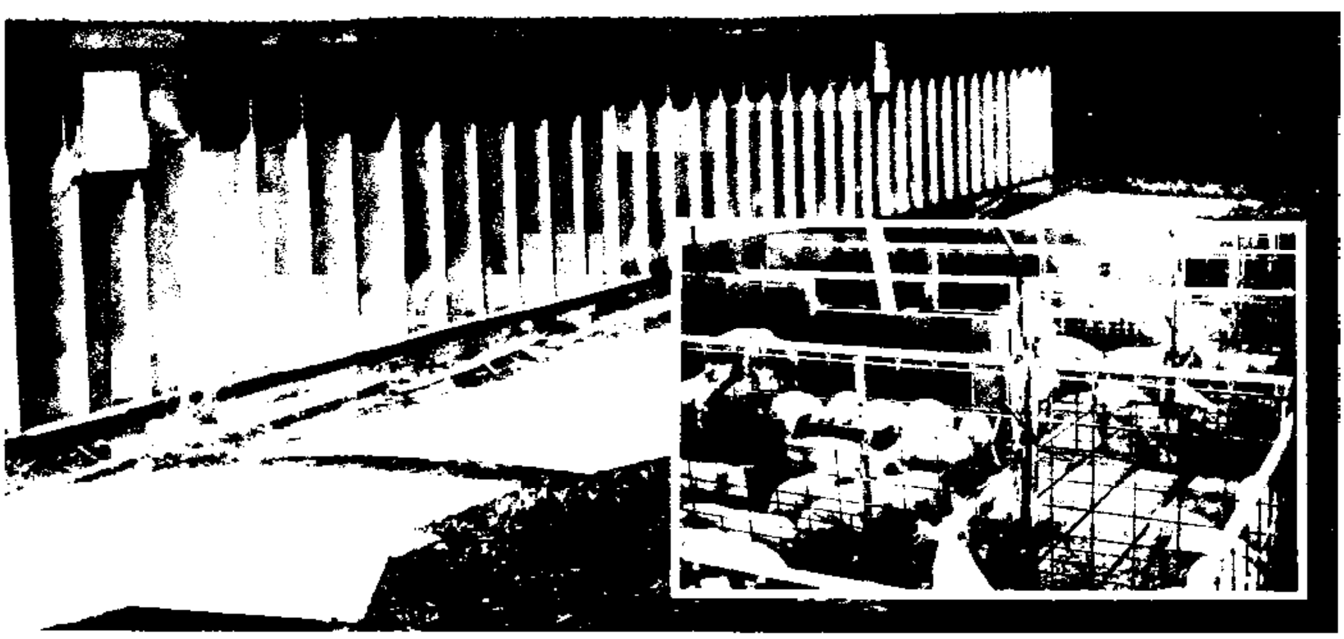
SOLAR HEATING SYSTEMS FOR SWINE HOUSING: AN ECONOMIC APPRAISAL



BULLETIN 645 SEPTEMBER 1983
AGRICULTURAL EXPERIMENT STATION, KANSAS STATE UNIVERSITY
JOHN O. DUNBAR, DIRECTOR

SOLAR HEATING SYSTEMS FOR SWINE HOUSING: AN ECONOMIC APPRAISAL

Jeffery R. Williams, Walter G. Heid, Jr., James P. Murphy and Francis V. Robbins*

ABSTRACT

A capital budgeting simulator estimates the annual costs and savings of four selected solar swine systems, taking into account initial investment, salvage value, tax credits, the time value of money, annual operating costs and estimated fuel savings with expected life of the collectors.

The results of this study generally show that under reasonable fuel cost increases a well-designed and operated solar-heated swine confinement unit, similar to the Kansas State University Solar Wall, should prove to be a very viable and wise farm investment.

Keywords: Solar, energy, swine, economics.

*Assistant Professor, Department of Economics; Agricultural Economist, National Economics Division, ERS, U.S. Department of Agriculture; Associate Professor, Department of Agricultural Engineering; and Instructor, Department of Agricultural Engineering, respectively, Kansas State University, Manhattan, Kansas.

CONTENTS

INTRODUCTION

Swine producers, like other farmers, are interested in methods of reducing their farming costs. Rising fuel costs in the past decade caused some producers to consider solar energy for heating and ventilating their swine houses.

The application of solar energy to swine production was recognized by public researchers by the mid-1970's. The Kansas Agricultural Experiment Station pioneered much of the early research, designing and testing a workable solar swine system. As a result, the Kansas State University Solar Wall has found application in a number of Midwestern states. Four of these systems are analyzed in this report.

The KSU Solar Wall, as well as other solar collector systems, is ideally suited to total confinement swine systems. Confinement systems require more intensive management than open-lot swine systems. One of the major differences in management is the conditioning of air. Confined livestock enterprises require fresh, low-humidity air to maintain acceptable levels of moisture, odor, and toxic gases. If located in the central and northern regions of the United States, they also may require large amounts of energy (heat) to maintain a proper temperature range, especially in buildings housing young animals. Energy used to heat the incoming ventilation air often represents 75 percent or more of the total energy used in young animal housing (l).

Trends in the U.S. swine industry point toward a continued increase in the number of total confinement systems and, therefore, more intensive energy consumption. The largest swine enterprises in the United States are typically confinement-type systems. The increases in large swine farms have been dramatic. The Census of Agriculture reported a total of 1,136 farms that sold 1,000 or more swine in 1964 (2), compared to 7,327 farms in 1978 (3). In other words, farms selling 1,000 or more swine per year accounted for 3 percent of all swine sales in 1964 and for 21 percent in 1978. Kansas, ranking within the top 10 swine-producing states, has experienced a similar trend.

Growing in numbers and being intensive users of L.P. gas, confined swine systems and other livestock and poultry systems gained the attention of U.S. Department of Energy (DOE) and Agriculture (USDA) officials in the late 1970's. Beginning in 1979, a nationwide on-farm demonstration program was conducted to establish acceptability. The program, entitled "Solar Heating of On-Farm Livestock Shelters," was funded by the DOE and administered by the USDA's Extension Service. This program, which was conducted by the Extension Agricultural Engineers at selected land-grant colleges, resulted in nearly 90 on-farm solar demonstration projects. A large majority involved confined swine buildings. Kansas was included in the program, having nine on-farm demonstration projects.

The collectors chosen in this program were 50 percent cost-shared by the government up to a maximum of $2,500. The collectors were constructed during 1979 and 1980, Most were home-made.

The purpose of the on-farm demonstration program was to test the performance of the four KSU solar walls analyzed in this report and other solar swine systems. The primary concern of the engineers who conducted the project was technical feasibility. Are laboratory designed solar collector systems technically feasible in full-scale use? This economic performance study goes one step further, by examining the payback of the demonstration systems. How critical to economic feasibility are such factors as initial investment, life expectancy and collector efficiency? Is the acceptance of solar swine systems by farmers dependent on tax credits? If so, at what level? And at what level of conventional fuel cost increase will their solar collectors become economical without tax credits?

Performance data were gathered on the Kansas demonstration collectors during the heating seasons of 1980-81 and 1981-82. The Kansas Final Report for the on-farm demonstration project was submitted to the Extension Service, USDA and DOE in September, 1982 (4).

Results of the demonstration project in Kansas suggest that solar swine systems have widespread application. However, it should be understood that the performance of these systems will vary, regionally, by the amount of incoming solar radiation, temperature, and other factors.

This economic analysis used the performance data as reported in the Kansas Final Report. The purpose of this study is to analyze the costs and returns associated with four selected systems to determine whether or not the economic payback for these systems is short enough and the net savings large enough that other farmers may want to invest in similar solar collectors.

DESCRIPTION OF SOLAR COLLECTORS

The KSU Solar Wall, sometimes referred to as the "Spillman Wall" because it was designed by Charles Spillman, Agricultural Engineer, Kansas State University, is basically a ventilating, air-preheater-type collector that tempers incoming air in winter. Shutters in the center of the collector are used to bypass the collector and admit air directly into the building when the solar heat is no longer needed to maintain the proper building temperature. The building is oriented with the ridge line running east and west to obtain a large south wall exposure on which to construct the collector. This collector is designed as an integral part of the livestock buildings and can be constructed using locally available materials.

Construction of the collector begins with a concrete foundation two feet wide and extending downward to below frost level.[1] Reinforcing steel can be extended horizontally from the foundation to attach a reflecting sidewalk or reflecting panels. The overhang on the south side of the building should extend at least 30 inches from the interior wall. The collector is 24 inches in depth, which leaves a minimum of a 6-inch overhang for icicle problems and summer shading. An opening in the south interior wall is utilized for ductwork, which admits air from the collector to the building.

The collector foundation is insulated with 1 inch of polystyrene and covered with cement-asbestos board. Clay tile, extending from the foundation, is utilized to pump animal waste from the building if under-floor manure storage is used. Solid concrete blocks, normally 16 inches long, are stacked on top of the foundation. All blocks are placed with the 16-inch dimension perpendicular to the foundation to produce a wall 16 inches thick. The blocks are arranged to leave a 6-inch air space between the building wall and the back of the blocks to allow airflow into the building.

Mortar or construction adhesive is used in the horizontal joints to hold the blocks in place. No mortar is used in the vertical joints and a 3/16-inch-wide vertical crack is left between each block. Incoming air passes through the 3/16-inch slots so that the heat may be exchanged between the block and the airflow.

The blocks then are painted with a petroleum-based flat black paint. Normally, two coats are required to obtain complete coverage and high solar radiation absorption.

After the blocks are stacked, the top of the block wall is sealed and insulated to reduce heat loss through the roof. Normal height of the block wall is about 8 feet; however, some buildings may require more or less.

White pine wood strips (3/4 inch by 1 1/2 inch wide) then are nailed and glued to the black face. These vertical wood strips are painted white and spaced 2 to 2 1/2 feet apart. White-painted wood strips (1 3/4 inch x 1 1/2 inch) are mounted horizontally along the top and bottom of the vertical strips to complete the mounting frame for one of two transparent covers. The first transparent cover is attached to the wooden framework with an adhesive. Then another 1 1/2-inch wood frame is applied directly over the inner wood frame and transparent cover with flathead wood screws so that a second transparent cover can be applied. If fiberglass-reinforced panels are used, holes should be drilled oversized to allow for thermal expansion and contraction. A 2-inch slot at the bottom of the inner cover is used to conduct air to the block wall. The outer cover has an air inlet at the top. This opening is screened to prevent debris from entering the collector. Wooden battens are fastened over the outer cover with wood screws to secure it.

Outside air enters the collector through the screened inlet slot at the top of the outer cover. This inlet is sized for a 0.05-inch water pressure drop to distribute air along the length of the collector. The air then travels downward between the two covers to the bottom of the inner sheet. It passes through the inner slot and turns 180 degrees to flow up along the black surface and through the vertical cracks in the concrete block wall. The vertical flow of air between the two transparent sheets reduces the heat loss from the concrete blocks. The black surface warms the air and the concrete acts as a temporary storage facility, releasing heat to incoming air after the sun is no longer on the collector surface. The air travels through the block wall and into the building through a shutter in the frame wall. A distribution duct admits the air to the animal confinement area.

Care must be taken during construction to insure that all joints are as airtight as possible to guarantee that ventilating air is conducted through the solar collector and concrete wall when desired.

The vertical, south-facing collector receives high solar intensity during the winter when shading by the building overhang is minimal. Snow cover or reflector panels on the ground significantly increase the the incoming solar radiation. As summer progresses, the solar intensity on the collector decreases and the shadow from the 6-inch overhang begins to shade the vertical collector. In mid-summer, solar intensity on the collector is quite low, so the solar heat load on the building is small. Ventilation air also can be drawn directly to most buildings with ventilators, thereby bypassing the collector.

[1]Construction details, reported in plan #81902, may be obtained from Extension Agricultural Engineering, Room 237 Seaton Hall, Manhattan, Kansas 66506.

Chimneys on the north side of the building enclose exhaust fans that power the ventilation system year round. Air is exhausted vertically from the building to eliminate the strong wind influence in Kansas. During normal winter operation, the fans are the only moving part of the collector, which decreases electrical operation costs of the system.

A brief description of the four solar collector systems analyzed in this study follows. (The confinement buildings and the solar collectors are described and illustrated as the size and construction of both units are crucial to system performance.)

Solar Heating System No. 1

The building size is 28 ft by 124 ft and houses two 10-crate farrowing rooms, two weaning nursery rooms, and two grower nursery rooms. A small entryway and utility room separates the farrowing rooms from the nursery rooms. Manure is removed from the building by flushing water under a slotted floor. The main frame of the building is constructed with 2 x 6 stud walls with 6 inches of fiberglass insulation. The ceiling contains 10 inches of cellulose insulation. The exterior shell of the building is enameled metal and the interior walls and ceiling are 1/2-inch exterior grade plywood. The building has a partially slotted floor. Supplemental heat is provided with non-vented propane furnaces. One 168,000 BTU/hr L.P. gas furnace serves both farrowing rooms and a 60,000 BTU/hr unit is used in each nursery room

Detailed illustrations of the building and the solar collector are presented in Figure 1. The total cost of the 392 ft^2 solar wall for the farrowing rooms and the 472 ft^2 solar wall for the nursery rooms was $6,900 or $7.99 per ft^2. The economic analysis is conducted for the farrowing unit only.

Sidewall-mounted exhaust fans ventilate the room. The fans create a slight vacuum in the room that induces airflow through the solar collector. Outside air enters between the two transparent covers and then passes through the 3/16-inch vertical cracks in the concrete block wall. The solar-heated concrete tempers the ventilating air as it passes before entering the farrowing or nursery rooms.

Separate solar walls serve the farrowing rooms and nursery rooms. The solar wall for the two farrowing rooms measures 56 ft by 7 ft, and the solar wall for the four nursery rooms is 61 ft 8 inches by 7 ft 8 inches. Airflow from the solar walls through the individual rooms is shown in Figure 1. During the heating season, the ventilating air from the weaning nursery rooms is exhausted into the grower nursery rooms. The weaning rooms are kept much warmer than the grower rooms, so exhausted air from the weaning rooms provides useful heat to the grower rooms.

Solar Heating System No. 2

The building is a 51 ft by 112 ft nursery with seven rooms. The main frame of the building is constructed with 2 x 4 stud walls with 3 1/2 inches of fiberglass insulation. Ten inches of cellulose insulation are installed above the ceiling. The exterior shell of the building is enameled metal and the interior walls and ceiling are 1/2-inch exterior grade plywood. The floor of the building is totally slotted with fiberglass slats and a pit below to store manure. Supplemental heat is provided by two non-vented, 60,000 BTU/hr L.P. gas furnaces in the ventilation distribution duct plus a 60,000 BTU/hr non-vented furnace in each room.

Detailed illustrations of the building and the solar collector are presented in Figure 2. The size of the collector is 7 1/2 ft by 112 ft with 840 ft^2 exposed to the sun. Collector cost was $10,676, or $12.71 per ft^2.

Fans, which are installed in exhaust chimneys in each room of the building, regulate the airflow through the building. All seven rooms draw air from the full-length walkway along their south side which serves as a distribution duct (see plan view). Air from the solar wall enters this walkway through four adjustable inlets along its length. Therefore, any combination of the seven rooms that need supplemental heat can utilize the solar wall. Manually adjustable shutters allow air from the walkway into each room. They are gradually closed as the pigs grow and require less supplemental heat. This keeps total airflow through the collector at a reasonable rate and allows more efficient use of the available solar energy. Additional shutters in the north wall of each nursery room are opened to admit outside air to the room as the solar-heated air supply is reduced. Air withdrawal from each room is accomplished by drawing the air through the slats into the pit area and then to the chimney, where it is exhausted vertically. The vertical chimney reduces wind pressure on fans and provides some natural ventilation if fans fail.

Solar Heating System No. 3

The building, a 36 ft by 96 ft structure, houses three nursery rooms. The main frame of the building is constructed with 2 x 4 stud walls. The walls contain 3 1/2 inches of fiberglass insulation. Ten inches of cellulose insulation are installed above the ceiling. The exterior shell of the building is enameled metal and the interior walls and the ceiling are 1/2-inch exterior grade plywood. A slotted stainless steel floor allows for use of a manure storage pit below. Supplemental heat is provided by a 60,000 BTU/hr non-vented L.P. gas furnace in each room.

Detailed illustrations of the building and the solar collector are presented in Figure 3. The size of the collector is 7 ft by 96 ft, or 672 ft^2. The collector cost was $5,420, or $8.07 per ft^2.

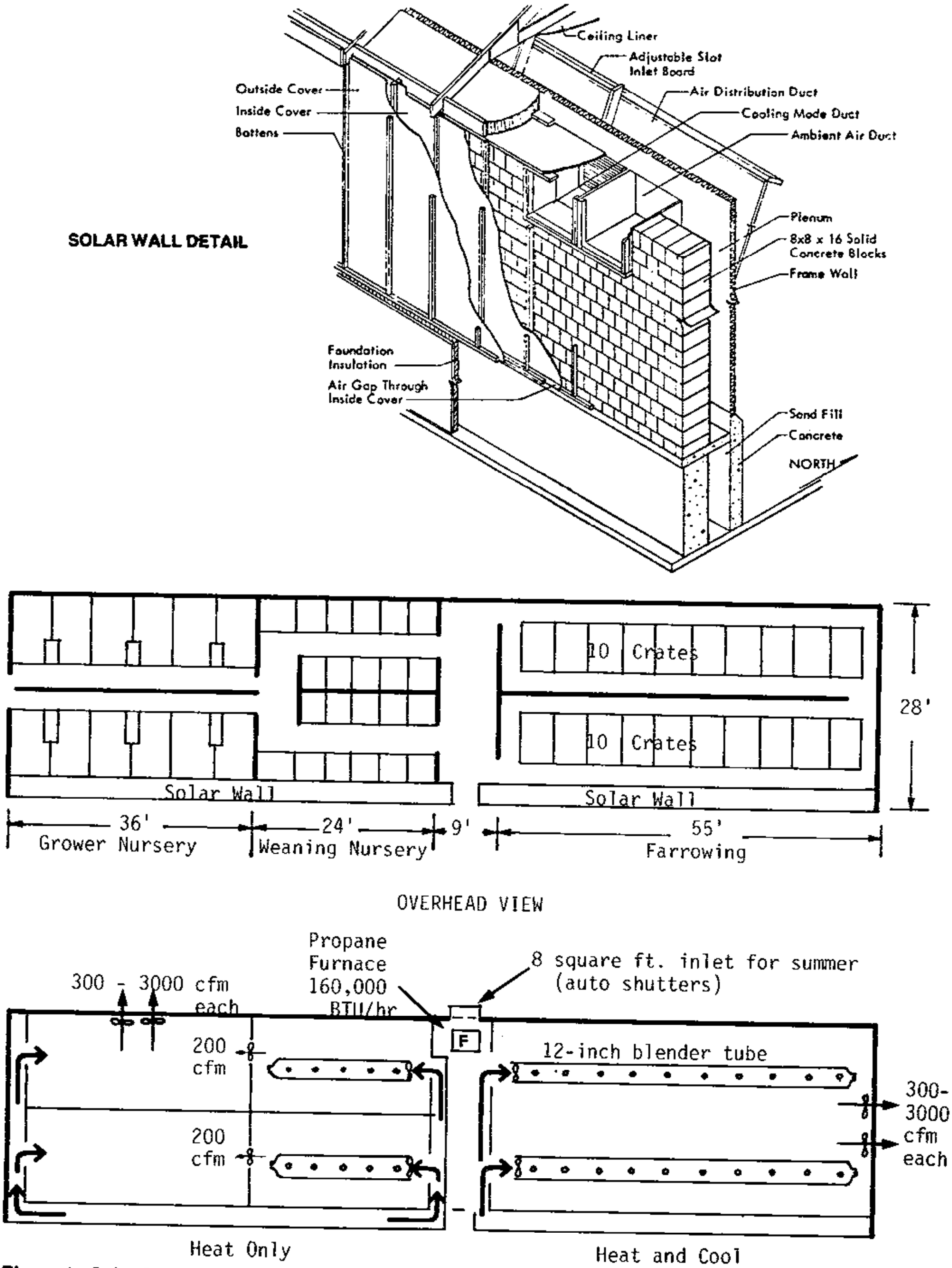


Figure 1. Solar System No. 1.

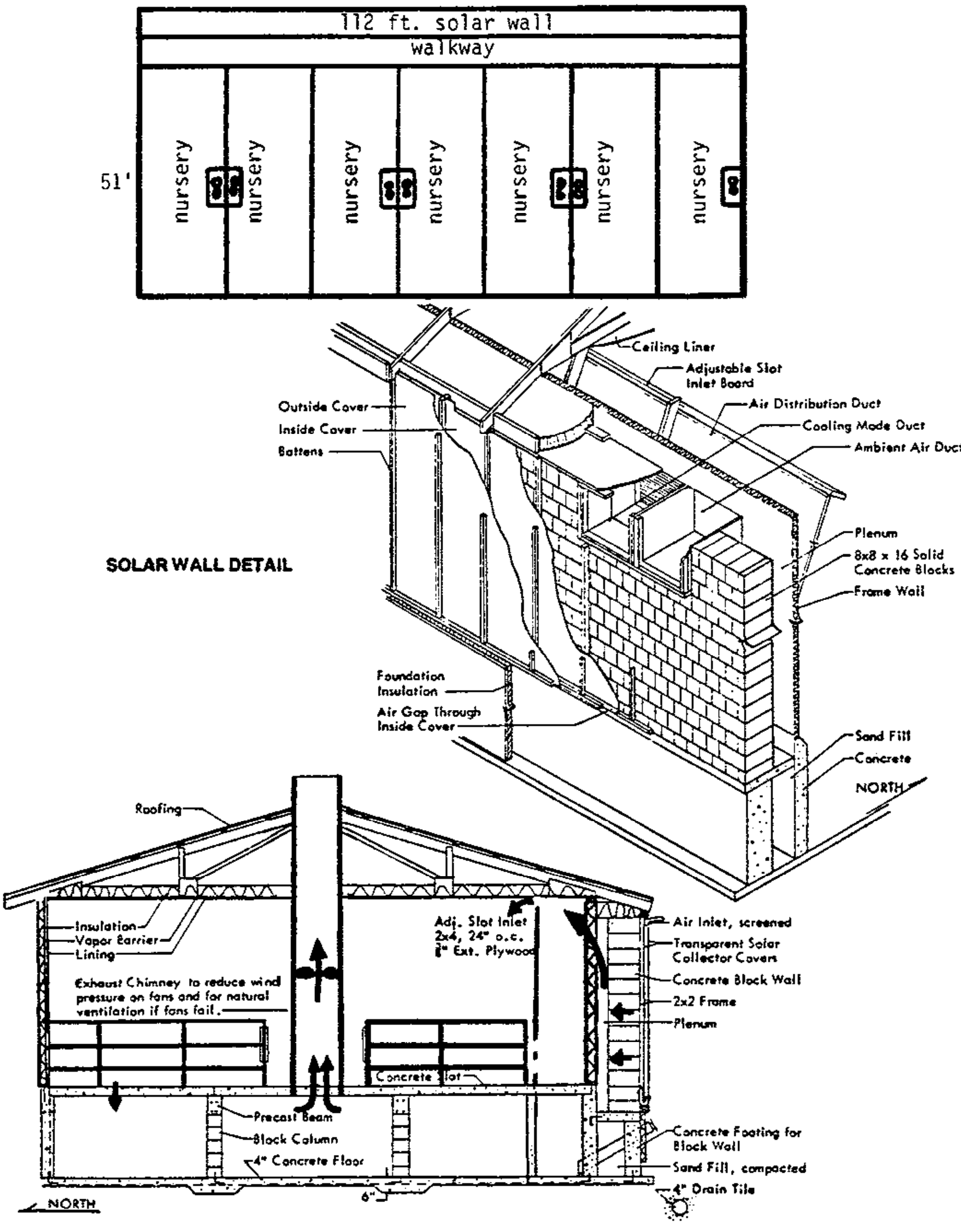
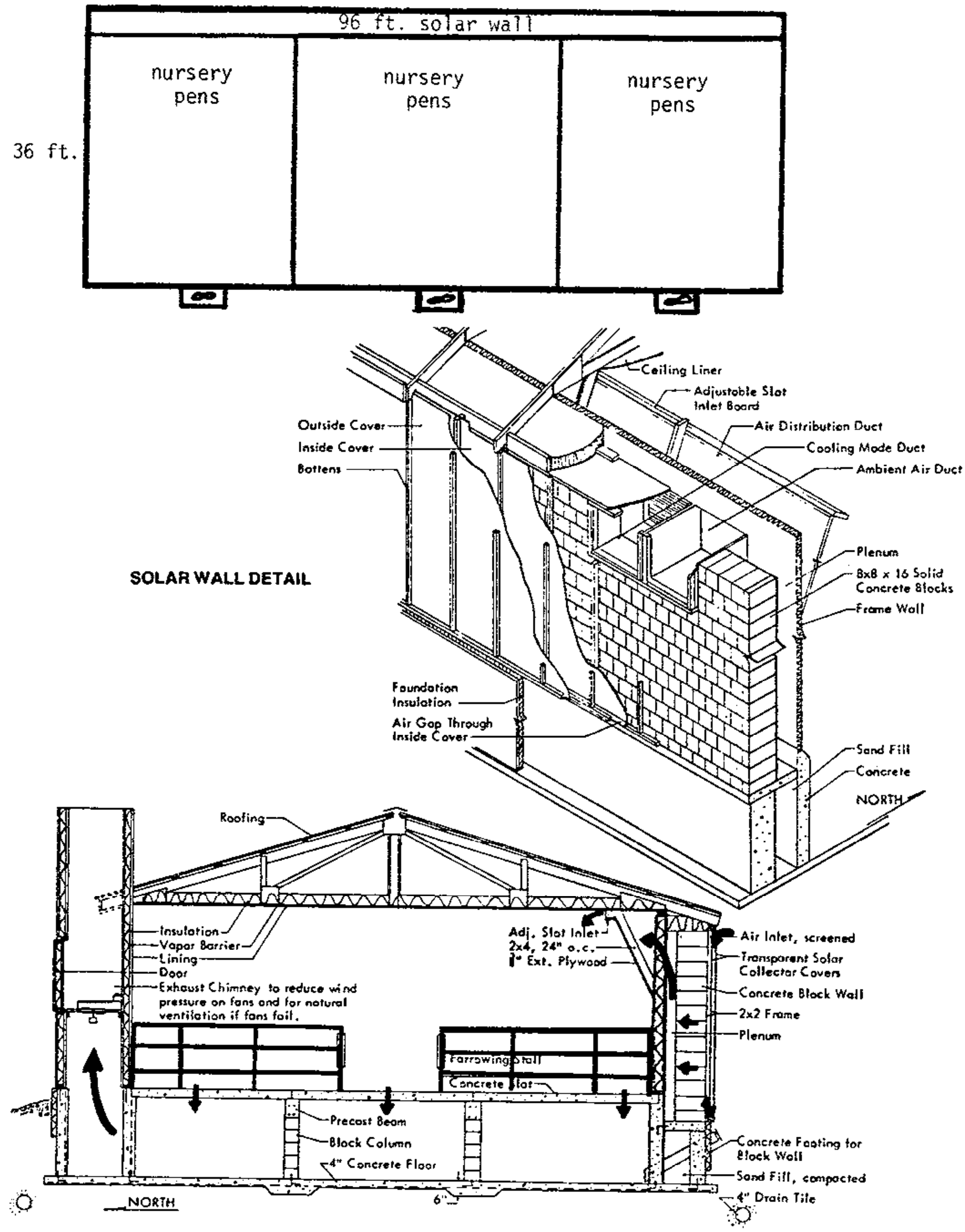


Figure 2. Solar System No. 2.



CROSS SECTION

Figure 3. Solar System No. 3.

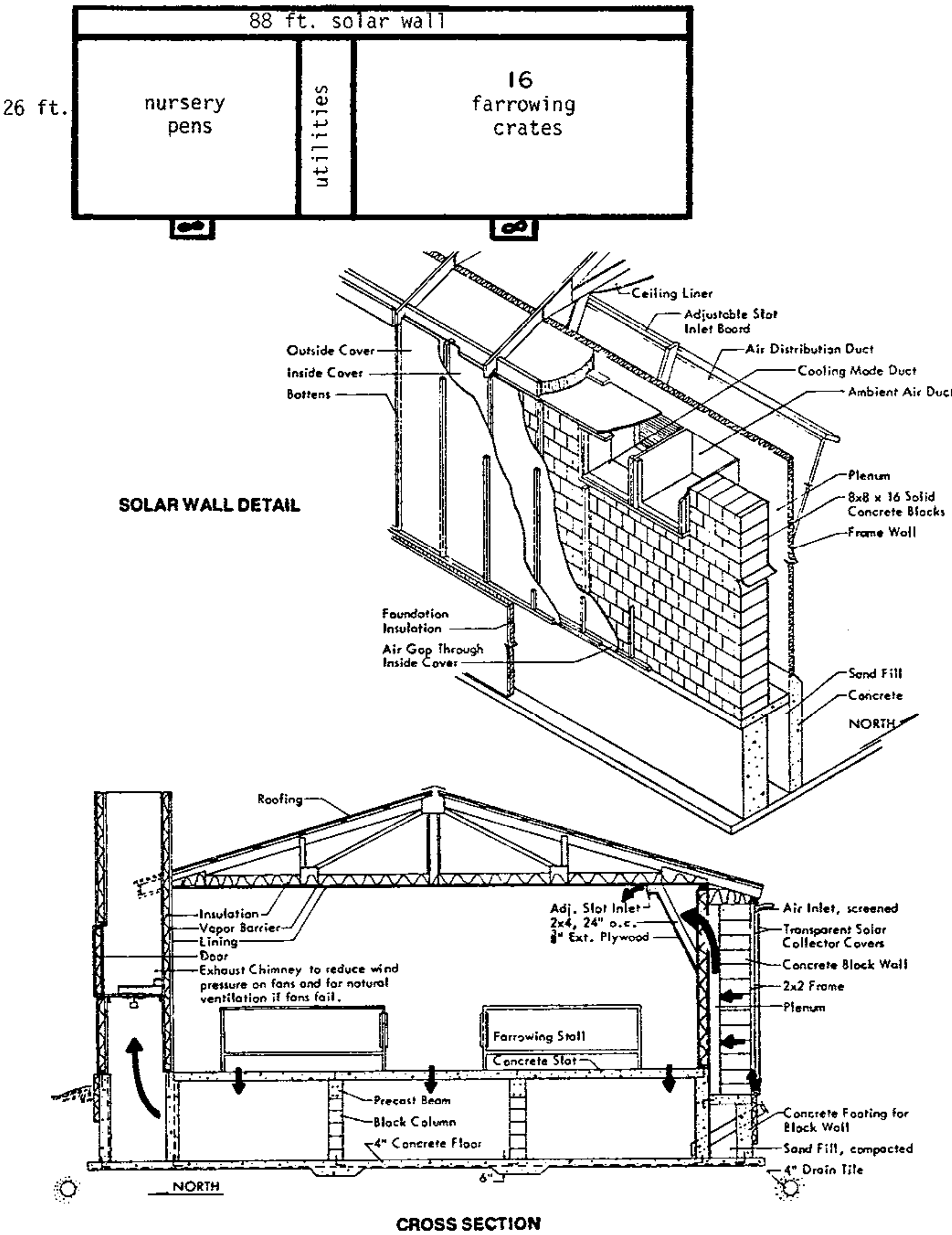


Figure 4. Solar System No. 4.

The fan system in this building is identical to the one in System No. 2. All three nursery rooms draw air from the full-length plenum behind the concrete block wall. Therefore, the entire solar collector storage unit can provide heat to any combination of rooms that requires heat. Again, air is removed from the rooms through the slotted floor into the pit area and out of the building through a vertical chimney.

Solar Heating System No. 4

The building is a 26 ft by 88 ft wood frame structure that includes a 46 ft by 24 ft farrowing room with 16 crates, a 32-ft nursery, and an 8 ft by 24 ft feed and utility room between the farrowing and nursery rooms. The sidewalls are 8 ft high, constructed with 2 x 4 inch studs with 3 1/2 inches of fiberglass insulation and a polyethylene vapor barrier. The ceiling has 8 inches of cellulose insulation over it. The exterior shell of the building is enameled metal and the interior walls and ceiling are 1/2-inch exterior grade plywood. The floor of the building is totally slotted stainless steel with a pit below to store manure. Supplemental heat is supplied by a 60,000 BTU/hr non-vented L.P. gas furnace in each room.

Detailed illustrations of the building and the solar collector are presented in Figure 4. The solar collector is 88 ft long and 6 ft 10 inches high with a total area of 600 ft^2. Collector cost was \$5,025, or \$8.38 per ft^2.

Again, the airflow system is similar to the others studied. Both the farrowing room and nursery room draw air from the full-length plenum behind the concrete block wall. Thus, the solar collector-storage unit can be utilized by either or both rooms depending on their heat demand. The air exhaust system is identical to System No. 3.

TECHNICAL PERFORMANCE

Performance data were gathered for the Kansas demonstration collectors during the heating seasons of 1980-1981 and 1981-1982 to determine their energy-saving capability.

During the demonstration tests, hourly performance data were collected and stored. The data included: outside air temperature, room air temperature, air temperature rise through the solar collector, and airflow rate through the solar collector. Measuring the energy supplied to a building by a solar collector was not sufficient to determine the energy saved by the collector. The building's demand for supplemental heat also was established to determine what portion of the collected solar energy actually saved fuel. An hourly energy balance, including animal heat production, was performed on each building to determine energy savings. The results were accumulated to determine total supplemental heat demand and total energy saved by solar heat during each monitored time period.

The measured performance results were used to determine if the collectors had operated satisfactorily and to discover any problems in the design or operation of the systems. All four systems in this study operated well during the monitored periods. The measured data and performance results also were used to develop equations to predict the supplemental heat demand of the buildings, as a function of inside and outside air temperatures. Differences in design and operation of the buildings produced large variations in the amount of supplemental heat needed. The heating season for System 1 included nine months per year, whereas the heating season of System 3 was only five months long. The supplemental heat demand equations were used along with a mathematical model of the KSU Solar Wall to project the typical, annual performance of each demonstration unit. Typical, annual performance is much more useful than short-term measured performance for both engineering and economic evaluations of solar heating systems.

Typical, annual performance of the four systems in this study is presented in Table 1. The solar collection efficiency was quite good for all four systems, although the annual building heat demand per unit area of solar collector varied greatly. The wide variation in heat demand produced a wide range of solar heating fractions. The

Table 1. Proiected Typical Annual Performance

System	Collected Solar[a]	Collector Efficiency	Heat Demand[a]	Energy Saved[b]	Solar Fraction[c]	Percent of Energy Saved to Solar Energy Collected
	BTU/ft^2	Percent	BTU/ft^2	BTU/ft^2	Percent	
No. 1	182600	63	317500	154200	49	84
No. 2	129500	55	582400	146700	25	113
No. 3	101500	60	268200	80200	37	79
No. 4	136400	53	187700	102500	58	75

[a]Supplemental heat demand of building per unit area of solar collector.
[b]Heating energy saved per unit area of solar collector, includes energy saved by reducing heat loss through south wall.
[c]Portion of annual heating demand that is supplied by solar energy.

energy saved by each collector differed from the solar energy it collected for two reasons. First, solar energy supplied to a building when no supplemental heat is needed does not save energy, and second, the solar walls save energy by reducing heat loss through the south building wall. System 2 typically will save more heating energy than the solar energy it collects because the building heat demand is very large and little solar energy is wasted. There is an inverse relationship between the solar heating fraction and the fraction of collected solar energy that is utilized to save energy. A large portion of the solar energy that each of these systems collects is utilized to save heating energy, emphasizing the desirability of the concrete heat storage.

ECONOMIC ANALYSIS METHODOLOGY

The economic analysis of the solar collectors used a capital budgeting approach. A capital budgeting simulator estimated the annual costs and savings that were generated by the collector over its expected life (5). This approach took into account the initial investment required, expected salvage value, tax credits and deductions, the time value of money, annual operating costs and estimated fuel savings over the expected life of the collector.

The after-tax, discounted, net present value was calculated with the use of the following equation.

$$PVSS_N = -C_0 + C_N (1+r)^{-N} + T[\sum_{k=1}^{N} D_k (1+r)^{-k}] + I_1 (1+r)^{-1} + SC_1 (1+r)^{-1} + (1-T)[\sum_{k=1}^{N} E_k (1+r)^{-k}] - (1-T)[\sum_{k=1}^{N} (R_k + TX_k + IN_k)(1+r)^{-k}]$$

where:

$PVSS_N$ = Present value of solar savings.

C_0 = The original investment required for construction and installation of the solar collector.

C_N = The salvage value of the solar collector at the end of the N^{th} year. This term is discounted to present value by (l + r)- N.

r = An after-tax discount rate.

T = The combined federal and state marginal income tax rate.

D_k = Depreciation in k^{th} year. This term is discounted and then multiplied by the tax rate to arrive at the effective tax deduction for depreciation.

I_1 = Investment credit that can be taken the first year of ownership. This term is also discounted by $(1+r)^{-1}$.

SC_1 = Combined state and federal solar credit that can be taken the first year of ownership. This term is discounted one year by $(1 + r)^{-1}$.

E_k = Energy savings in k^{th} year. This is the savings in fuel from using solar energy. This term is discounted and multiplied by (1 –T) to arrive at the actual after-tax savings. Savings are similar to income in this case.

R_k = Maintenance cost in the k^{th} year.

TX_k = Property tax cost in the k^{th} year.

IN_K = Insurance cost in the k^{th} year.

R_k, TX_k and IN_k also are discounted and multiplied by (1 – T) to arrive at the after-tax costs. These costs are deductible expenses for farm business tax purposes and, therefore, the effective rate is found by multiplying the costs by (1 - T).

Cost estimates and energy savings must be adjusted to an after-tax basis to account for allowable deductions and credits associated with using solar facilities in a farm business. Depreciation, investment credit and the solar energy credit items must be considered in the analysis to adjust actual cash flows for tax purposes.

The values used in the analysis were based on actual collected data and assumptions or forecasts of future conditions. Because future estimates are uncertain, a sensitivity analysis was included to demonstrate how a change in their value might affect the results.

If the calculated net savings or net present value was positive, when using the previously defined equation under the conditions outlined, including the values of the variables specified, the investment was judged to be acceptable.

The number of years required for payback of the initial investment by generated fuel savings, tax credits and deductions also was calculated. The payback estimation (years) took into account fuel savings, maintenance costs, investment and energy credits, salvage value and the allowable depreciation deduction, using an after-tax discount rate as well as the time value of money. Taking these factors into account, payback is attained when the cumulated net saving equals the initial investment. Payback throughout this report is based on the number of years required for this equalization to occur. The reader should be aware that this incremental measure is less sensitive to change than a measure of payback reported in months.

Percent return on investment also was calculated, using the internal rate of return method. This method determined the compound rate of interest that equates the present value of the future cash earnings (savings) over the collector's life with the initial investment cost. This rate can be compared with the minimum acceptable rate of return or returns from other investments. The return on investment was based on fuel savings less operating costs plus investment and solar energy credits, allowable depreciation deductions, and the after-tax salvage value.

Base case conditions for the technical and economic variables are summarized in Table 2. The ranges for the sensitivity analysis of the selected technical and economic values are reported in Tables 3-12.

Initial Investment

Farm records provided the cost of materials (1980 $), data and construction expenses for each collector.

Salvage Value

Salvage value of the collector was assumed to be $1.86/sq. foot of collector surface or $20/per sq. meter after a 15 year life of operation. This estimate was based on the value of the concrete blocks, which should not deteriorate.

Depreciation

Depreciation deductions were taken into account in the analysis on an after-tax basis. Three methods were used to figure depreciation in the analysis. The initial base case analysis, using a simple straight-line approach, was calculated as follows:

$$DEP_K = \frac{INVEST - SV_N}{N}$$

where

DEP_K = Depreciation in year k where k ranged from 1 to N.

INVEST = Original investment required for the solar collector.

SV_N = Salvage value in the last year of life(N).

The new straight-line method and the ACRS method instituted with the Economic Recovery Tax Act of 1981 served as a basis for further analysis. These methods are applicable to collectors constructed after the 1980 calendar year. Although all pre-1981 items will continue to be depreciated under the old rules, use of the new depreciation methods shows the effect they may have on decision making, if one were planning to install a collector now. The two methods are outlined below.

Essentially, depreciation under the new straight-line method is figured by dividing the original investment by the expected life of the investment. In the first year, half of the value is allowed while the remaining half from the first year may be taken in the year after the last year of expetted life.

$$DEP_1 = INVEST/N/2$$

$$DEP_{2\text{ to }N} = INVEST/N$$

$$DEP_{N+1} = INVEST/N/2$$

The Accelerated Cost Recovery System (ACRS) is based on standardized percentages for different types of investments. The solar collectors analyzed in this report fall into the 5-year classification. The percent of original investment for depreciation in each year is indicated below.

Year	% of Original Investment
1	15%
2	22%
3,4,5	21%

Under the new straight-line and ACRS methods, salvage value is not used for determining the depreciable base, therefore, the salvage value is taxed as ordinary income or adjusted for tax purposes in the last year of expected life.

Investment Credit

A credit for investment in depreciable property against federal income tax was allowed. Under the tax regulations that were in effect for property installed before 1981, an investment tax credit of 10 percent would be taken the year the solar collector was installed, if the collector would be used for 7 years or longer. Under ACRS, an investment tax credit of 10 percent is allowed on property constructed in 1981 or later, if it is to be used in the business for 5 years or longer.

Solar Energy Credit

A credit for investment in solar energy facilities against federal and state income tax also was included in the analysis. In the base case analysis, the federal tax credit was calculated as 15 percent of the initial investment. A state tax credit of 30 percent of the initial cost was used. In other words, this study initially assumed that a total of 45 percent solar investment tax credit would be taken the first year against federal and state income tax liability.

Energy Savings

Energy savings were based on the fuel saved by the use of the collector rather than the conventional fuel source that would have been used to heat the building.

Fuel saved by the solar collector was determined by actual on-site monitoring in conjunction with computer simulation. A simple accounting of the energy supplied to a building by a solar collector is not adequate to establish the actual fuel saved by the solar collector. The energy flows of a building and its demand for supplemental heat also must be established to determine what portion of the total solar energy supplied actually saves fuel (refer to Technical Performance section). Typical monthly temperature and solar data, collected at the closest official meteorological data collection site, served as the basis for estimating collector efficiency and supplemental heat demand. Further details concerning the actual collector monitoring and performance simulation can be found in Murphy, Schwartz and Robbins, 1982 (4).

Once an average annual fuel savings for each collector was estimated from the computer simulation technique, this information was used to project the annual fuel savings ($) for the economic analysis. Natural gas and L.P. gas were the two fuels replaced by solar energy in these demonstration projects. The fuel prices were initially set at $3.40/1000 ft^3 of natural gas and $.57/gallon of L.P. gas. The prices were converted to a BTU basis for use in the program because energy savings generated by the solar collector were based on BTU'S. To do this the efficiency of the furnace and BTU content of the fuel were taken into account. It was assumed that the L.P. gas contained 84,500 BTU/gal and natural gas contained 900 BTU/ft^3. The non-vented furnace efficiencies were assumed to be 90 percent. With this efficiency, each gal of L.P. gas delivers approximately 75,500 useful BTU/gal and natural gas delivers approximately 800 useful BTU/ft^3. Under these conditions, the effective prices of the fuels were $.00755/1000 BTU for L.P. gas and $.00425/1000 BTU for natural gas. The price at which each fuel increased on an annual basis was initially assumed to be 13 percent.

Maintenance Costs

Annual maintenance costs were assumed to be $0.10 per square foot of collector surface. This figure included an average value for labor and materials to repair punctures in the transparent covers, framing or ventilation components. No major replacement of the collector components was planned for the first 15 years of operation.

Property Taxes and Insurance

Property taxes were included on the solar collector facility and were estimated a 1.95 percent of the original investment value per year. The annual insurance cost of the solar collector was estimated as 0.6 percent of the investment value.

Discount Rate

The discount rate used in the program can be adjusted for capital that is jointly or independently financed from owner's equity and/or borrowed funds with the use of the following equation.

$$r = (pe \times (re \times (1 - T))) + (pf \times (rf \times (1 - T)))$$

where:

r = after-tax discount rate

re = before-tax interest rate or opportunity cost on equity capital used to finance the investment

rf = before-tax interest rate or opportunity cost on financed or borrow capital used to finance the investment

pe = percent of financing from equity capital

pf = percent of financing from borrowed capital

T = marginal combined federal and state income tax rate

The discount rate was adjusted for tax purposes to account for the interest deduction allowed for interest payments on borrowed funds and the after-tax rate of return on equity capital. The after- . tax rate for borrowed funds was multiplied by (1 – T) where T is the combined federal and state marginal tax rate. The discount rate used in this analysis was based on the assumption that 20 percent of the initial investment cost was financed from owner's equity and 80 percent from borrowed funds. The before-tax opportunity rate for owner's equity and the before-tax interest rate for borrowed funds was assumed to be 10 percent.

Tax Rate

The combined marginal federal and state income tax rate considered appropriate for this analysis was 25 percent. This rate also was varied for sensitivity analysis purposes.

Expected Life

The initial expected life of the solar collectors was set at 15 years. This is a reasonable period of time, based on the expected life of materials used in these homemade collectors. A shorter, more conservative expected life of 10 years also was included to show how it affected the results of the analysis.

ANALYSIS

In addition to the base run, described in the preceding section and outlined in Table 2, numerous other tests were made to provide knowledge of economic sensitivity. Subsequent computer runs tested the sensitivity of the economic analysis to changes in 1) depreciation method, 2) collector life, 3) collector efficiency, 4) tax credits, 5) initial investment costs, 6) fuel prices, 7) discount rate, and 8) marginal tax rates. The following analysis treats each of these variables.

Base Run

The initial computer run was based on the set of variables most likely to enter a farmer's decision making process. Assumptions used in the base run are shown in Table 2. Payback for the four systems ranged from 6 to 14 years, Table 3. The present value of the net saving over the life of the collector (1980 $) ranged from $1170.83 to $8443.42. The after-tax rate of return on investment ranged from 12.3 percent to 30 percent.

It is important to remember that the base run assumed the current level of tax credit—15 percent Federal and 30 percent State of Kansas. In a later section of the report, the effects of reduced and eliminated tax credits will be discussed.

Depreciation

In addition to the old straight-line depreciation method assumed in the base run, two other computer runs measured the economic effects of new straight-line and ACRS depreciation methods. Both of these depreciation methods allow complete write-off of the initial investment as de-

Table 2. Study Parameter for Base Case Analysis

All Systems

Years of Life = 15	Fuel Inflation Rate = 13%[a]
Discount Rate	Investment Tax Credit = 10%
for equity capital = 10%	State Solar Tax Credit = 30%
for borrowed funds = 10%	Federal Solar Tax Credit = 15%
Combined After-tax Discount Rate = 7.5%	Depreciation Method = Old Straight-Line
Combined Fed. & State Tax Rate = 25%	

Each System	No. 1	No. 2	No. 3	No. 4
Investment[b]	$2,874.14	$ 10,107.62	$4,965.39	$4,619.00
Investment Credit Value	287.41	1,010.76	496.54	461.91
Solar Credit Value	1,293.36	4,548.43	2,234.42	2,078.59
Net Salvage Value	730.00	1,560.00	1,248.61	1,114.80
Lifetime Net Savings	5,188.96	8,443.42	3,146.15	1,170.83
BTU (usable)	60,600,600	123,228,000	55,894,400	61,500,000
Fuel	LP gas	LP gas	LP gas	Nat. gas
Fuel Price	$.57/gal.	$.57/gal.	$.57/gal.	$3.4/1000ft^3

[a]This fuel inflation rate combined a discount rate of 10% and a 3% real increase in fuel prices.
[b]These figures are less than those reported in the text because the cost of the enameled siding, which would be required if the solar collector was not attached to the building, was deducted to arrive at the net cost. A cost of $.67 sq. ft. of enameled siding was used for the systems.

Table 3. Solar Heating Systems: Economic Parameters, Using Base Run Assumptions

System	Initial Capital Investments	Savings[b]	Payback Period[b]	Average Annual Rate of Return on Investment
	Dollars	Dollars	Years	Percent
No. 1	2,874.14	5,188.96	5	40
No. 2	10,107.62	8,443.42	7	27
No. 3	4,965.39	3,146.15	9	23
No. 4	4,619.00	1,170.83	12	16

[a]Before tax credits.
[b]Tax credits are used to calculate the savings, payback period and return on investment.

preciation expense over a period of 5 years. These methods apply to solar collectors constructed at the present time. The old straight-line method figured depreciation over 10 years and was used in the base case because it was applicable when these collectors were constructed.

Applying the new straight-line depreciation method, payback was reduced by 1 or 2 years (Table 4).

As expected, using ACRS depreciation method yielded paybacks that were identical to the new straight-line method. As shown in Table 5, payback ranged from 4 to 11 years. Neither of the alternative depreciation methods greatly changed the economic performance of the solar heating systems. However, these methods allow for more depreciation to be taken sooner which slightly improves the economic performance.

Life Expectancy

Payback also was estimated on the assumption of a shorter life expectancy—10 years. A life expectancy of only 10 years is recognizably conservative, but it also reflects present uncertainty of material durability under the stresses of weather and high temperatures. Furthermore, since solar technology is in what might be called the development stage, perhaps investment should not be planned for longer than 10 years. Also, improvement in design and efficiency may be forthcoming that will make present solar heating systems technically and economically obsolete.

Payback, assuming only a 10-year life, was the same as in the base run for all systems except No. 4 (Table 6). Payback for System No. 4 was reduced to 10 years because the salvage value received in the 10th year contributed to payback within 10 years.

Table 4. Solar Heating Systems: Comparison of Old and New Straight-Line Depreciation Methods on Payback

Depreciation Method	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
		Years		
Old straight-line	5	7	9	12
New straight-line	4	6	7	11

Table 5. Solar Heating Systems: Comparison of Straight-Line and ACRS Depreciation Methods on Payback.

Depreciation Method	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
		Years		
Straight-line	5	7	9	12
ACRS	4	6	7	11

Table 6. Solar Heating Systems: Effect of Assumed Physical Life on Payback

System Life	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
		Years		
15 years (base run)	5	7	9	12
10 years	5	7	9	10[a]

[a]Payback equals life expectancy because of salvage received for the collector blocks in the 10th year.

Collector Efficiency

Aside from initial investment cost, perhaps efficiency is the most important collector characteristic that research scientists struggle with as they develop this new technology. In the case of the four solar swine systems analyzed in this study, it is interesting to observe the variation in usable BTU output per square foot of collector surface, in comparison with the initial investment cost. Some of the variation is directly attributable to management of the system.

System	BTU Output/ft^2-yr.	Cost/ft^2
No. 1	154,200	$7.99
No. 2	146,700	12.71
No. 3	98,320	8.07
No. 4	108,363	8.38

System No. 1, according to these factors, should yield the fastest payback which, in fact, the analysis verifies. These figures also show that cost is not necessarily related to system efficiency, at least not in the case of these home-built solar collectors.

We also conducted sensitivity analysis by increasing the BTU's saved by 10 and 25 percent, respectively, for each system. This analysis suggested that 10 and 25 percent increases in efficiency, assuming the energy is usable, had some effects on payback (Table 7). Assumed incremental increases in usable BTU's (efficiency) had the greatest effect on Systems No. 3 and 4, decreasing payback by 2 years. These increases in efficiency had the least effect on the systems already reporting a faster payback. However, payback was reduced by 1 year for these systems, assuming a 25 percent increase in efficiency.

Solar collector efficiency is highly dependent upon the proper sizing of solar collectors. Optimum size determination is critical both to system performance (payback) and to the incurred investment cost. Detailed procedures to use in sizing collectors may be obtained in Solar Heating of Livestock Structures Handbook, MWPS-23 published by Midwest Plan Service, Ames, Iowa, in 1983. Additional information is available from state extension agricultural engineers. In Kansas, for example, a computer model, which takes into account building design and heat needs, is available for sizing collectors (6).

Tax Credits

State and federal governments allow tax credits on solar collectors to encourage the adoption and use of alternative energy sources. Tax credits first became available to homeowners, farmers, and other businessmen in the 1970's when there was much concern about future petroleum supplies. The federal tax credit law was passed in the late 1970's. As amended, it allows a 15 percent tax credit on solar collectors for business purposes. State tax credits vary by state; in Kansas a 30 percent credit is allowable.[2] The federal tax credit statute expires on January 1, 1986, but a bill to extend it is before the U.S. Congress. Under the present law, tax credits allowed by the State of Kansas will expire as of December 31,1985.

With no tax credits only System No. 1 had a reasonable payback (Table 8). Systems No. 2 and 3 approached breakeven situations. Conversely, System No. 4 would not have a favorable payback within its life expectancy.

The 15 percent federal tax credit, alone, would result in paybacks ranging from 7 years upward. However, the payback would exceed the system's life expectancy only for System No. 4. Table 8 also shows the anticipated effects on payback if state credits were reduced to 20, 10 and 0 percent and if only state tax credits were avail-

[2]Both State and Federal tax credit statutes include numerous stipulations concerning qualifications for eligibility, maximum amounts allowable, and dates of expiration.

Table 7. Solar Heating Systems: Effect of Increases in Assumed System Efficiency on Payback[a]

Efficiency Level	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
	Years			
Base run	5	7	9	12
10% increase	5	7	8	11
25% increase	4	6	7	10

[a]Collector efficiency is measured in terms of increases in usable BTU'S.

able. Basically, it doesn't matter to the operator whether the credits are allowed by the state or the federal government. It is the level that is important. Given the level of technology that was applied to these solar swine systems, the full 45 percent tax credit—state and federal—may not be necessary for farmers to achieve a payback within the life of the system. Based on the results of this study, solar swine systems currently would have a favorable payback even if total tax credits were reduced to 30 or 35 percent. In other words, state credits alone, assuming the Kansas level, could result in economically feasible systems. Higher tax credits, of course, should speed adoption of solar technology and in the long run lead to greater conventional fuel savings.

Fuel Escalation Rates

The impacts of changes in conventional fuel prices also were studied. The impact of natural gas deregulation, if and when this occurs, and future prices of petroleum and other related fuels are highly uncertain. Therefore, payback for the four solar heating systems was estimated on the assumption of three annual fuel inflation scenarios. In effective terms or real dollars (fuel inflation less discount rate) the three annual fuel inflation rates were – 3, +3, and + 10 percent, respectively. The effect of higher fuel prices is quite obvious, especially for the systems with higher initial investment (Table 9).

If fuel costs increase in the future, the economic performance of solar swine systems could be very favorable. Table 10 shows that, given a fuel inflation rate of 20 percent per year, payback was generally well within the technical life of the collector, even without tax credits.

Table 8. Solar Heating Systems: Effects of Reduced Tax Credits on Payback, Based on a 15-Year Life Expectancy

	Payback Period			
Tax Credit Assumption	System No. 1	System No. 2	System No. 3	System No. 4
		Years		
Base run[a]	5	7	9	12
20% state—15% federal	6	7	10	14
10% state—15% federal	6	10	11	15
0% state—15% federal	7	11	12	_ b
0% state—0% federal	8	12	14	_ b
30% state—0% federal	6	9	11	15

a Based on 30% state and 15% federal tax credits.

b Payback exceeds assumed 15-year life expectancy.

Table 9. Solar Heating Systems: Effect of Changing Fuel Prices on Payback

Fuel Inflation Rate[a]		Payback Period			
		System No. 1	System No. 2	System No. 3	System No. 4
Nominal Percent	Real Percent		Years		
13 (Base run)	3	5	7	9	12
7	–3	5	9	12	– b
20	10	5	6	7	10

[a] The effective or real dollar fuel adjustment can be calculated by subtracting the assumed 10 percent discount rate from each fuel inflation percentage.

[b] Payback exceeds life expectancy.

Investment Cost

The initial investment cost used for the four solar swine systems (Table 2) were actual construction costs including materials and labor reported by the owners. In the base run the payback at those investment levels ranged from 5 to 12 years (Table 11). Those investment levels were increased and decreased by 10 percent to determine the effect of initial investment on payback.

Again this analysis shows that, when varying only one factor, the effect on payback was limited. A change in initial cost of +10 percent could result in a one year longer payback. Conversely, a 10 percent decrease in initial cost may have little effect. Undoubtedly, greater decreases in initial cost would lower payback.

Discount Rate

Changes in the discount rate affected changes in payback by about the same magnitude as changes in initial investment and other factors measured (Table 12). Lower discount rates result in faster payback and vice versa. If lower discount rates, primarily caused by low interest rates on borrowed funds, can be maintained as fuel prices increase, then a combination of these two factors can significantly shorten payback. Low discount rates generally would be associated with low interest rates for both investment and borrowing.

Table 10. Solar Heating Systems: Effect of Changing Fuel Prices on Payback Assuming No Tax Credits

Fuel Inflation Rate[a]	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
Percent	Years			
7	10	_[b]	_[b]	_[b]
13	8	12	14	_[b]
20	7	10	11	13

[a] The effective fuel adjustment can be calculated by subtracting the assumed 10 percent discount rate from each fuel inflation percentage.

[b] Payback exceeds life expectancy.

Table 11. Solar Heating Systems: Effect of Initial Investment Cost on Payback

Investment Cost	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
	Years			
Base run[a]	5	7	9	12
10'% Increase	5	8	9	13
10% Decrease	5	7	8	12

[a] Cost assumptions for the base run were:
System No. 1 = $ 7.99/ft^2
System No. 2 = $12.71/ft^2
System No. 3 = $ 8.07/ft^2
System No. 4 = $ 8.38/ft^2

Table 12. Solar Heating Systems: Effect of Changes in Discount Rate on Payback

Discount Rate	Payback Period			
	System No. 1	System No. 2	System No. 3	System No. 4
Percent	Years			
Base run[a]	5	7	9	12
6	5	7	8	11
8	5	7	8	11
12	5	8	9	14
14	5	8	10	15

[a] A 10% discount rate was assumed In the base run.

Tax Rate

The combined federal and state marginal income tax rates were varied from 20 to 50 percent to determine how they affected payback. Table 13 reveals that the payback period changed very little with a change in the tax rate. In general, the higher the tax rate, the higher the present value of net savings from the investment on an after-tax basis. This is due to the fact that a higher tax rate resulted in a lower after-tax cost of financing the investment from borrowed funds. Depreciation became more valuable and returns were reduced, but the overall impact was to increase net present value. The percent of funds borrowed for the investments was assumed to be 80 percent.

Internal Rate of Return

The internal rate of return (IRR) generally reflected rates between 12 and 30 percent[3]. System No. 1 reflected the highest internal rate of return; System No. 4 the lowest (Figure 5).

Like payback, internal rate of return was affected to varying degrees by changing the parameters of the study. Figure 6 illustrates the effect of fuel inflation rate and solar credits on the IRR. Some of the other major changes, using the base run as the norm, are summarized as follows:

Change to:	Effect on Internal Rate of Return
New straight-line depreciation	1 to 2 percent increase
ACRS	1 to 2 percent increase
10-year life	3 to 4 percent decrease
Increase of investment cost (10%)	1 to 2 percent decrease
Decrease of investment cost (10%.)	1 to 2 percent increase
Lower fuel inflation rate to 7%:	
with tax credit	5 to 6 percent decrease
without tax credit	12 to 15 percent decrease
Raise fuel inflation rate to 20%:	
with tax credit	6 percent increase
without tax credit	1 to 3 percent decrease
Increase collector efficiency (10%)	1 to 2 percent increase
Increase collector efficiency (25%)	2 to 5 percent increase
Decrease in solar tax credit (10%)	1 to 3 percent decrease
Increase in tax rate (10%)	.2 to 2 percent decrease

[3]The compound interest rate for the present value of the cash flows, or net savings, is equal to zero, over the life of the investment. (Refer to the discussion of internal rate of return in the Economic Analysis Methodology section.)

Table 13. Solar Heating Systems: Effect of Change in Combined Marginal Tax Rate on Payback

Combined Marginal Tax Rate	Payback Period System No. 1	System No. 2	System No. 3	System No. 4
Percent	Years			
Base run	5	7	9	12
20%	5	8	9	13
30%	5	7	9	12
40%	5	7	8	11
50%	5	7	8	10

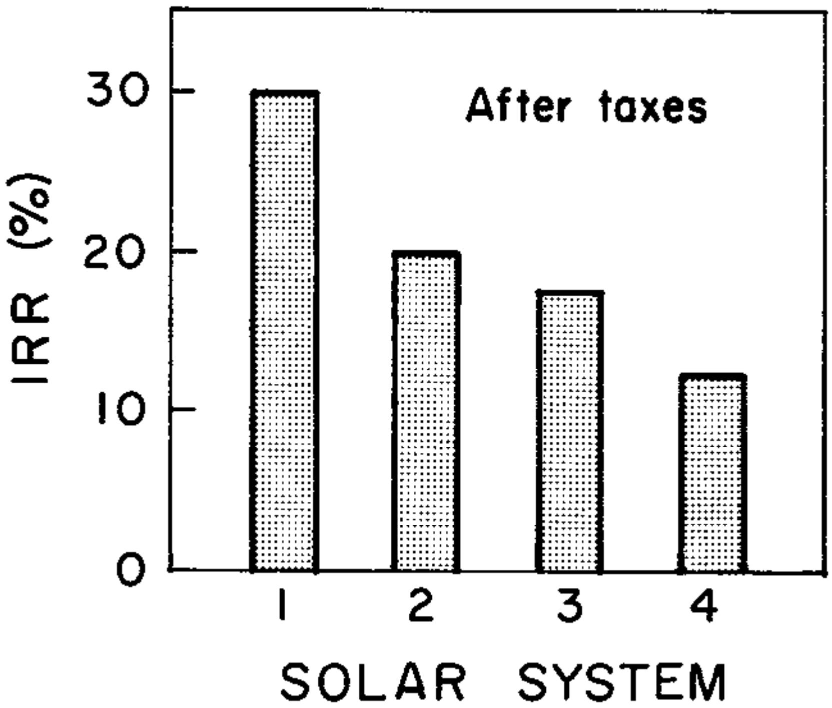


Figure 5. Internal Rate of Return, After Taxes.

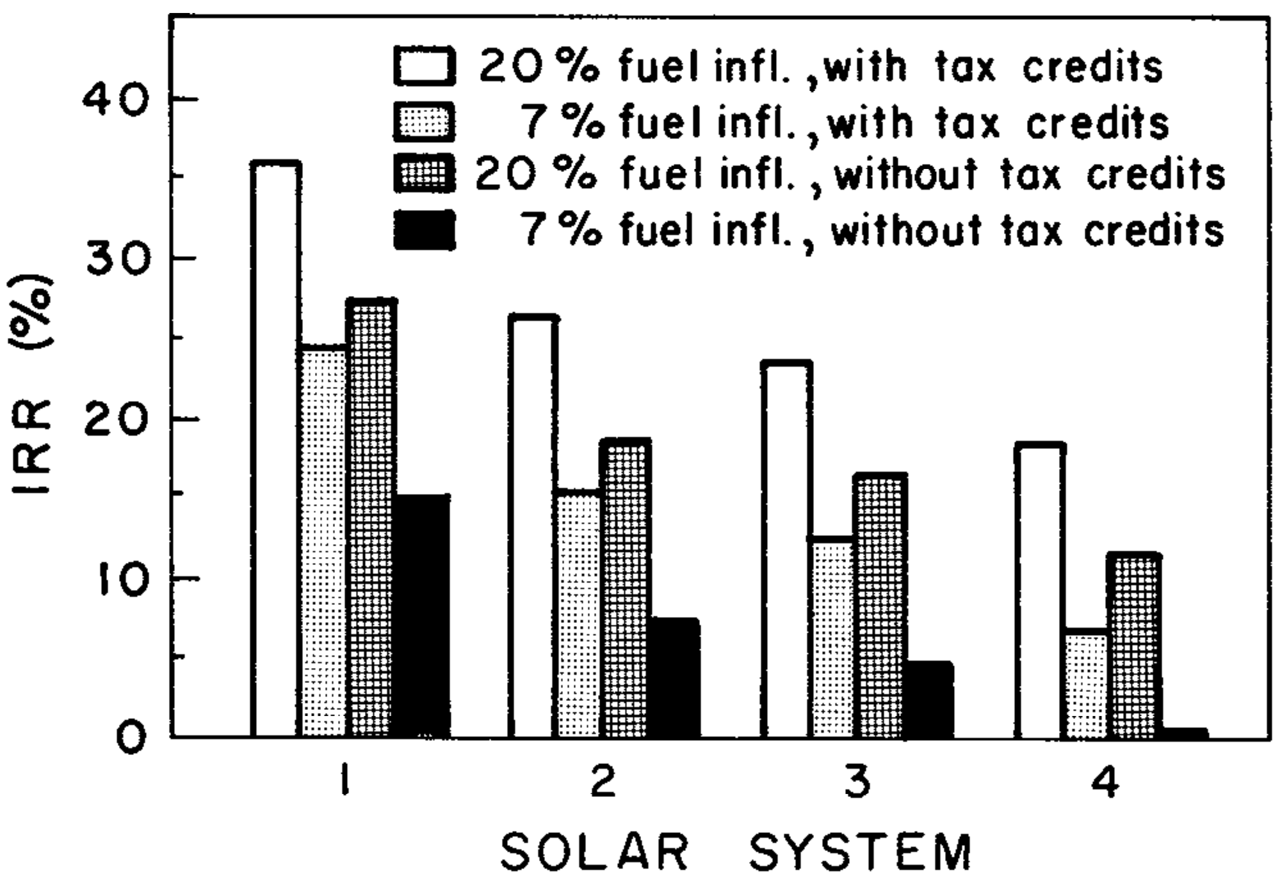


Figure 6. Effects of Solar Tax Credits on Internal Rate of Return.

SUMMARY

The results of the economic analysis of four demonstration solar collectors illustrate that, under the conditions outlined, the solar collectors would pay for themselves over their physical life of 15 years. Specifically, three of the four systems studied had payback periods of less than 10 years. All of the systems generated positive net savings ranging from $1,170.83 to $8,443.42 (1980 $), in comparison with conventional fuel sources.

Systems 1, 2 and 3 had better economic performance. A major factor that contributed to this was the fuel source. Systems 1, 2 and 3 save L.P. gas whereas System No. 4 saves natural gas. Natural gas in this study is relatively cheaper than L.P. gas on a BTU basis. The price of L.P. gas per BTU is 78 percent higher than the price of natural gas. Therefore, the value of solar energy is greater when L.P. gas is saved than when natural gas is saved. If L.P. gas had been the alternative for system No. 4 the solar collector would have had a better economic performance.

Therefore, it would appear that if natural gas prices are relatively low, a solar heating system for swine buildings may be much less desirable at the current time. However, solar systems would deserve additional consideration if (or when) natural gas prices rise.

Solar energy credits of up to 45 percent of the initial costs were used in the analysis. The effect that these credits had on the economic performance of these systems was substantial. Without the federal and state tax credits, only one of the four systems had a very reasonable payback and one would not pay for itself within the 15 year period specified for physical life. Without the solar tax credits, payback periods of all systems were not as good, even if the higher annual rate of energy price increase (20 percent) evaluated in this report were applicable. In other words, the tax credit effect was greater than the fuel inflation effect.

Although the solar energy credits were important, the fuel price escalation rate also was important. The initial analysis used an annual inflation rate of 13 percent per year which, after discounting at a 10 percent rate, was equivalent to approximately a 3 percent increase per year in real dollars. However, if energy prices for the conventional fuels that were replaced (natural gas and L.P. gas) rose at a slower rate, 7 percent nominal increase per year or a – 3 percent per year decrease in real dollars, the economic performance of the systems was altered. The payback period increased by 2 years for System No. 2, and by 3 years for System No. 3. This analysis also showed that under these conditions System No. 4 would not pay for itself within 15 years. Payback time for System No. 1 was not affected.

Alternatively, if energy prices increased at a greater rate, 20 percent or approximately 10 percent in real terms, the economic performance of the systems was improved. The payback period remained the same for System No. 1 but declined by 1 year for System No. 2 and by 2 years for Systems 3 and 4.

Most of the other variables that entered into the analysis had some impact on the solar collectors' payback period when they were varied individually. A 10 percent increase or decrease in the initial investment cost only affected the payback period by 1 year. Changes in the discount rate and marginal tax rates caused marginal changes (1 year) in the payback period for three of the four systems. Increases in efficiency of the solar collector by 25 percent resulted in a 1-year shorter payback for two of the systems and a 2-year shorter payback for the other two.

The results of this study generally show that, under reasonable fuel cost increases, a well-designed and well-operated solar heated swine confinement unit, similar to the ones described here, should prove to be a very viable and wise farm investment. However, if a farm manager is in a situation where energy prices, particularly natural gas, are relatively low and are not expected to increase, and if solar tax credits are not available, an investment in solar heating for confinement buildings may not be wise. Of course, a manager should evaluate any investment in a solar system for his particular operating condition as best he can.

LITERATURE CITED

(1) Heid, Walter G., Jr. and Warren K. Trotter. 1982. *Progress of Solar Technology and Potential Farm Uses.* AER No. 489. Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

(2) U.S. Department of Commerce. Bureau of Census. 1968. *Census of Agriculture, 1964. General Report.* US. Government Printing Office, Washington, D.C.

(3) ____________. Bureau of the Census. 1981. *Census of Agriculture, 1978. General Statistics.* U.S. Government Printing Office, Washington, D.C.

(4) Murphy, James P., Michael Schwartz and Francis V. Robbins. 1982. *Kansas Final Report, Solar Heating of On-Farm Livestock Shelters.* KSU Project no. 60810-0810 and USDA Agreement no. 12-05-300-421. Department of Agricultural Engineering, Kansas State University, Manhattan.

(5) Williams, Jeffery R. 1983. *EASE1—A Program to Calculate Economic Analysis of Solar Energy Facilities.* Report no. 83-1 79-D, Department of Agricultural Economics, Kansas State University, Manhattan.

(6) Robbins, F.V. and C.K. Spillman. 1981. "Predicted Performance of the KSU Solar Collector-Storage System. " *Agricultural Engineering.* Vol. 1. ASAE Pub. 3-81. Am. Soc. Agr. Engrs., St. Joseph, Mich.

Agricultural Experiment Station, Kansas State University, Manhattan 66506

Bulletin 645 September 1983

Publications and public meetings by the Kansas Agricultural Experiment Station are available and open to the public regardless of race, color, national origin, sex, or handicap. 9-83—3M