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Abstract

A solar energy-intensifier-thermal energy storage system was developed and tested under actual climatic conditions in South Dakota. Performance characteristics of the system are presented for its use in drying shelled corn and for agricultural space heating. Comparisons between solar and conventional drying and between solar supplemented and conventional heating are reported.

1. INTRODUCTION

Agricultural crop drying and space heating provide numerous operation where low to moderate temperature rises can provide a large percentage of the energy requirements. Widespread acceptance of solar energy for these applications is dependent on performance data that document the characteristics of specific systems under actual operating conditions. Because of the importance of the development of solar energy as an alternate energy source and the potential of solar energy concentrators as a compatible solar system alternative, a research project with the following objectives was initiated:

1) Design a solar energy-intensifier-thermal energy storage system for drying corn and agricultural space heating.
2) Evaluate the performance of a solar energy-intensifier-thermal energy storage system for drying shelled corn and for agricultural space heating.
3) Evaluate the thermal performance characteristics of a solar energy-intensifier-thermal energy storage system under actual climatic conditions.

Detailed literature reviews on those aspects of solar energy related to this paper were presented by Saienga, Hellickson and Peterson (1977) and Julson, Hellickson and Peterson (1977). This research was sponsored in part by a grant from the USDA-ERDA.

2. DESCRIPTION OF RESEARCH FACILITIES

A solar energy-intensifier system was designed and developed, Figure 1, 2 and 3, for use in drying shelled corn. A recirculating air flow plenum and a thermal energy storage unit were added to the thermal energy-intensifier and the system was used to provide energy for agricultural space heating applications, Figure 4. The concentrator-collector-thermal energy storage consisted of a two-sided collector, a portion of a parabolic curved surface as a concentrator and a native stone thermal energy storage unit.

The curved surface used as a concentrator consisted of the upper portion of a parabolic curve having a 4.5 m focal length. The portion used was the section from 0.6 m to 4.2 m above the parabola's vertex. The concentrator was positioned 0.46 m above the ground and hinged to wooden posts so that no shadowing resulted due to the collector being positioned south of the concentrator. This also allowed for ease of manual adjustment of the concentrator, approximately weekly, to allow for optimum focusing of the sun's rays on the collector. The concentrator was constructed in three sections, each 3.6 m in length with a projection of 3.56 m. The concentrator structure was designed to withstand an 128 km/hr (80 mph) wind. The concentrator surface was fabricated from tempered masonite sheets which were bolted to the support structure and painted on the back side to reduce moisture absorption. The masonite was covered with, adhesive backed, .0125 cm (5 mil) polished aluminum which had an average reflectivity of 80 to 90 percent from wavelengths of 0.3 micron to 2.2 micron. The polished aluminum was treated to reduce weathering and had a high emissivity beyond wavelengths of 2.5 micron, which allows for effective re-emission of absorbed radiation. The collector is 1.2 m high, 10 cm wide, and 7.2 m long. The collector support structure was constructed of vertical 5 by 10 cm members located at the ends and 2.4 m on center, dividing the collector surface into three sections. The collector surface consisted of 29 guage, corrugated, sheet metal painted flat black on both sides, installed with the corrugations perpendicular to the air flow, covered with two layers of transparent film and sealed into the support structure. The two transparent layers consisted of an inside layer of .0075 cm (3 mil) polyester film located 1.56 cm from the absorber surface. This 1.56 cm space between the absorber surface and the inner sheet of plastic allowed air to be circulated from the intake plenum up the south side of the absorber surface over the top and down the north, reflector, side of the absorber and into the exhaust plenum. The outside layer of .0125 cm (5 mil) clear plastic was separated from the inside layer by a 1.88 cm insulating, air space. Both transparent layers had transmissivities similar to glass and the outer layer was treated to reduce weathering.

The thermal storage unit (used only during the space heating studies) consisted of a rectangular wood-framed structure 1.86 m wide, 2.46 m long and 1.2 m high. The sides and top of the box were insulated with 12.7 cm of styrofoam and the bottom with an equivalent (thermal) layer of wood fiber sheathing. Two point nine cubic meters, approximately 5000 kg, of 3.75 cm diameter rocks were used as the thermal storage media.

3. RESEARCH PROCEDURE

The solar energy-intensifier (Figures 1, 2 and 3) was used as a supplemental heat source for in-storage drying of 35.2 m^3 of shelled corn from November 8 to November 30, 1977. Air (28.3 m^3/min) was drawn through the solar collector and was mixed with 28.3 m^3/min of outside air and was forced through the shelled corn. Corn drying rate comparisons were made with a similar 35.2 m^3 conventional, low-temperature drying bin.

The thermal energy storage (TES) unit was added to the solar energy-intensifier and this unit (Figure 4) was used to provide supplemental heat to a room designed to have a specific heat loss. Comparisons were made between this space which was provided solar heat and a similar space heated with an electrical resistance heater from February 14 to March 13, 1977.

A differential thermostat was used to control air flow through the circuit involving the solar collector and the TES. Whenever temperature near the top and center of the solar collector exceeded temperature near the center of the TES by 5 C air flow moved energy from the solar collector into the TES. Temperature control in the solar heated space was controlled using a minimum thermostat and a two-stage thermostat. The minimum thermostat was used to insure that the temperature in the TES was 5.5 C warmer than desired ambient temperature (21.1 C) in the solar heated space. The first stage of the two-stage thermostat operated a fan that moved air (12.0 m^3/min) through the TES and into the heated space. The second stage, which operated at 1.65 C below the first stage controlled a 4000-watt space heated. A 4000-watt electrical resistance heater was used to maintain the other heated space also at an ambient temperature of 21.1 C. All research was conducted on the Agricultural Engineering Research Farm located near Brookings, South Dakota.

4. RESULTS AND DISCUSSION

The results of this investigation include evaluation of the solar energy-intensifier used for drying shelled corn and evaluation of the solar energy-intensifier thermal energy storage system for space heating. Additional performance details and basic test data were presented by Julson (1977) and Saienga (1977).

4.1 EVALUATION OF THE SOLAR ENERGY-INTENSIFIER FOR DRYING CORN

The solar energy-intensifier system efficiency was evaluated in terms of the energy actually collected compared to the solar energy available on two surfaces, horizontal and vertical, Figure 5. Two efficiencies are presented, one indicates the efficiency considering the entire area of the collector (1.2 x 7.2 m) plus the total area of the reflector (3.6 x 10.8 m), while the second considers the effective collector area (total area minus area of the support members) plus the instantaneous reflector area (3.56 x 7.2 m).

Average efficiencies of up to approximately 88 and 62 percent were noted for the total and instantaneous areas, respectively. The maximum, average, instantaneous efficiency using solar energy on a vertical surface as a datum was approximately 40 percent. The maximum instantaneous efficiency on clear days, using solar energy on a vertical surface as a reference, was 62.7 percent. Maximum average temperature rise across the solar collector was 13.5 C for the 23-day period.

Cumulative totals of solar energy on a horizontal surface and energy collected are presented in Figure 6. The total energy collected was 3.25 x 10^9 J as compared to 4.21 x 10^9 J. This indicates an overall system efficiency of 77 percent and that an equivalent of 906 kwhr of energy was provided by the solar energy-intensifier system.

Comparisons between the drying rates of corn in the bin provided solar heated air with the bin provided cold air indicated approximately twice as fast a drying rate in the solar bin. Drying rates in the conventional and the solar dried bins were 0.35 and 0.65 percent per day, respectively.

4.2 EVALUATION OF THE SOLAR ENERGY-INTENSIFIER-THERMAL ENERGY STORAGE SYSTEM FOR SPACE HEATING

Efficiency of the solar energy-intensifier-thermal energy storage system was also evaluated on the basis of total area and instantaneous area, Figure 7. Using solar energy on a horizontal surface as a datum, average, maximum total and instantaneous area efficiencies were 27 and 42 percent, respectively. However, instantaneous area efficiencies as high as 80 percent were achieved on a clear day. Lower than expected efficiencies and energy collection values can be at least partially attributed to warping of the support material of the solar reflector. This reduced the effectiveness of the solar concentrator system.

The total energy accumulated during the test period and the accumulated solar energy on a horizontal surface were 2.7 x 10^9 J and 6.75 x 10^9 J, respectively, Figure 8. The energy collected was equivalent to 762 kwhr of electricity and overall energy collection efficiency for the study was 41 percent. This is lower than that found during the drying study since the average temperature rise across the collector was much higher (55 C as compared with 13.5 C) and more warping of the reflector surface was noted.

A thermal energy storage unit was included in the system to allow overnight heating of a room.

Temperature profiles indicate that the temperature in the TES was above the minimum specified (26.7 C) for heating the room on 13 of the 28 days of the study. Comparisons between the conventional energy requirements to maintain the two similar rooms at 21.1 C indicated an electrical energy usage of 660.4 kwhr in the conventional room and 255.4 kwhr in the solar supplemented room. However, it should be noted that temperature in the conventionally heated room average 0.77 C warmer than the solar supplemented room.

5. CONCLUSIONS

The following conclusions were reached on the basis of this research:

1) A solar energy-intensifier system was developed that collected 77 percent of the energy on a horizontal surface from November 8 to November 30, 1976 in South Dakota.
2) A total of 3.95 x 10^9 J of solar energy (equivalent to 906 kw-hr of electricity or 34 gallons of propane) was collected during the 23-day drying study.
3) The solar energy-intensifier collected sufficient energy to approximately double the drying rate of shelled corn as compared to a conventional, ambient air drying system.
4) The solar energy-intensifier-thermal energy storage system collected 2.7 x 10^9 J of energy from February 14 to March 13, 1977 in South Dakota and had an overall efficiency of 41 percent (based on solar energy on a horizontal surface).
5) Sufficient solar energy was collected to reduce the electrical energy required in heating similar rooms from 660.4 kw-hr to 255.4 kw-hr.
6) Overall performance of the solar energy-intensifier-thermal energy storage system was less than expected. Improved reflector support materials should improve system performance characteristics.

6. REFERENCES

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BIOGRAPHIES

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B.S. Ag.E.	NDSU	1964
M.S. Ag.E.	NDSU	1966
PhD Engr.	WVU	1969

Over 60 publications and 1 patent.

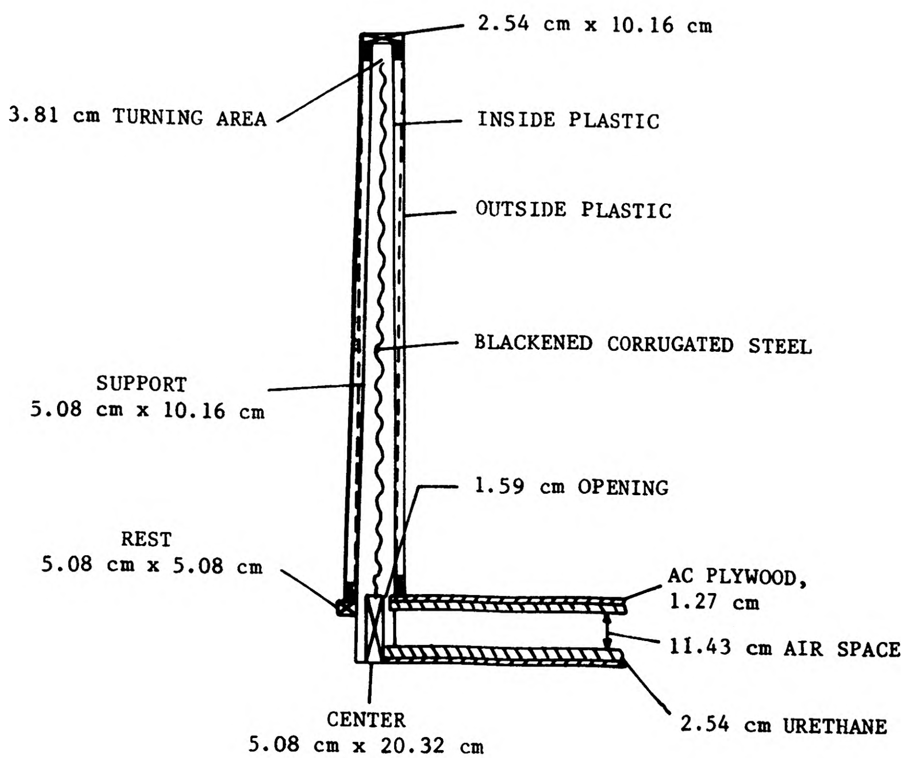

Figure 1. Collector cross-section.

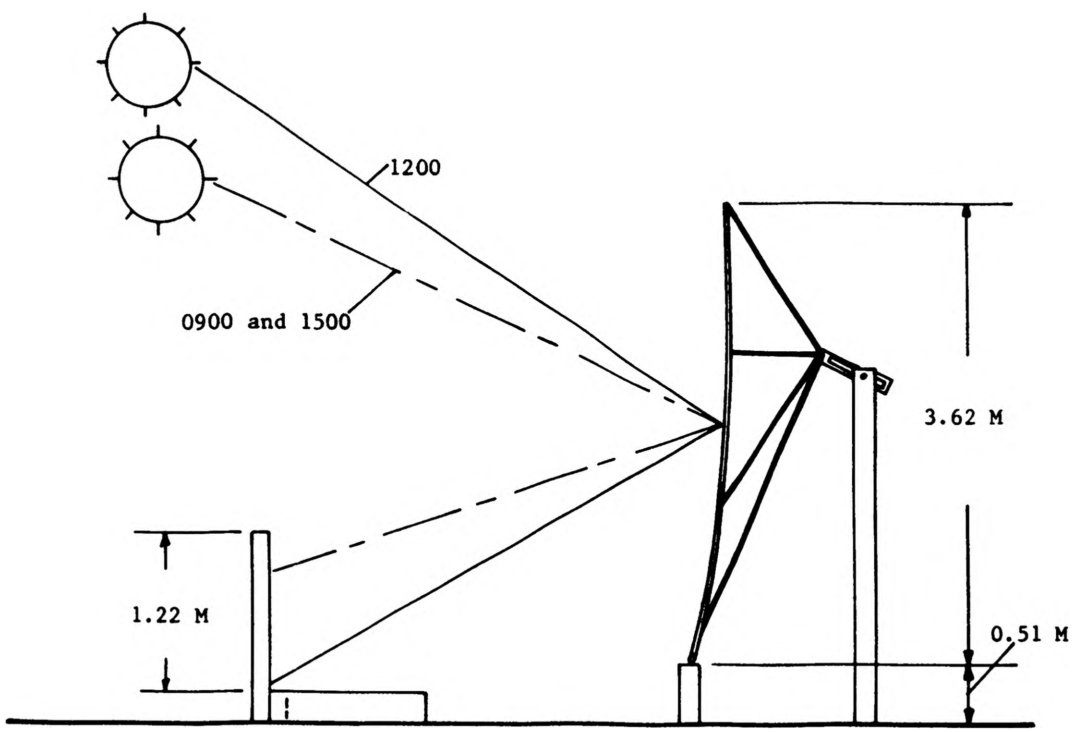

Figure 2. Side view of solar energy-intensifier representing daily focal movement on the collector.

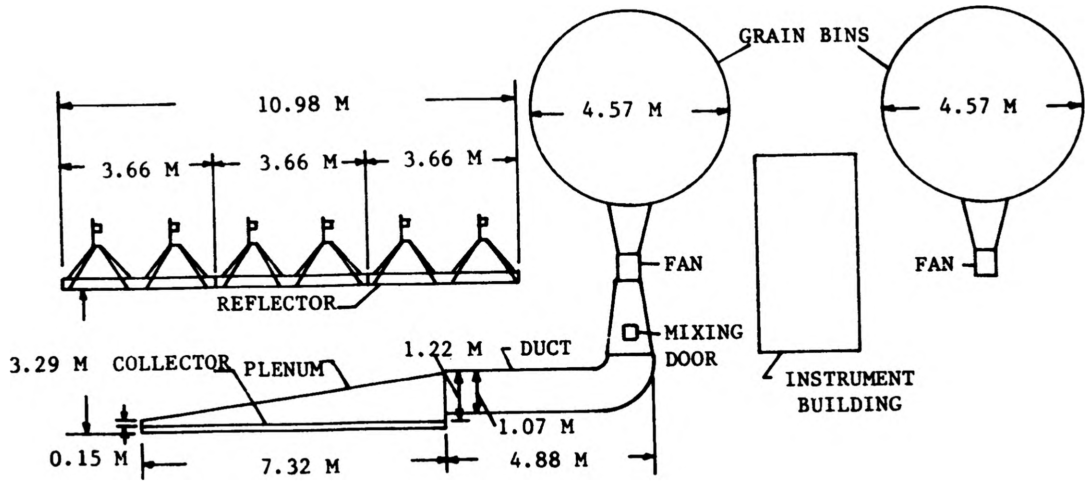

Figure 3. Plan view of the research facility.

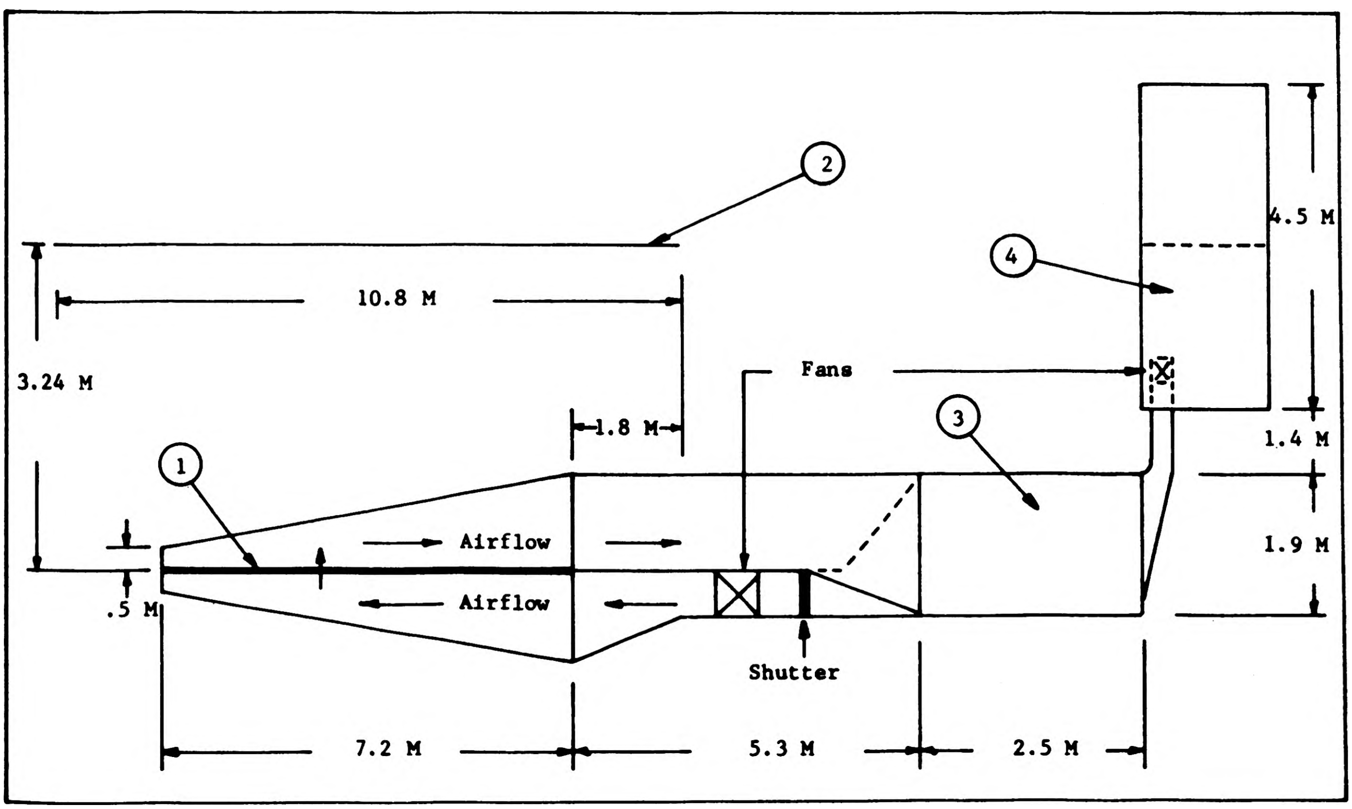

Figure 4. Top View of Experimental Facilities; 1-Collector, 2-Concentrator, 3-Thermal Storage, 4-Instrument Building.

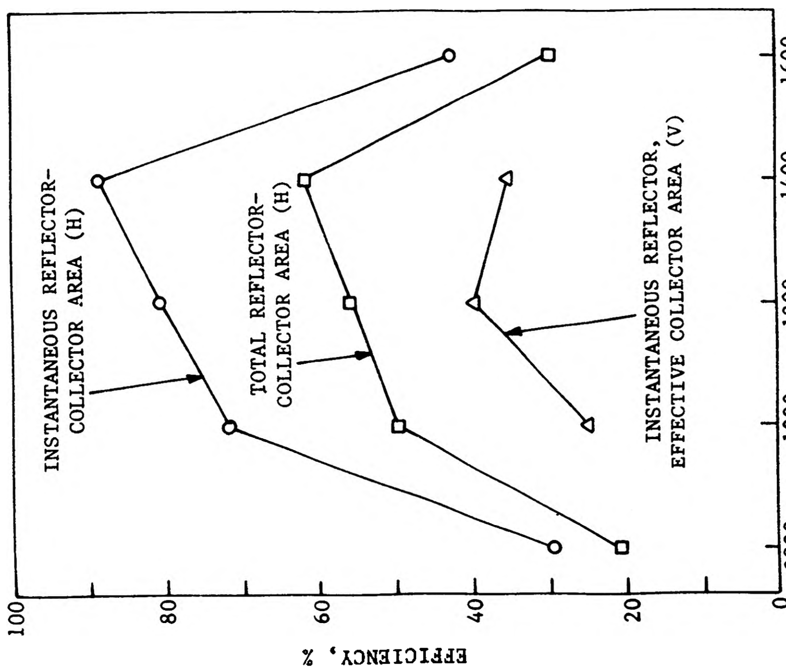

Figure 5. Average efficiency as influenced by time of day, energy on a horizontal (H) and vertical (V) surface as a datum.

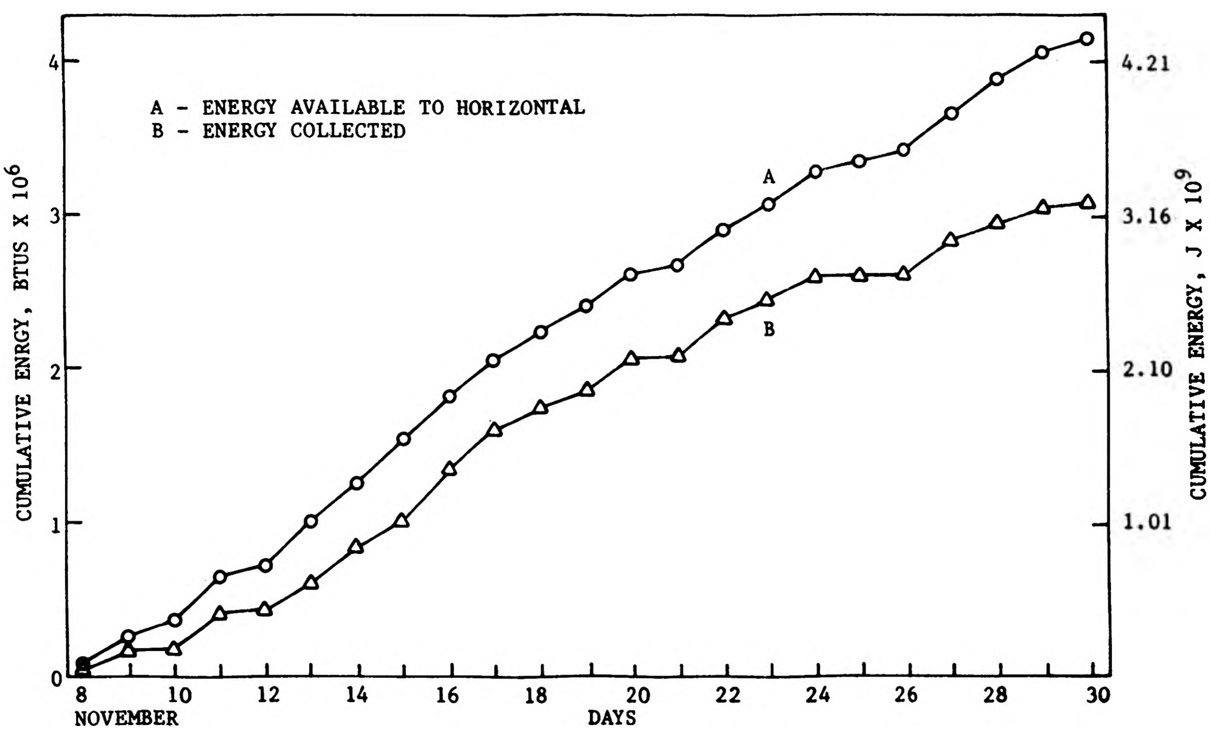

Figure 6. Cumulative energy available and energy collected over the 23-day period.

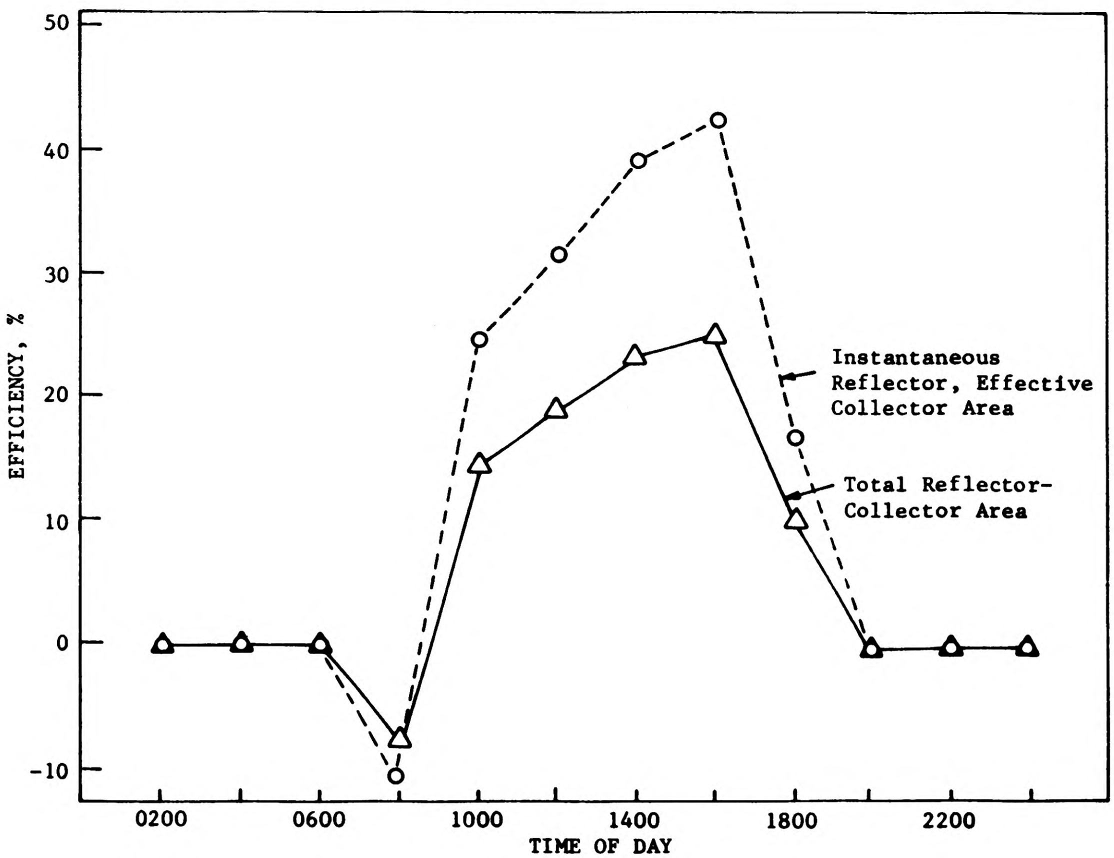

Figure 7. Average Efficiency as Influenced by Time of Day, Solar Energy on a Horizontal Surface Used as a Datum.

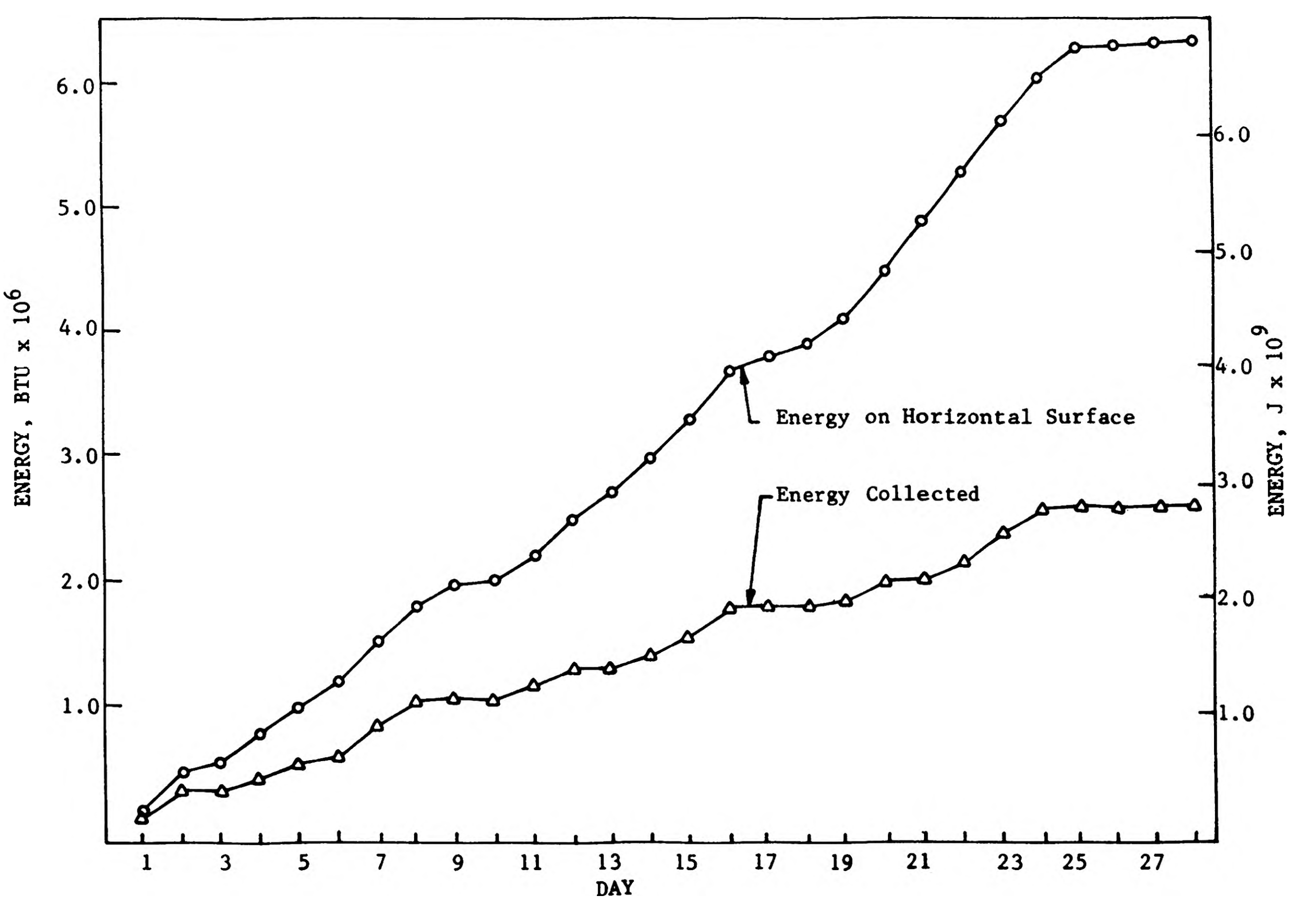

Figure 8. Accumulated Energy Collected and Accumulated Solar Energy on a Horizontal Surface Over 28-Day Period.