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Solar energy for preheating ventilating air

Abstract

The basic concept of the solar energy collector- storage system for preheating ventilating air is sound, and it should be an economic alternative as energy becomes less available and/or more expensive. Based on current energy prices it can't be justified on a strict economic basis without large tax credits. We plan to continue research, working with other scientists, to develop it so that functional and reliable units can be constructed when our national energy situation demands such a solar energy system.; Swine Day, Manhattan, KS, November 10, 1977

Keywords

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Summary

The basic concept of the solar energy collector-storage system for preheating ventilating air is sound, and it should be an economic alternative as energy becomes less available and/or more expensive. Based on current energy prices, it can't be justified on a strict economic basis without large tax credits. We plan to continue research, working with other scientists, to develop it so that functional and reliable units can be constructed when our national energy situation demands such a solar energy system.

Introduction

The basic idea, brief structural details, building sketch, and early operational data were presented in the 1976 Swine Day Report of Progress 283 (page 3). In this report we describe construction in greater detail, update data collected, and discuss some alternative uses for the solar wall.

The solar unit we are using incorporates an energy storage feature that allows the solar energy arriving during the day to be used more effectively during the night hours than units without storage. The thermal flywheel effect of the storage also reduces the influence of outside temperature fluctuations and provides stabler conditions inside during moderate weather. For Kansas, where there is relatively great spread between high and low temperatures on summer days,

feasibility of using the storage for cooling is being considered.

Construction Details

The solar energy collector-storage unit (8' high and 50' long) has a net collecting area of about 380 sq. ft. It is parallel to (and 16" in front of) the existing south wall of the farrowing barn on grounds of the Kansas State University Agricultural Experiment Station. Its main features are a massive wall, painted black on the south side and with openings from front to back, and a double transparent cover on a frame that allows ventilating air to pass between the covers as it enters the system. Air moving through the space between the covers picks up some of the heat that would otherwise be lost. The air removes heat from the south side of the blocks first, thereby cooling the surface to reduce further heat loss from the storage.

Solid concrete blocks (6" x 8" x 16") purchased from a local plant were used for the wall (nominal thickness, 16 inches). We selected concrete blocks because they could be delivered to the site for less than \$18 per ton, compared with

¹Department of Agricultural Engineering.

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\$32 per ton for random-sized field stone. Also, blocks were easier to lay up than stone would have been. Courses of the blocks were laid up, mostly by students, without mortar. (Skilled labor could place mortar in the horizontal joints, but expansion joints would be needed every 25 to 30 ft.). Without mortar, blocks tended to move, which made it difficult to maintain uniform gaps in the vertical joints to provide openings for the air to move through the wall.

The blocks, approximately 31 tons, were laid on a course of footing-extender blocks (4" x 8" x 16") placed on edge (and 8" on center). The gaps between the extender blocks were filled with glass fiber insulation to reduce thermal communication between the storage area and footing. The outside of the footing and footing extender blocks was insulated with two inches of extruded, expanded polystyrene.

Flat-black RUST-OLEUM*, #412, was used to paint the south surface of the blocks. The first coat on half the unit was rolled on and required one gallon (for approximately 200 sq. ft.); a second coat was sprayed on. For the other half we used a sprayer to apply two coats (cover approximately 500 sq. ft. per gallon). During a storm, rain on the section covered with two coats of spray paint leached minerals from the concrete onto the black surface, so it had to be resprayed. (Leaching of a deposit onto the black surface illustrates a problem that occurs if the roof leaks. Our roof leaked, and about one square foot of surface was damaged before it could be repaired).

Before they were installed, boards for the frame to support the transparent cover were painted with white enamel, so solar energy would

be reflected to the collector surface. All vertical supports, made of 3/4-inch lumber, were spaced 24 inches apart; the inner cover was positioned about one and one-half inches from the collecting surface and the outer cover about one and one-half inches in front of it. An adhesive (Tan Mastic from H. B. Fuller)* was used to fasten the first support to the concrete block wall; mechanical fasteners also were used where possible.

To attach the transparent covers (of nominal 4-mil. TEDLAR film*, approximately 3.2 mils. thick), we applied an adhesive transfer tape (Scotch Brand No. 465)* to the surfaces of the supports. The inside cover was aligned, stretched slightly, and then placed against the sticky surface, which held it in place. Where two ends of the cover lapped, a strip of adhesive transfer tape was placed between them; such joints were made at supports so transmission was not reduced. The inside cover was run horizontally; a gap of about one inch along the center of the wall was left to allow air to pass.

Wood screws were used to fasten supports for the outside cover to the inner supports. Adhesive transfer tape then was applied to the surfaces of the supports and the outer cover installed.

Installing covers on the site was tedious, at least two workers were required and wind was a problem. On-site installation, however, had an advantage: Few support members were required, permitting larger surface area for collection of solar energy. Because tightness across the supports was not critical for the inner cover,

* Mention of specific items is for description only and does not imply endorsement.

installing it took less time than installing the outer cover.

A centrifugal fan connected to a duct (approximately 60' long) moves air to the furnace in the farrowing building. Air flow rate is measured with a flow nozzle, which requires the additional pressure available from a centrifugal fan. The ventilating system installed in a farrowing building can be used to move air through the unit where there is no need to measure air flow rate.

Performance of the Unit

The unit was placed in operation January 5, 1976, when winter in Manhattan, Kansas, was warmer than usual, followed by a spring cooler than usual. Solar radiation, as measured on a horizontal surface by Kansas State University's Department of Physics, was about as expected from January through March, lower in April and May, and higher in June. Solar energy collected and used through March, 1976, was equivalent to burning 335 gallons of propane at 75% combustion efficiency. By using solar energy, from April 1 through June, we saved 170 gallons. Temperature desired in the KSU farrowing house was above 80°F. and we continued using solar heat until July 7, 1976.

During February, with air flow at 1.1 cfm. per sq. ft. of collector, ventilating-air temperature increased an average 30.2°F., and energy collected was about 51% of solar insolation on the covers.

Maximum temperature of ventilating air is reached several hours after maximum solar radiation, usually around 9:00 p.m. and the thermal flywheel effect tends to attenuate the change in

temperature of ventilating air when outside temperatures suddenly drop.

Collector Size

Economics will be a controlling factor in determining the amount of collector area to install. We have additional research to conduct and many calculations to perform before predicting energy savings for a given combination of collector area, building size, and use. We are now sizing collectors for farrowing houses in Kansas to allow about 1 cfm. of ventilating air per sq. ft. of collector. For winter months, air entering the building will be heated an average of about 30°F. During afternoons of clear days, air is heated only about 10°F. but will be heated 40°F. or more during much of the night. Temperature increase, much less on cloudy than on sunny days, will depend on how outside temperature changes with time.

The collector should be sized to give the desired or reasonable temperature increase for the minimum winter ventilating rate. The rate generally recommended for farrowing houses in this region is about 20 cfm. per sow and litter. Thus, we would need 20 sq. ft. of collector for each farrowing crate. The typical crate is 5 ft. wide, and in buildings having two rows of crates, each sow uses 2½ ft. of the building length. An 8-ft. high collector would provide the 20 sq. ft. desired. Most of the south wall (buildings should be oriented east-west) would be used for solar collection.

In Kansas installed ventilating capacity is likely to exceed the recommended 20 cfm. because producers ventilate for odor control, it is difficult to get reliable air movement at low

rates, and fans for low rates are not generally available.

Most animal shelters do not have large enough south walls to provide collector areas with an air flow rate of 1 cfm. per sq. ft. Area available on south walls of swine nursery buildings, probably would provide about 2 cfm. per sq. ft. of collector area, so the expected temperature rise would be less. Solar-energy collection efficiency is increased somewhat by increasing flow rates.

Reduction in Fuel Consumption

It is almost impossible to predict a percentage of energy use that can be replaced with solar energy unless the use situation is very well defined. It is easier to predict how much energy can be collected on the average; some years may be more, some less. Generally, it is recommended that farrowing houses be maintained at 60 to 65°F. For that temperature we would estimate the equivalent of about 1.2 gallons of propane could be saved for each sq. ft. of collector area. Many producers in Kansas, however, maintain a temperature of 80°F. or more in their farrowing houses, extending the heating season over a much longer period than if the house were kept at 60 to 65°F. We would estimate 1.8 gallons propane equivalent annually per sq. ft. of collector for those buildings.

These projections for which essentially full-time use of facilities is assumed, are based on the best estimates we can make at this time. There are many variables that can influence results, such as the effect of snow cover or white-painted reflecting panels (not accounted for in our projections). Reflector panels can increase collected energy about 15%, but they also add to total system cost. We believe that a supplemental

reflecting surface running 8 ft. horizontally in front of the collector would be economical if it could be installed for about \$1.00 per sq. ft.

Advantages of the Storage Wall

A solar collector could be placed on the south wall and used without the energy storage provided by the concrete blocks. In that case, energy would be supplied to the building only during the daylight hours, as it is being collected. During fall and spring and on many moderate winter days, the building would tend to overheat in the daytime unless a small collector was used. Then, at night, there would be no solar energy available.

Our use of concrete to store heat spreads the arrival time of the solar energy to the farrowing building over the entire day increasing the effective use of each sq. ft. of collector area. It also allows us to use a larger collector and to supply more of the total heating load without overheating the building during the collection period. In addition, the concrete mass smooths out any wide temperature variations, resulting in a much stabler ventilation air temperature. The following data collected during February and March, 1978, show the percentage of the total collected energy added to the building during consecutive 4-hour periods: 12 mid.-4 a.m., 24%; 4 a.m.-8 a.m., 20%; 8 a.m.-12 noon, 10%; 12 noon-4 p.m., 7%; 4 p.m.-8 p.m., 16% and 8 p.m.-12 mid., 23%. As can be seen, only 17% of the total is added to ventilating air during daylight hours. The concrete storage causes the supply of solar energy to match the building's demand for heat more closely than it would otherwise.

Alternative Uses

Alternative uses of the system being considered are to dry grain during the fall and to cool summer ventilating air. From late September to early November, energy collected by the unit would be at about the same level as during the cooler months. Energy not required by the animal shelter could be used for drying grain. Professor Lipper² estimates that each 100 sq. ft. of south wall could supply enough energy to evaporate moisture from 15 bushels of corn (9-point moisture reduction) per day. The proposed use for Kansas is to attain a small temperature rise on ambient air to speed natural air grain drying or to provide a margin of safety during less favorable years.

Where grain drying could be considered, it is projected that energy collected during an 8-week drying period would replace the use of 1/3 to 1/2 gallon of propane per sq. ft. of collector. Obviously that would not fit well into the concept of short-term, high-speed drying. Also, there would be problems of materials handling and farmstead layout. However, it is not clear what alternatives we will have in the future, so development of contingency plans seems a reasonable objective.

The system also could be used to cool ventilating air during the summer. The low temperature at night averages 24^oF. below the high during the day at Manhattan, Kansas, and the difference is greater for days when the maximum is above 95^oF. We have done only limited work on cooling the storage at night and using the cooler blocks to decrease temperature of ventilating air during the day. Apparently we could lower peak afternoon temperature of ventilation air by 10^oF., which

would provide a better environment in farrowing houses. It is still too early in our research program to estimate benefits, but they should be adequate to recommend its use. Some additional equipment and controls which would add about \$1.00 per sq. ft. of collector, would be required, however. A cooperator has installed this feature on two farrowing houses, each 96 ft. long.

Economic Considerations

Materials for constructing the part of our experimental unit (8' x 50') required for a farm installation cost \$1,400 in late 1975. They were purchased locally (paint, lumber, hardware, insulation, etc.) except for the concrete blocks and TEDLAR, which were purchased through state bids. The 6 x 8 x 16-inch, solid-concrete blocks were delivered for 45 cents each; TEDLAR, for about 25 cents per sq. ft. We made these assumptions:

1. Labor costs would equal materials cost (\$1,400).
2. We could use the Kansas state income tax credit for solar-heating installations. (Limited to 25% of cost, or \$3,000, to be used during year unit is installed.)
3. The U. S. Government would enact a statute allowing a 20% income tax credit for solar-heating installations.
4. Repair costs would be \$25 per year-- basically, to repair damaged sections of the covers.
5. Property taxes would be \$50 per year and interest would be 9% on the prorated net investment after using income tax credits. (Property taxes have been waived during the next 5 years in Kansas.)

²Department of Agricultural Engineering.

6. Prorated net investment can be recovered in 10 years. (Assumes no salvage value.) Summarized, the budget would be, based on those assumptions:

Cost of unit	\$2,800
Kansas income tax credit	700
Federal income tax credit (projected)	560
Net invested after tax credits	\$1,540

Average annual cost for an 8 x 50-ft. solar collector-storage unit:

Repairs	\$ 25
Taxes	50
Interest	69
Investment recovers	154
	<u>\$298</u>

Assuming such a unit is used with a building Heated to 65F., the energy collected would be equivalent to that from 456 gallons of propane (1.2 gallon per sq. ft. x 380 sq. ft.) or 9120* kilowatt-hours of electricity. If we assume there would be no benefits for the remainder of the year, propane must cost as much as 65 cents per gallon or electricity 3 cents per kilowatt hour to break even. When the unit is used with a building maintained at 80^oF., more energy could be saved, and the corresponding break-even points would be 44 cents for propane and 2 cents for electricity.

During this past heating season (1976-77) in Manhattan, Kansas, propane cost approximately 35 cents. Hence, the unit could not be justified, economically, if propane is available at that price; it would be economically competitive with electricity assuming the use of Kansas and projected Federal tax credits.

Calculations considered here are based on a

unit that does not have reflector panels installed. Our unit has been operated without them, and projected energy collected does not include any increase they provide. Also, they increase costs. Panels in the upright position would block radiation during the summer and allow use of the storage for summer cooling; however, summer cooling would require additional equipment and operating costs.

General Observations

TEDLAR was used for covers on our unit because it was available in the winter of 1974-75 when the model was built, and because it had reasonably good transmission characteristics, serviceable life, and could be installed without complicated framework. Our research unit was divided so that we can use different cover combinations. This past winter 0.025-inch thick, glass-fiber-reinforced resin sheets were used for the outer cover on half the unit. We plan to use other combinations in the future. We still must determine the best choice of covers which will depend on (1) the cover's probable length of serviceable life, (2) short-wave and long-wave radiation transmission properties, (3) materials cost, and (4) ease of installation.

During construction, flies got between the covers, so screen wire was installed to cover the air inlet holes. There is a noticeable buildup of dust on covers where air enters between them. Possibly we can use a filter to trap the dust particles. Foreign materials collecting in the channel will restrict solar transmission to the collecting surface, and a suitable method of

*Resistance heating @ 100% efficiency.

cleaning seems unlikely. Thus, serviceable life may not depend on physical strength.

In the system planned for a local producer, ventilating air will be moved through the collector-storage unit all fall, winter, and spring. A conventional exhaust-type ventilation system will move air continuously through the storage unit except when inside temperature is too high; then a motor-operated shutter will admit outside air to the distribution duct. The energy storage unit will be used to cool summer daytime air; to cool the storage at night, a system of motor-operated shutters and fans will be used to force outside air back through the blocks. A differential thermostat will be used to change to the back-flushing mode of operation when outside temperature is 3°F. below that at the center of the block storage.

Soil was graded to within about 3 inches of the bottom of the covers on our unit, so mud splashes onto the cover and snow can build up over the bottom inlets. When air moves through snow before entering the bottom holes, its dewpoint can increase. Then it condenses on the inside of the outer cover, so grade should have been several inches below the bottom of the collector cover.

Attaching the support for the inside cover was somewhat of a problem; we recommended to the producer now building a unit that he use bolts anchored in mortar in horizontal block joints to solve that problem. We also suggested that, to reduce labor, he paint the wood supports black at the same time he paints the blocks.

A question often asked is whether spraying the wall with water would make a summer cooler of the unit. That should not be considered because

minerals would tend to leach from the concrete and deposit on the black surface, which would reduce absorption of solar energy. When the roof on our unit leaked for a short time, deposits formed over a small area.

Future Research

Objectives

Research on using solar energy in livestock shelters at Kansas State University during the 1979 fiscal year, assuming funding is continued, will be directed toward these objectives:

1. Collecting performance data at the KSU site using other systems of transparent covers (basically corrugated-type materials where transmission characteristics are hard to predict as a function of incidence angle) for different air-flow rates and ground reflectance.
2. Working on phase three of the solar-energy program by assisting in the development of on-farm systems in Kansas; monitoring performance of units installed by producers near Manhattan, Kansas; and comparing the performance with predictions of the computer model.
3. Verifying the computer modeling program and predicting output of the solar collector-storage system under variable conditions of solar energy, temperature, and air-flow rates for different cover systems. Interaction of output temperatures of the solar collector-storage system with internal building environment will be considered, as well as a simplified form of the modeling program to predict performance by using daily solar

- insolation rather than hourly values.
4. Improving solar-collection efficiency and multiple-use applications by one or more of the following: (1) increasing air-flow rate during daytime hours; (2) reducing losses at night by using automatically controlled shading systems; and/or (3) using a diathermanous cover system, which could make it possible to consider evaporative cooling during the summer.
 5. Writing a publication describing our work on solar energy; preparing plans swine producers could use in constructing solar-energy units; and developing a slide set showing construction and operation of the solar-collector-storage system, which extension specialists on farm buildings could use for educational programs in the major hog-producing area of the United States.