ENERGY FACTS

70¢

Cooperative Extension Service
Michigan State University

Extension Bulletin E-1817

April 1985 (New)

The Feasibility of Solar Energy for Crop-Drying Applications in Michigan

Roger Brook and Ron Melvin,
Agricultural Engineering Department

Energy resources, future and present, are a concern for both agribusiness operators and the farm public. In the past 10 years, less expensive alternatives have been weighed according to their value for both the long and the short term. The analysis has often involved engineering and economics but seldom politics and ethics.

The following discussion will focus on the feasibility of solar energy for grain-drying applications in Michigan. The first section summarizes information useful in understanding solar energy and solar collectors. The next section covers the more practical aspects of solar engineering, including various kinds of collectors and differences in materials, design and operation. The last section will focus on the results of experimental measurements made on solar collectors throughout Michigan. The discussion concludes with a review of the problems associated with evaluating solar as a feasible energy source on economic, ethical and political grounds.

Available solar energy

The sun delivers a constant energy flow to the outer reaches of the earth's atmosphere. The fraction of the energy that passes through the earth's atmosphere could be collected as solar energy (see Fig. 1). The amount of solar energy available varies with location, time of year and time of day. Variations in local climate also play an important role in determining the amount of useful solar energy that can be collected.

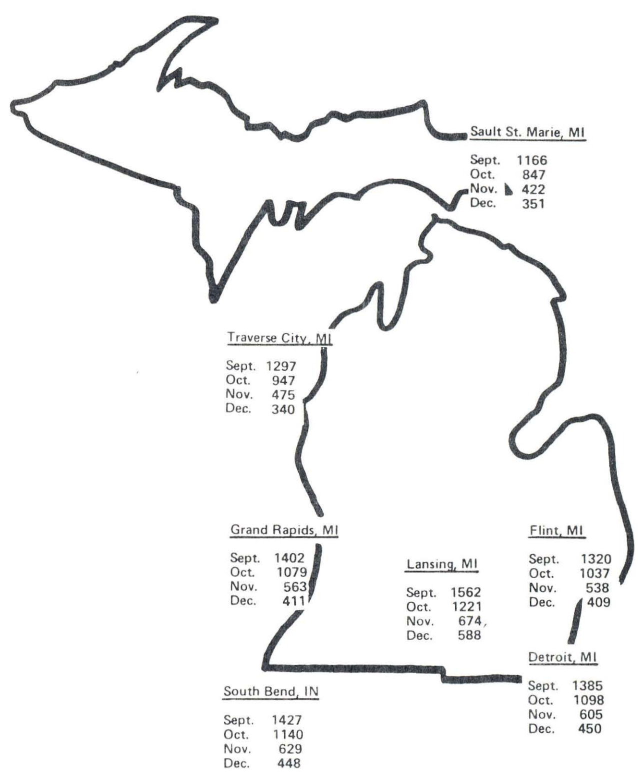

Fig. 1. Geographical distribution of average solar energy collected (BTU per square foot per day).

All the available solar energy is not collected by a solar collector. The efficiency of a solar collector is expressed as the ratio of the total energy at the collector surface to the usable energy at the output end. The usable heat collected depends on airflow velocity through the solar collector.There are also heat losses because solar energy is reflected from the collector surface, heat losses through the collector surfaces, heat losses from the ducting from the collector, and heat losses because of degradation of the collector surface by weather. The typical range of solar collector efficiencies will vary from 20 to 50 percent, depending on material and design.

Solar collectors

The application chosen for a solar collector is perhaps more important than all other considerations. The basic possibilities for on-farm use of solar energy are grain drying, space heating and water heating. Using multipurpose collectors throughout the year for both grain drying and space heating improves economic feasibility.

The two general types of solar collectors are the flat plate collector and the concentrating collector (see Fig. 2). The concentrating collector delivers a high temperature output—in the range of 200 to 350 degrees F—but is expensive and complex to build. At this time, concentrating collectors are not cost effective for agriculture because of the expense of construction.

The flat plate collector is used most often for farm and home heating because it is simple and relatively inexpensive to build. A number of designs for flat plate collectors are in use today (see Fig. 3). The collector design should provide maximum useful energy with a minimum of repair, maintenance and replacement of components.

Flat plate collectors — The functions of the cover plate are to allow the solar radiation to pass through to the absorber surface and to prevent the heat radiated by the absorber to pass back out. The choices for cover materials range from glass to fiberglass-reinforced plastics (see Table 1). Glass is the most expensive, it breaks easily, and it expands as it warms up, so special expansion gaskets must be installed. But glass also has some excellent solar properties. More than 87 percent of all incoming solar radiation can pass through glass. Glass covers are also an excellent trap for heat energy, and they are easy to clean.

Plastic and fiberglass covers are not as efficient as glass covers. They allow more heat radiated from the absorber to be lost. They gradually become cloudy when exposed to solar radiation. This reduces the amount of solar radiation that enters the collector.

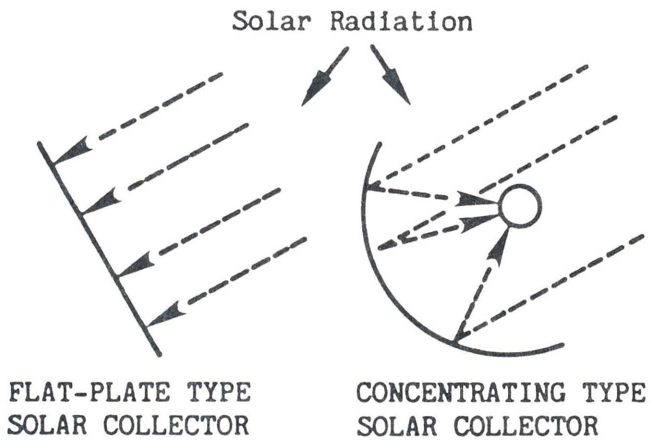

Fig. 2. Types of solar collectors.

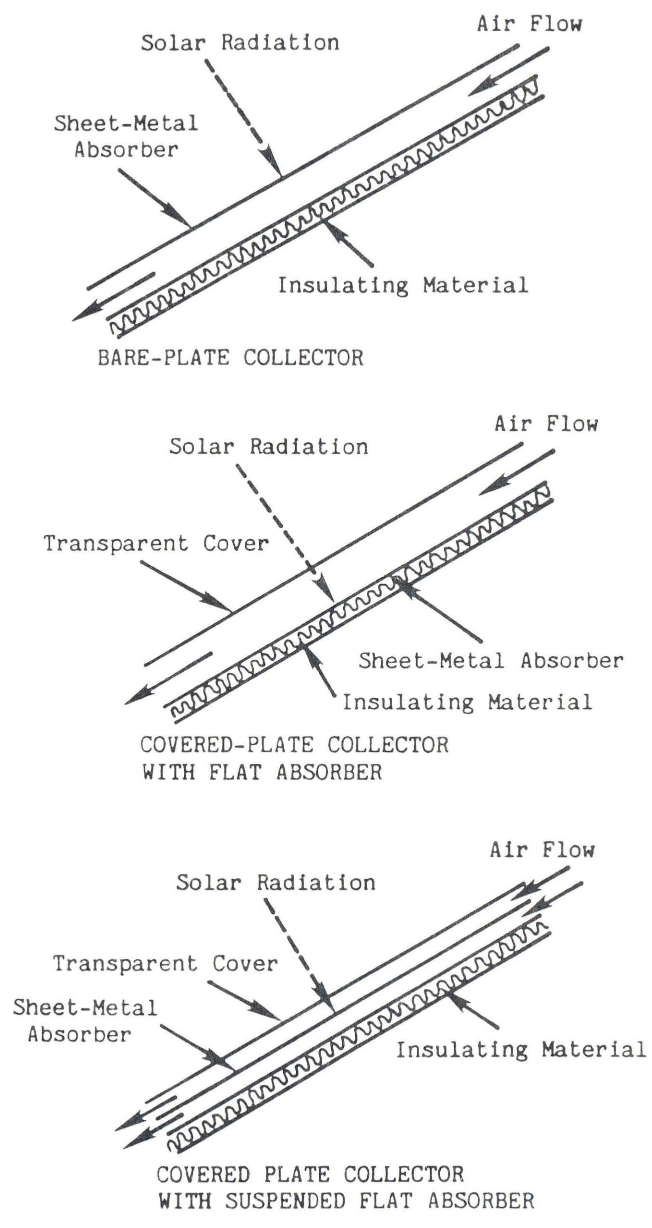

Fig. 3. Designs for flat plate collectors.

Table 1. Properties of Cover Materials.

Cover material	Solar transmittance	Longwave transmittance[1]	Relative cost[2]	Other characteristics
Glass Double strength, 1/8 inch	0.88	0.03	25	Breaks easily; needs expansion gaskets; cleans easily; no solar degradation
Flat FRP[3] Regular, 25 mil	0.83	0.12	14	Cannot take temperatures over 200 degrees F; sags when warm
Flat FRP Premium, 40 mil	0.73	0.06	21	Surface slowly deteriorates; easy to use
Corrugated FRP Coated with polyvinyl fluoride, 40 mil	0.79	0.07	26	Rigid; requires wood strips to seal edges; coating may peel; easy to use
Polyethylene 4 mil	0.89	0.80	1	Tough; degrades fast; requires annual replacing
Polyester Weatherable surface, 5 mil	0.87	0.32	9	Easily damaged; degrades fast; not recommended for single cover
Polycarbonate 1/16 inch	0.84	0.06	125	Punctures easily; high thermal expansion; lightweight; 10 percent solar deterioration in 10 years
Polyvinyl fluoride	0.91	0.43	9	Hard to install; shrinks at high temperatures; lightweight; 10-year life

[1]Longwave energy is radiated from absorber back through the cover material and represents energy lost to the environment.
[2]Cost per foot squared relative to polyethylene (normal plastic).
[3]FRP is fiberglass-reinforced plastic.

Plastics and fiberglass do offer some advantages, however. They are usually inexpensive and easy to install. There is no need to install special expansion gaskets.

The function of the absorber plate is to absorb the solar energy and convert it to heat. The air flowing through the solar collector is then heated by contact with the absorber plate. Absorber plates are often painted flat black. The paint should be able to withstand up to 300 degrees F without peeling or cracking. The absorber plate can be made from a variety of materials, depending on the design of the collector. Metal is the best material to conduct heat to the air flowing through the solar collector. For agricultural purposes, common absorber materials are plywood, chipboard, black plastic and roofing metal. Concrete, brick or rock is also sometimes used. These materials can also provide some storage of heat. The choice of material depends upon its cost, availability and ease of construction. The absorber plate must be able to withstand weather variations and high collector temperatures without sagging or degrading.

The final component of the flat plate collector is the casing. Essentially, the casing is an insulated box that allows air to be drawn across the absorber plate and ducted to a heating application. The casing can be made from wood, sheet metal or fiber-plastic materials. The materials need to be moisture and corrosion resistant. For collectors with a low temperature gain, the "R" value of a wood casing would be enough insulation. Insulation from "R" values of .6 (plywood) to 4 will increase the efficiency of the solar collector but probably not enough to pay for the cost of the insulation. Insulation above an "R" value of 4 has no further effect on efficiency. (See Table 2 for "R" values of materials commonly used in the construction of solar collectors.)

Building the solar collector into the overall design of a new or existing structure significantly affects the design and cost of the collector. The same size solar collector could be built into a new building for two-thirds the cost of a stand-alone unit. However, if the hot air must be ducted a large distance to the grain bin, the construction savings could be easily offset by the cost of

Table 2. Insulation Values of Materials

Material	Resistance/in. (Approx.)
Blanket or batt	
Glass wool, mineral wool or fiberglass	3.5
Loose fill	
Glass or mineral wool	2.5
Vermiculite	2.2
Sawdust	2.2
Wood pulp	3.5
Rigid	
Polystyrene	4.5
Glass fiber	4.0
Urea formaldehyde	4.7
Building board	
Plaster or gypsum	0.5
Plywood	1.2
Hardboard	1.4
Particle board	1.1
Masonry	
Brick, common	0.2
Concrete	0.1
Woods	
Hardwoods	0.9
Softwoods	1.3

the ducts. If a new structure capable of supporting a solar collector is not available, then consider a stand-alone unit.

Modifications in collector design to improve efficiency must be balanced with the cost increase, additional maintenance requirements and effect on flexibility of use. If a collector is going to operate at more than 40 degrees F difference between ambient and output temperatures, the efficiency can be increased by adding a second cover or more casing insulation. Making absorber plates out of corrugated material makes them more efficient. Remember that any of these changes will increase the cost of the collector. Your objective in building a solar collector should be to keep the construction cost as low as possible.

For maximum performance in Michigan, the collector should face due south and the solar collector surface should be tilted 50 to 60 degrees from the horizontal during the winter. In the summer, a collector angle of 25 to 35 degrees from the horizontal will pick up the greatest amount of radiation.

Solar collectors in Michigan

The Department of Agricultural Engineering and the Cooperative Extension Service at Michigan State University began an agreement in early 1981 with USDA/SEA-Extension and the U.S. Department of Energy to demonstrate the use of solar energy in Michigan. Funding was made available to select and monitor cooperating farms utilizing solar energy for crop drying.

Several solar collector facility designs were employed during the monitoring phase of the project. The sites and their solar collector characteristics are summarized in Table 3.

The calculated performance characteristics for each of the five sites monitored are summarized in Table 4. These characteristics were estimated using data taken at each site during the fall of 1982.

The solar collector characteristics presented in Tables 3 and 4 were used for each site to perform a preliminary economic analysis. The results, presented in Table 5, assume the solar collectors for crop drying will be used for a total of 30 days during the fall. The range of investment break-even costs per square foot result from the variation in observed solar radiation values. The following factors and assumptions were used in calculating the break-even costs:

Annual interest rate	10 percent
Term of the loan	5 years
General inflation rate	10 percent per year
Fuel cost escalation rate	10 percent per year
Discount rate (after-tax return on best alternative investment)	12 percent per year
Cost of LP gas	80 cents per gallon
Insurance and maintenance	1 percent
Period of economic analysis	10 years

The analysis presented above does not consider the benefit of using the solar collector to supplement space

Table 3. Solar Collector Types and Sizes.

Site Name	Collector Type	Area (sq ft)	Glazing	Orientation
Barry County	Wraparound on a storage bin	1,206	Corrug. Filon	Variable at 90 degrees
Menominee County	Solar attic on dairy calf housing	686	Clear acrylic	South at 60 degrees
St. Joseph County	Portable stand-alone Illinois plan	288	Corrug. FRP	South at 60 degrees
Mecosta County	Solar attic on swine farrowing	2,112	Corrug. Filon	South at 18.4 degrees
Cass County	Inflatable plastic	192	Clear plastic	South at 60 degrees

Table 4. Solar Collector Performance Characteristics.

Site Name	Measurement Date	Airflow (cfm)	Incident Solar (BTU/hr)	Solar Gain (BTU/hr)	Average Efficiency (percent)
Barry County	Sept. 20, 1982	11,927	400,973	191,264	47.7
Menominee County	Oct. 31, 1982	15,763	206,013	115,779	56.2
St. Joseph County	Dec. 16, 1982	3,644	49,924	11,836	23.7
Mecosta County	Sept. 24, 1982	13,032	486,705	138,711	28.5
Cass County	(a)	---	---	---	---

(a) Because of problems experienced with the solar collector during the fall of 1982, data for a detailed performance analysis of this solar collector system were not collected.

heating needs on the farm. When considering solar heat vs. other heat sources, the user must consider not only the break-even cost, but also the potential savings in capital equipment, other heat-producing devices included in the system, the potential return for space heating uses and any applicable solar tax credits.

Another method of analysis incorporates a number of factors not usually considered. These range in scope from the ethical to the political. The factors are extremely difficult to determine, and assigning an adequate dollar value to them is next to impossible. These properties typically arise from a concern over health, the environment, and the quality of life for ourselves and our offspring. Fossil fuels are limited. Many argue that using these fuels when it is not absolutely necessary is being irresponsible to the needs of the future. Other arguments focus on the pollution caused by the hydrocarbon industries in the collection, refinement, distribution and use of petroleum-based products. Any conservation of resources will help preserve our land, air and wildlife. Each factor, most would agree, has merit. The trouble begins when the factors have to be evaluated. Ultimately, each individual must determine which properties are most important and whether solar energy is cost effective.

Table 5. Preliminary Economic Analysis Using Solar Radiation Data of 550-850 BTU per sq. ft. per day.

Site Name	Break-Even ($/ft²)	Construction ($)	Cost ($/ft²)	Construction Year
Barry County	0.74-0.94	1,100.00	0.91	1980
Menominee County	1.69-2.15	4,835.00	7.05	1981
St. Joseph County	0.40-0.63	600.00	2.08	1979
Mecosta County	0.47-0.72	1,675.00	0.79	1980
Cass County	(a)	1,900.00	9.90	1980

(a) Economic analysis not done because performance data for fall 1982 were lacking.

Conclusions

Solar energy for crop drying is weather dependent and may be least successful during the years when it is needed most. During years when the crops mature late or when field drying conditions are poor, solar radiation levels are usually low. The economic feasibility of solar crop-drying systems is largely related to savings in fuel vs. the investment cost for the solar collectors. Fuel costs are likely to continue to rise in the coming years, and this may alter the disadvantages of solar energy use for crop drying in Michigan.

The cost of solar collectors and the small amount of energy collected during the crop-drying season are limiting enough that a producer would not want to replace usable conventional equipment. It is not yet clear if a new facility can justify the expense of the solar collectors. It appears that a natural air drying system may be equally workable in Michigan without the additional expense of the solar collectors.

Investigations into the use of solar energy for crop drying in Michigan have resulted in the following conclusions:

A. Solar drying has a better chance for success when it is started later in the fall. Humidity tends to go down as the fall season progresses.

B. The maximum recommended moisture content for grain in a solar drying system is approximately 20 percent, using an airflow rate of 2.5 cfm per bushel of grain dried.

C. Solar collectors should be sized according to the amount of grain dried. A range of 0.1 – 0.3 square foot of collector per bushel of grain is recommended.

D. The use of heat energy supplied by the solar collectors will result in frequent overdrying of the bottom layers of grain in the drying bin. The overdrying can be alleviated to some extent by using devices to stir the grain, but these represent an additional expense.

E. Using a solar collection system reduces the energy requirements of the bin drying process, but the energy savings will generally not be sufficient to justify the investment cost of the solar collectors.

References

1. Low Temperature and Solar Grain Drying Handbook. MWPS-22. Plan Service, Agricultural Engineering Department, Michigan State University, East Lansing, Mich.
2. Home Hot Water Heating With Solar Energy. Bulletin E-1151. Plan Service, Agricultural Engineering Department, Michigan State University, East Lansing, Mich.
3. Solar Energy. Bulletin AEIS-465. Plan Service, Agricultural Engineering Department, Michigan State University, East Lansing, Mich.
4. Solar Energy Handbook. F. Kreith and J. Kreider. McGraw-Hill Book Co., 1981, New York, N.Y.
5. Solar Energy Thermal Processes. J. Duffie and W. Beckman. John Wiley & Sons, 1974, New York, N.Y.
6. Solar Heating for Home, Farm and Small Business. AE-88. Plan Service, Agricultural Engineering Department, Purdue University, West Lafayette, Ind.
7. Solar Energy Heat Storage for Home, Farm and Small Business. AE-89. Plan Service, Agricultural Engineering Department, Purdue University, West Lafayette, Ind.
8. Solar Heat for Grain Drying — Selection, Performance, Management. AE-108. Plan Service, Agricultural Engineering Department, Purdue University, West Lafayette, Ind.

MICHIGAN STATE UNIVERSITY
CES
COOPERATIVE EXTENSION SERVICE

MSU is an Affirmative Action/Equal Opportunity Institution. Cooperative Extension Service programs are open to all without regard to race, color, national origin, sex, or handicap.

Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Gordon E. Guyer, Director, Cooperative Extension Service, Michigan State University, E. Lansing, MI 48824.

This information is for educational purposes only. Reference to commercial products or trade names does not imply endorsement by the Cooperative Extension Service or bias against those not mentioned. This bulletin becomes public property upon publication and may be reprinted verbatim as a separate or within another publication with credit to MSU. Reprinting cannot be used to endorse or advertise a commercial product or company.

0-15435

New-5:85-1.5M-KMF-UP. Price 70 cents. For Sale Only.

FILE: 18.151