{ cfm airflow.}$$

Accordingly, a 720-cfm airflow for home heating was assumed desirable for the Young collector design. A 9.5-inch diameter fan with a 0.25-hp motor was selected to produce this airflow.

**Air Channel Requirements**

The collector is designed with three air spaces: (1) the top space under the fiberglass cover is the dead air space, (2) the second, or middle space, is the warm air channel for the home heating and grain drying modes, and (3) the back space is the cold air return for the home heating mode. In the grain drying mode, this cold air return serves as an additional heat collection airway (fig. 3). When drying grain, the direction of airflow through this channel is the opposite of the home heating airflow.

The dead air space does not add to the efficiency of the grain drying operations. However, it improves the efficiency of the collector for home heating.

Most commercial units are designed for 1,000 feet per minute (fpm), although engineers suggest using 800 fpm for air velocity. The Young collector was designed for an air velocity of 1,000 fpm.

For home heating, a 0.7-square foot cross sectional gap (700 cfm $\div$ 1,000 fpm) was required to produce the desired airflow. A cross section of 0.7-square foot $\div$ 10 feet (collector width) yielded a 0.07-foot gap, or 0.8 inch which is nearly the width of a 1- $\times$ 2-inch batten plus half the thickness of the corrugated metal collector plate (0.875 inch). Therefore, 1-x2-inch battens were used to give the air channel needed for home heating.

For grain drying, 3,000 cfm ÷ 1,000 cfm suggested a 3-square foot cross sectional gap. Three square feet of cross section ÷ 10 feet (collector width) yielded a required 0.3-foot air gap, or a 3.6-inch gap for grain drying. Both the air channel for home air delivery and the return air passages of the home heating mode are used to move heated air for grain drying. Therefore, the capacity of the air channel for home heat delivery (0.84 inch) must be subtracted from the total drying airflow requirement (3.6 inches) to determine the required size of the back air channel (2.8 inches). Considering the supply of used lumber on the Young farm, this requirement was best satisfied by using either double 2-×4-inch battens or a combination of 2-×4-inch and 2-×2-inch lumber, giving 3 inches.

Near the left end of the collector, when facing the back, two openings each 1.5 square feet are made, which extend from the back into the first air channel (fig. 4). These openings are plugged when the collector is used for home heating and opened when higher airflow is needed for grain drying.

Figure 3

Air System Design for Young Solar Collector

One of two 1.5 square foot openings at left end of back that serve as air inlets when the collector is used for grain drying.
Near the right end of the collector, when facing the back, are two circular openings to which air ducts are attached. One opening serves as an air inlet and one as an air outlet for home heating. Both serve as air outlets for grain drying.

Another unique feature of the Young system is the protective weatherproof covering over the insulated ducts that carry the air to and from the collector. The Small Farm Energy Project staff selected an 18-inch diameter corrugated drain tile for the duct covering. The material in 30-inch lengths was flexible and easily cut; it was riveted in desired lengths (fig. 5). The 12-inch “hot” air duct was reinsulated with 3.5-inch fiberglass insulation before placing in the drain tile. The 16-inch “cold” air duct was made of wire mesh and insulated with 1-inch fiberglass. Both ducts served as warm air ducts for grain drying. An adaptor was placed on the grain drying fan to accept both ducts of the collector. (If larger grain drying fans are used with this size collector, separate openings must be supplied to blend outside air into the fan and to lower the S.P. drop in the collector to avoid collector damage. It appears that an opening with sliding door, or two openings, sized less than one square foot for

Figure 4

Mr. Young unfastens one of the openings to allow flexible airflow.
each 1,000 cfm over the 3,000 cfm free air would be adequate. The slides can be closed gradually as the bin is filled in order to maintain a temperature rise of about 12°F, as desired.)

Construction

The 10- × 24-foot, 240-square foot Young collector was constructed during the winter of 1978. The Youngs had a supply of used lumber, mostly two-by-fours and sheathing lumber from an old hog barn, that could be used to build the collector. They also had adequate time to devote to the construction of the collector during the winter months, and no expensive tools were required. Recycled materials and personal labor are key factors in minimizing collector costs and producing a quick payback.

The collector frame was built using 2- × 10-inch lumber. Collector components were fitted in this frame as follows, starting with the back (fig. 6):

- One-inch sheathing
- 2- × 4-inch studs lined with 3.5 inches of fiberglass insulation, vapor side up

Figure 5
Corrugated drain tiles used for duct covers.
• 4-mil vapor barrier
• Used aluminum press plates nailed to studs
• 3-inch battens forming 3-inch air channel
• Layer of used Masonite or plywood wall paneling
• 1 × 2-inch battens forming 0.75-inch air channel
• Corrugated metal absorber plate
• 1 × 2-inch battens forming 0.75-inch dead air space
• Cover plate—5-mil corrugated Filon fiberglass

Both a corrugated metal absorber plate and a corrugated fiberglass cover plate were used to increase the rigidness of the collector since all portable collectors are subject to a certain amount of twisting as they are moved from site to site.

Figure 6
Cross Section of the Young Solar Collector
Sheets of baked enamel aluminum were selected for the absorber plate. Although the metal was not available in black, selection of a metal that has undergone the baking process insured a good paint bond to the metal. The aluminum was buffed lightly with steel wool before painting to improve its bonding capacity. It was then painted with flat black Rustoleum paint. All battens were also painted black.

All seams were caulked with a water seal caulking compound and pop riveted. Foam strips were used under the corrugated absorber plate around the edges of the cover plate to make the collector as airtight as possible.

The assembled basic flat-plate collector was prepared for mobility, tilting, and wind protection. It was hoisted onto a four-wheel running gear that had been lengthened and framed. The collector was attached to the running gear by hinges so that it could be hauled from one location to another and to permit tilting at various angles. A winch, cable, and pulley system was used to change the angle of the collector: 60° above horizontal for home heating during winter, 45° for fall grain drying, and 30° for transporting. A system of anchors and cables was used to prevent collector movement by the wind when the collector was in use.

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Some of the earlier collectors of the Small Farm Energy Project and others used galvanized metal absorber plates. It is difficult to obtain a good paint bond on galvanized surfaces, even when the surfaces are etched with vinegar.
Economics and Statistics Service

The Economics and Statistics Service (ESS) collects data and carries out research on food and nutrition, international agricultural trade, natural resources, and rural development. The Economics unit researches and analyzes production and marketing of major commodities; foreign agriculture and trade; economic use, conservation, and development of natural resources; trends in rural population, employment, and housing and rural economic adjustment problems; and performance of agricultural industry. The Statistics unit collects data on crops, livestock, prices, and labor, and publishes official USDA State and national estimates through the Crop Reporting Board. Through its information program, ESS provides objective and timely economic and statistical information for farmers, government policymakers, consumers, agribusiness firms, cooperatives, rural residents, and other interested citizens.