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The economic feasibility of solar heat
in Iowa swine production

by

Darrell Gene Sloth

A Thesis Submitted to the
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Requirements for the Degree of
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CHAPTER I. INTRODUCTION

Objectives

The purpose of this study is to evaluate the economic feasibility of using solar heat in Iowa swine production. As prices for fuels used in supplying heat increase, the cost of farrowing during winter months increases. This could have a significant impact on winter hog production in cold weather states. Approximately 20 percent of Iowa's farrowings currently take place in the December 1 to February 28 period accounting for a sizeable portion of Iowa swine production (34).

Solar energy in Iowa swine production has its most practical application as a supplemental heating source for those producers who farrow in total confinement buildings during the winter months. Galm, in a population study of Iowa swine producers, found the following in relation to winter farrowings (12).

1. 80 percent of Iowa swine producers farrowed some or all of the pigs they produced.
2. Of those that farrowed, 88 percent used some type of confinement facility for farrowing.
3. 48.5 percent of all swine producers had a totally confined building.
4. 71.3 percent of the totally confined buildings were primarily used for farrowing and 7.4 percent were primarily used for a nursery.

5. 89 percent of the totally confined buildings had a concrete floor while 6.6 percent were partially or fully slatted.
6. 84 percent of the totally confined buildings used supplemental heat.
7. 15 percent of the swine producers planned to remodel present facilities. About 25 percent of the remodeling would be towards total confinement farrowing and 5 percent to total confinement nursery.
8. 14 percent of Iowa swine producers planned to build new facilities of which about 18 percent of the new facilities would be for totally confined farrowing.

Galm's data show that a significant portion of Iowa swine producers could possibly benefit from the use of solar heat. The goal of this study is to determine the economic feasibility of using solar heat in swine production.

The study looks at the feasibility from different standpoints. It will examine solar energy as a means of reducing swine production costs, as a means of reducing purchased fuel, and as a capital investment alternative. It examines the economic feasibility of solar energy in an economy experiencing inflationary pressures. In doing so, the study attempts to build an inflationary impact component into the investment analysis and explains why this component is necessary. The study examines collectors of different sizes and efficiencies and draws conclusions as to these differing sizes and efficiencies for different sizes of swine systems. Assumptions are made to simplify the procedures used, while keeping the analysis in the realm of actual conditions.

The objective of the study is to provide useful information to swine producers as to the feasibility of adopting solar energy. The solar energy collection systems evaluated are simple to construct and operate, with no expertise or background in solar technology required.

Solar Energy Overview

There appears to be a great potential for solar energy in Iowa agriculture. A nonpolluting, nondepletable energy source, it provides approximately 290 Btu/hr-ft^2 at solar noon to a surface perpendicular to the sun's rays on a clear day in the Midwest.

Solar energy is available in three forms: direct, diffused, and reflected radiation. Direct radiation is the radiation passing through the atmosphere without being deflected. The more direct radiation that strikes the earth, the more solar energy there is available. Diffused radiation is the radiation scattered or absorbed by water vapor, dust, carbon dioxide, and other compounds in the air. Reflected radiation is the radiation reflecting off another surface, such as off snow.

On a clear day, 85 percent of the radiation that strikes the earth's surface will be direct radiation. When cloudy, more radiation is scattered or absorbed; on a completely overcast day, only diffused radiation strikes the earth. Since less solar energy is available from diffused radiation, the atmospheric and weather conditions greatly affect the amount of solar energy that can be collected.

The angle of incidence of the collector to the sun's rays also affects the amount of solar energy that can be collected. Maximum interception (or maximum collection) of solar radiation occurs on a collector with an angle of incidence to the sun's rays of zero (i.e., the collector is perpendicular to the sun's rays). With a greater angle of incidence, more solar radiation is reflected off the collector, so less radiation is intercepted.

Because the sun's position is constantly changing, the best collector would be one that followed the sun, maintaining a zero angle of incidence. However, a collector of this type is not only complex, but very expensive. Therefore, a fixed collector, which is cheaper to construct and operate, would probably be more practical for agricultural uses. The best angle for a fixed collector depends on where it will be used and when it will be used. If the collector is to be used year round, it is usually set at an angle from level equal to the latitude of the location where the collector is to be built. For the period October through February, an angle equal to the locale's latitude plus 15° receives the most solar energy (20). As an example, for Ames, Iowa, the angles would be 42° for the year round collector and 57° for the October to February collector.

However, a vertical wall collector receives only 12 percent less energy than a latitude plus 15° collector in the same October through February period. Therefore, it may be cheaper to install a collector on the south wall of a building than to build a collector to meet the latitude plus 15° angle. A vertical collector would also have fewer frost and snow cover problems and would be easier to shade in the summer when it would not be in use.

There are two types of solar energy collection systems. The passive system utilizes no outside energy in the collection of solar energy. An example of a passive system is a glass window that allows the sun's rays to pass through it and heat a room. While this may be a good collection system, it has problems. Glass is a poor insulator, so it is possible that more heat will be lost through the glass at night than is collected during the day. An insulated curtain, closed at night and on cloudy days, would reduce the heat loss through the window.

The second system is an active system. The active system utilizes fans or pumps to move a fluid (air, water, or some other liquid) through a collector. The fluid absorbs the solar energy. An active system utilizing fans and air as the fluid is well suited for some agricultural uses, like grain drying where air must be moved through the grain. Since air is already needed, an active system could be set up to preheat the drying air by drawing it through the collector first. Likewise, in swine production, an active system could be set up to preheat winter ventilation air before it enters the swine facility.

Since forced air is already required in some production activities such as grain drying and swine production where ventilation air is mechanically moved, a large portion of the operating costs of an active solar system are foregone (the energy required to move the fluid through the active collector can amount to as much as one half of the solar energy collected) (6).

There are three basic types of active collectors: bare plate, covered plate, and suspended plate. The bare plate is an absorption plate with the fluid drawn under the plate to collect the solar energy. The bare plate is the least efficient in collecting solar energy. The covered plate has a transparent cover over the absorption plate with the fluid drawn between the transparent cover and the absorption plate. It is more efficient than a bare plate collector, while less efficient than a suspended plate. The suspended plate collector has a transparent cover over the absorption plate with the fluid drawn between the transparent cover and from under the absorption plate. (Suspended plate and covered plate collectors illustrated on page 28.)

Different materials are available for use as the transparent cover, each with their own strengths and weaknesses. They will not be discussed here.

The efficiency of the collector can be improved by adding an extra transparent cover, especially when there is a large temperature difference between collector temperature and outside temperature.

If more energy can be collected than used during the collection period, it is possible to store the excess energy to be used at night and on cloudy days. Since peak solar energy collection is when heating demand is the lowest (around midday), a system without storage may have excess solar energy collected that is unusable. Thus, storage added to the collection system increases the system's efficiency.

Common storage materials are water, rock, and concrete. The amount of heat a material can store is dependent on the specific heat and the change of temperature of the storage materials. Generally, rock or concrete are the storage materials in air systems, while water is common in liquid solar systems.

The rate at which the fluid flows through the collector can also affect the efficiency of the collector. Although a slower moving fluid will result in a larger temperature change, it will also have a larger heat loss resulting in a diminishing efficiency of solar energy collection. Rates too fast do not allow long enough exposure time to the fluid to absorb the energy. Fast rates also require more energy to move the fluid.

Feasibility of Solar Energy Collection

Much work is being done at various institutions on the feasibility of solar energy collection and its application in agricultural uses. Though the period of study, for the most part, has not been long enough for definitive conclusions, some preliminary results have been published. Vaughan, et al. (39), concluded from their study of a solar assisted heat pump system in a pig nursery that the solar system performed comparably to conventional heating systems. They used an insulated, covered water pond as the storage medium and plastic pipe for a heat exchanger.

DeShazer, et al. (9), using solar energy collection in a modified open-front swine finishing unit, found that hogs finished in the solar assisted unit had a slightly higher feed requirement than those fed in a conventionally heated unit. However, the air temperature in the solar assisted unit was only 1° to 4°C (2° to 7°F) warmer than the conventional unit, a difference not enough to affect swine performance. Therefore, the reduction in feed efficiency was attributed to the air velocity of the fans needed in operating the solar collector. In comparison to the conventional unit, the solar assisted unit did reduce the purchased energy needed by 25 percent. However, increased electrical needs for fan operation accounted for about 50 percent of the solar energy collected.

Spillman (31) worked with solar energy to preheat ventilation air in swine farrowing facilities in Kansas. Using a suspended plate with solid concrete blocks as the storage medium, he concluded that air preheated by solar energy has a potential for reducing the need for fossil fuels in heating ventilation air in animal shelters. He found that, due to heat storage, the maximum temperature of the ventilation air was reached several hours after maximum solar radiation. Energy reduction was projected at 1.5 gallons of LP gas per square foot of collector area per heating season when the inside temperature is maintained at 60-65°F, and at 2 gallons of LP gas per square foot when inside temperature is maintained at 80°F. (A system similar to Spillman's is used in this analysis.)

Bern (19) found that solar heat can effectively reduce purchased energy needed in drying grain in a low temperature bin dryer with a stirrer. With the solar collector, a desiccant system can be used with overdried grain as a storage medium. Summer solar energy is used to overdry the grain kept in the bin. The overdried grain acts as a desiccant, thereby reducing fall energy needs. Solar energy is also usable in high temperature bin drying by preheating the air that goes to the burner.

CHAPTER II. PROCEDURES

Swine Systems to be Evaluated

Only solar energy collection used in conjunction with totally confined hog production systems were evaluated in this study. The systems were:

1. A farrowing unit where weaned pigs were kept in the farrowing unit after weaning, and
2. A farrowing unit used in conjunction with a nursery unit.

Both solid floored and slatted floored units were considered.

The farrowing schedules for the two systems are listed in Table 1.

Farrowing units only

Under the farrowing-unit-only system, sows were farrowed at five times per year, approximately every ten weeks. All pigs were weaned six weeks after the first sow farrowed and kept in the farrowing unit for four weeks after weaning. Twenty sows were farrowed in each period with an average litter size of 7.5.

Farrowing unit with nursery unit

Under the farrowing unit and nursery unit system, two farrowing schedules were used. The first schedule called for sows to be farrowed at six times per year, approximately every two months. All pigs were weaned six weeks after the first sow farrowed and moved into the nursery unit for four weeks. The farrowing facility was assumed idle and empty between weaning and the next group of sows to farrow. The

Table 1. Farrowing schedule

Farrowing unit alone	Farrowing unit with nursery	
5 farrowings	6 farrowings	8 farrowings
Jan. 15	Jan. 15	Feb. 1
Apr. 1	Mar. 15	Mar. 15
June 15	May 15	May 1
Sept. 1	July 15	June 15
Nov. 1	Sept. 15	Aug. 1
	Nov. 15	Sept. 15
		Nov. 1
		Dec. 15

nursery was assumed idle and empty every other month (between weaned groups). Twenty sows were farrowed in each period with an average litter size of 7.5 pigs. Excess capacity in the nursery was filled by purchased feeder pigs to minimize heating requirements.

The second farrowing schedule called for sows to be farrowed at eight times per year, approximately every six weeks. All pigs were weaned six weeks after the first sow farrowed and moved to the nursery. The nursery was kept full year round, moving pigs out when newly weaned pigs were moved in. Twenty sows were farrowed in each period with an average litter size of 7.5 pigs.

The buildings

The farrowing unit was a 24' X 50' facility with a capacity for twenty sows. It is a totally confined facility with either a solid cement floor or a slatted floor. The farrowing unit was assumed to be insulated to Midwest Planning Service recommendations (22) and in excellent condition. The insulation factors will be specified later.

The nursery unit was a 24' X 40' facility with a capacity of two hundred 30-pound pigs. It is a totally confined facility with either a solid cement floor or a slatted floor. The nursery unit was assumed to be insulated at recommended levels and in excellent condition.

The slatted floor units were assumed to have a pit below them. For the nursery, the pit was assumed to be eight feet deep. The pit under the slatted floor farrowing unit was assumed to be four feet deep.

The buildings were assumed to have an unobstructed southern exposure. They were also assumed to be situated end-to-end and within twenty feet of each other.

It was assumed that no heat was needed in the growing-finishing facilities or the breeding-gestating facilities, so they were excluded from the study.

Supplemental Heat Required

The total heating requirements for each system were approximated. The amount of supplemental heat required is dependent on animal heat production and the differential between the inside and outside temperature (affecting ventilation heat loss and building heat loss).

For purposes of this study, the monthly average temperatures were used as the outside temperature. In order to use monthly averages, it was necessary to assume that there was a linear relationship between the outside temperature and the supplemental heat required, provided the outside temperature is below that point where supplemental heat is no longer necessary.[1] Since only winter months are used in the study,

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[1] The outside temperature where supplemental heat is no longer needed is approximately 40°F for slatted floor units and 50° for solid floor units.

it is assumed that this is the case.[1]

The inside temperature used was dependent on the type of flooring (slatted or solid) and on the use of the building (farrowing or nursery). In determining the inside temperature for the farrowing unit, the comfort zone[2] of the sow was used with supplemental zonal heat for the nursing piglets. This supplemental zonal heat was not taken into account when determining the total supplemental heat required.[3] The comfort zone of a 30-pound pig was used in determining the inside temperature for the nursery.

Also, in determining inside temperature, the solid floors were

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[1] It was recognized that there are periods during the November through March time period when supplemental heat is not necessary. Since these times of higher temperatures are averaged with lower temperatures, a margin of error is introduced into determining heating requirements. However, when this method was checked against one using daily average temperatures, the total supplemental heat required varied by only about ±10 percent. Since the animal heat production has a margin of error of at least this magnitude, the simpler method was employed. Further, periods of unseasonably warm or cold temperatures vary from year to year and are unpredictable when they will occur. Since the heating requirements were determined for specific farrowing schedules, trying to predict when these unseasonable temperatures occur would have as much of an effect on the study as excluding them; therefore, they were excluded. While more precision may have been possible the use of monthly averages should be sufficient and lead to the same general conclusions.

[2] The comfort zone is the ambient temperature range of peak animal performance.

[3] The supplemental zonal heat will provide some of the heat necessary in meeting the supplemental heat needed to maintain sow comfort zone. There are times when the supplemental zonal heat will meet the entire supplemental heat requirements for the buildings. However, the heat from the zonal heater was not taken into account when determining total heating requirements.

assumed not to be bedded, so the ambient temperature is kept higher than for bedded units, but approximately the same amount of heat is required to maintain the temperatures.

The building heat loss is determined by the difference between the inside temperature and the outside temperature, the size of the building and the resistance of the structural materials to heat loss (i.e., the R factor). The higher the R factor of the building, the greater the resistance, so the smaller the heat loss is. For the study, it was assumed that the building was insulated to R factors of 16 (ceiling), 12 (walls), and 7 (foundation). (Although these are the recommended R factors for Iowa, there was some feeling by agricultural engineers who helped with this study that higher R factors may be more desirable.) The overall R factor of the building could be defined as the weighted average (based on areas) of the different areas' resistance factors.

Ventilation heat loss represents the largest heat loss. Ventilation rates were set at the higher of either the moisture balance ventilation rate or the minimum recommended ventilation rate (22). (Temperature balance ventilation rates were not considered since it was assumed that supplemental heat was always required.)

The moisture balance ventilation rate is the ventilation rate in which a constant humidity is maintained inside the building. Animals work as a humidifier adding moisture to the air. Moisture collects on any cold surface. This can reduce the life of the equipment and building and increase maintenance costs; therefore, it needs to be removed. A relative humidity of 60 percent was assumed as the desired inside relative humidity.

Ventilation is also necessary to remove obnoxious and dangerous gases. The minimum ventilation rate fills this need.

Ventilation heat loss is dependent on the temperature difference between the inside and outside air, the amount of air being ventilated and the specific volume of the air. A monthly average ventilation rate was used as the amount of air being ventilated. It was assumed that the low ventilation rates were attainable and maintainable.

Minimizing ventilation rates can play a significant part in reducing the heating requirements. Assuming a minimum ventilation rate of 20 ft^3 per sow and litter, an increase of only 1 ft^3 per sow and litter increases the ventilation heat loss by 5 percent; therefore, overventilation can significantly add to the cost of heating swine facilities.

Animal heat production plays a significant role in offsetting heat loss. The heat production of an animal is of two forms; latent heat and sensible heat. Latent heat is the heat required for a change of phase of a substance; in hog production, this would be the heat needed for liquid evaporation. Only sensible heat can be used to increase air temperature. While the total heat production by the animal is fairly constant, the proportion of the total heat production that is either latent or sensible heat is dependent on the type of flooring used. The animal needs more of its heat production in the form of latent heat under a solid floor system than with a slatted floor because of greater water vapor production and liquid evaporation.

Since water vapor production and evaporation are higher on solid floors, the humidifying affect of the animal is greater, so the moisture balance ventilation rate is higher than on slatted floors. With a higher ventilation rate, ventilation heat losses are greater. Therefore, since sensible heat production is also less on solid floors, the supplemental heat needed to maintain a given inside temperature is greater with solid floors than with slatted floors.

In determining supplemental heat requirements, the following equations were used.[1]

1. $Q_{SH} = Q_B + Q_V - Q_S$

   where Q_{SH} = supplemental heat requirements

   Q_B = building heat loss

   Q_V = ventilation heat loss

   Q_S = room sensible animal heat production

2. $Q_B = (\Sigma \frac{A}{R})\ \Delta T$

   where $(\Sigma \frac{A}{R})$ = the sum of the area to R factor ratios (i.e., heat loss at different areas of the building)

   ΔT = difference between inside and outside temperatures

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[1] Supplied by Fred Vosper, Instructor. Iowa State University, Department of Agricultural Engineering.

3. $Q_V = \frac{14.4Q(\Delta T)}{V}$

where Q = monthly average ventilation rate

V = specific volume of air

ΔT = difference between inside and outside temperature

Therefore,

$$Q_{SH} = (\Sigma\frac{A}{R})\ \Delta T + \frac{14.4Q(\Delta T)}{V} - Q_S$$

To minimize supplemental heating requirements, it was assumed that the building was kept at capacity levels. (The exception of this is the farrowing unit only system where weaned pigs were kept in the unit.) It was assumed the building was emptied completely and that no heat was used when the facility was idle. The animal heat production values (Q_S) used in determining heating requirements are listed in Table 2. Table 3 lists the sum of the area to R factor ratios used in determining building heat loss (Q_B).

Electrical Requirements

The only electrical requirement tabulated was that needed to run ventilation fans. The electrical requirements for ventilation are not well-defined. The performance efficiency of the fans vary from manufacturer to manufacturer. The condition of the fan also greatly affects the performance.

Fan efficiencies range from less than 6000 cfm per kilowatt hour (kWh) to over 11,000 cfm per kWh for fans with a 1,000 to 2,500 cfm capacity. It was assumed that the fan would produce

Table 2. Animal heat production[a] (BTUs/hr/animal unit)

	Room sensible heat	Room latent heat	Total heat
Per sow and litter (70°)[b]			
solid floor	750	750	1500
slatted floor	1188	312	1500
Per 30-pound pig (75°)			
solid floor	84	166	250
slatted floor	166	84	250

[a] Estimated from Midwest Planning Service data.

[b] Ambient room temperature.

Table 3. Building heat loss (BTU/°F temperature difference/hour)[a]

	Building heat loss/°F temperature difference/hour
Farrowing unit (29' x 50')	
solid floor	263.55
slatted floor	279.55
Nursery (24' x 40')	
solid floor	223.40
slatted floor	278.26

[a] Buildings are assumed to be insulated at R values of 16 (ceiling), 12 (walls) and 7 (foundation).

7,500 cfm of ventilated air per kWh against a static pressure of 0.2 inches of H_2O.

Although with the use of a solar collector there is an increase in air friction resulting in an increase in the amount of energy needed to move the same amount of air (i.e., a reduction in fan efficiency), this increase was considered negligible and ignored.

Only winter ventilation electrical requirements were figured. The equation for determining ventilation electrical requirements is (30):

$$EL = \frac{Q \text{ X } M_H}{7500}$$

where EL = monthly electrical requirements (in kWh)

Q = monthly average ventilation rate

M_H = hours per month

Tables 4 through 9 list the outside and inside temperatures, the average ventilation rate used, and the resulting electrical and supplement heating requirements for each unit of each swine system.

Since the ventilation rates affect heating requirements, the electricity needed to run the ventilation fans was included as part of the heating costs.

Collector Systems and Costs

The collectors evaluated were a one-cover, covered plate (Figure 1), a two-cover, covered plate, and a two-cover, suspended

Table 4. Farrowing unit only--solid floor

Month	Average outside temp. (F°)	Inside temp. (F°)	Ventilation rate (cfm)[a]	Electrical needs (KWH)	Supplemental heating requirements (1000 BTUs)
November	38°	70°	520	49.9	8,092
December	25°	70°	543	53.8	19,765
January	19°	70°	518	51.4	22,458
February	24°	70°	440	39.4	12,620
March	34°	70°	645	68.4	21,186
TOTAL				262.9	84,121

[a] Average of ventilation rates for sow and litters and for weaned pigs held in unit.

Table 5. Farrowing unit only--slatted floor

Month	Outside temp. (F°)	Inside temp. (F°)	Ventilation rate (cfm)[a]	Electrical needs (KWH)	Supplemental heating requirements (1000 BTUs)
November	38°	75°	400	38.4	1,742
December	25°	75°	358	35.5	7,648
January	19°	75°	350	34.8	10,266
February	24°	75°	400	35.8	8,282
March	34°	75°	330	32.7	3,126
TOTAL				177.2	31,064

[a] Average of ventilation rates for sow and litters and for weaned pigs held in unit.

Table 6. Farrowing unit with nursery--solid floor--six farrowings

Month	Outside temp. (F°)	Inside temp. (F°)	Ventilation rate (cfm)	Electrical needs (KWH)	Supplemental heating requirements (1000 BTUs)
Farrowing unit					
November	38°	70°	520	24.9	4,046
December	25°	70°	440	43.6	13,426
January	19°	70°	420	20.9	7,946
February	24°	70°	440	39.4	12,620
March	34°	70°	480	23.8	4,828
Nursery					
November	38°	75°	1000	96.0	22,360
December	25°	75°			
January	19°	75°	820	81.3	33,364
February	24°	75°			
March	34°	75°	920	91.3	24,343
TOTAL				421.2	122,933

Table 7. Farrowing unit with nursery--slatted floor--six farrowings

Month	Outside temp. (F°)	Inside temp. (F°)	Ventilation rate (cfm)	Electrical needs (KWH)	Supplemental heating requirements (1000 BTUs)
Farrowing unit					
November	38°	75°	400	19.2	871
December	25°	75°	400	39.7	8,644
January	19°	75°	400	19.9	5,901
February	24°	75°	400	35.8	8,282
March	34°	75°	400	19.9	1,953
Nursery					
November	38°	80°	600	57.6	3,925
December	25°	80°			
January	19°	80°	600	59.5	17,064
February	24°	80°			
March	34°	80°	600	59.5	6,794
TOTAL				311.1	53,434

Table 8. Farrowing unit with nursery--solid floor--eight farrowings

Month	Outside temp. (F°)	Inside temp. (F°)	Ventilation rate (cfm)	Electrical needs (KWH)	Supplemental heating requirements (1000 BTUs)
Farrowing unit					
November	38°	70°	520	49.9	8,092
December	25°	70°	440	43.6	13,426
January	19°	70°	420	41.7	15,892
February	24°	70°	440	39.4	12,620
March	34°	70°	480	47.6	9,656
Nursery					
November	38°	75°	1000	96.0	22,360
December	25°	75°	860	85.3	30,043
January	19°	75°	820	81.3	33,364
February	24°	75°	860	77.1	27,903
March	34°	75°	920	91.3	24,343
TOTAL				653.2	197,699

Table 9. Farrowing unit with nursery--slatted floor--eight farrowings

Month	Outside temp. (F°)	Inside temp. (F°)	Ventilation rate (cfm)	Electrical needs (KWH)	Supplemental heating requirements (1000 BTUs)
Farrowing unit					
November	38°	75°	400	38.4	1,742
December	25°	75°	400	39.7	8,644
January	19°	75°	400	39.7	11,802
February	24°	75°	400	35.8	8,282
March	34°	75°	400	39.7	3,906
Nursery					
November	38°	80°	600	57.6	3,925
December	25°	80°	600	59.5	12,956
January	19°	80°	600	59.5	17,064
February	24°	80°	600	53.8	12,321
March	34°	80°	600	59.5	6,794
TOTAL				483.2	87,436

plate (Figure 2) with storage. The collectors are attached to the south wall of the swine facility (Figure 3). These collectors were chosen for their simplicity in design and their use of ventilation air as the energy absorbing fluid. It was assumed these collectors could be constructed by the farmer without the need of skilled labor and the operation of the collectors would be a relatively simple procedure.

The one-cover, covered plate consists of a polyethylene film (4 ml thickness) covering the frame attached to the south wall of the swine unit. There is a 1 1/2 inch gap between the film and the structure through which the ventilation air is drawn. The south wall is painted black to increase its absorption of solar radiation. This collector is assumed to have an efficiency of 35 percent (i.e., 35 percent of the solar radiation striking the collector is converted into heat energy). It is the cheapest to construct, but the polyethylene cover will need replacing about every other year.

The two-cover, covered plate consisted of an outer greenhouse-grade fiberglass (GGF) cover and an inner polyethylene film cover attached to the south wall of the swine unit. There is a 1 1/2 inch gap between the two covers and between the inner cover and the structure. Ventilation air is drawn between the two covers, then between the inner cover and the structure. The south wall is painted black. This collector is assumed to have an efficiency of 40 percent. Due to the GGF cover, the costs were much greater than for the one-cover, covered plate, but the GGF cover and the inner polyethylene

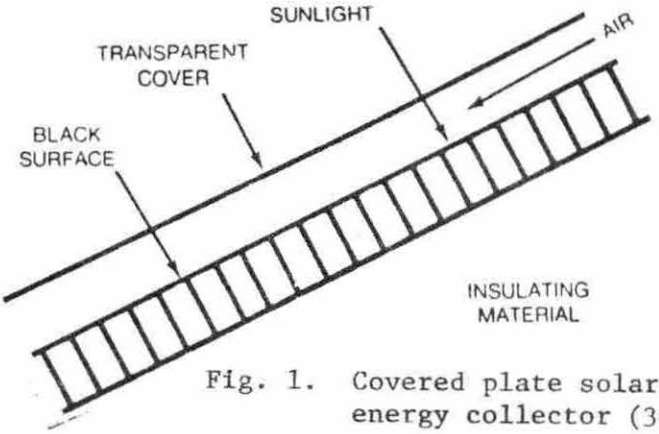

Fig. 1. Covered plate solar energy collector (30)

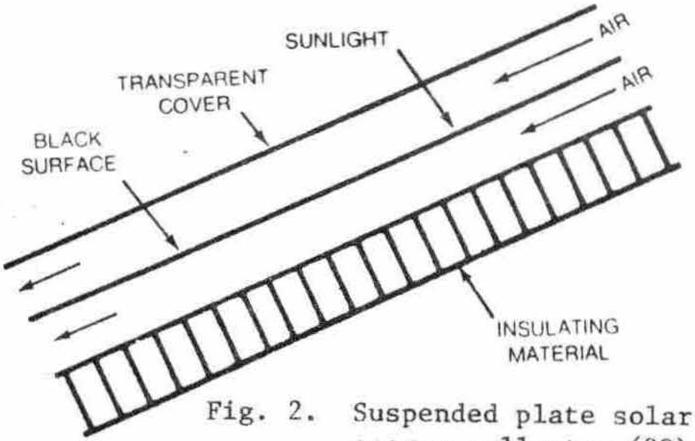

Fig. 2. Suspended plate solar energy collector (30)

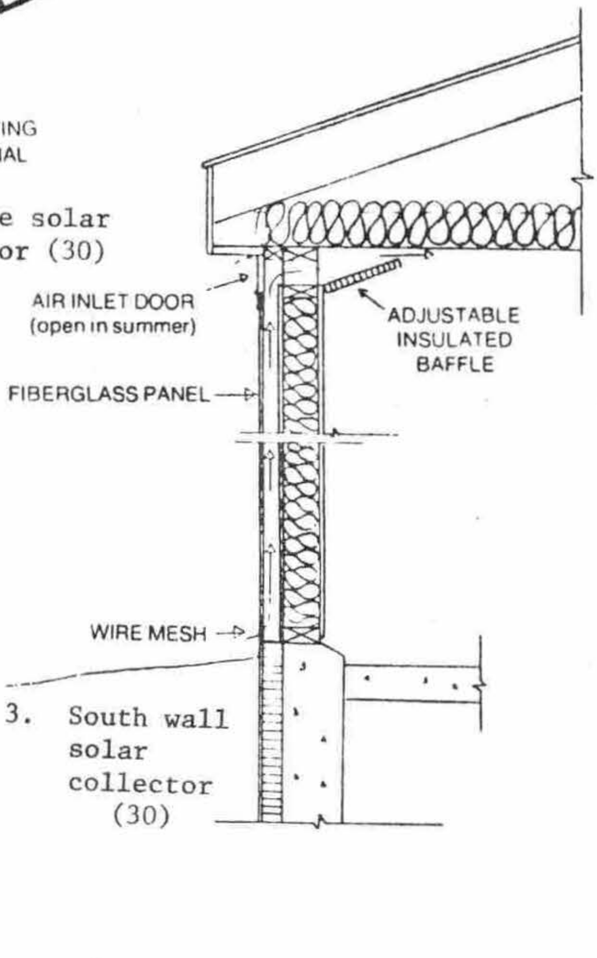

Fig. 3. South wall solar collector (30)

cover were assumed not to need replacing during the life of the collector.

The two-cover, suspended plate with storage is similar to the two-cover, covered plate. Instead of being attached to the south wall, the covers are attached to a cement block wall built along the swine unit (Figure 4). Gaps are left between the cement blocks so air could be drawn through the wall. Ventilation air is drawn between the two covers, then through the cement-block wall. The cement-block wall is painted black to improve its absorption ability. This collector is assumed to be 55 percent efficient. It is the most expensive to construct.

Three sizes of each collector were evaluated: 8' X 30', 8' X 40', and 8' X 50'. The 8' X 50' was only evaluated for use with the farrowing unit, since it is ten feet longer than the south wall of the nursery. The effective square footage (the area capable of collecting solar radiation) for the three sizes are, respectively; 214 ft^2, 289 ft^2, and 361 ft^2.

It was assumed that with the 361 ft^2 collectors, it was possible to transfer some of the excess heat collected to the nursery unit through insulated duct work (R = 7). There was an assumed 10 percent heat loss associated with this energy transfer.

Only material costs were included in first cost estimates. Labor used in construction was assumed to have been supplied by the farmer. The value of labor can be considered equal to the opportunity cost to labor. The opportunity cost to labor is the highest value of labor

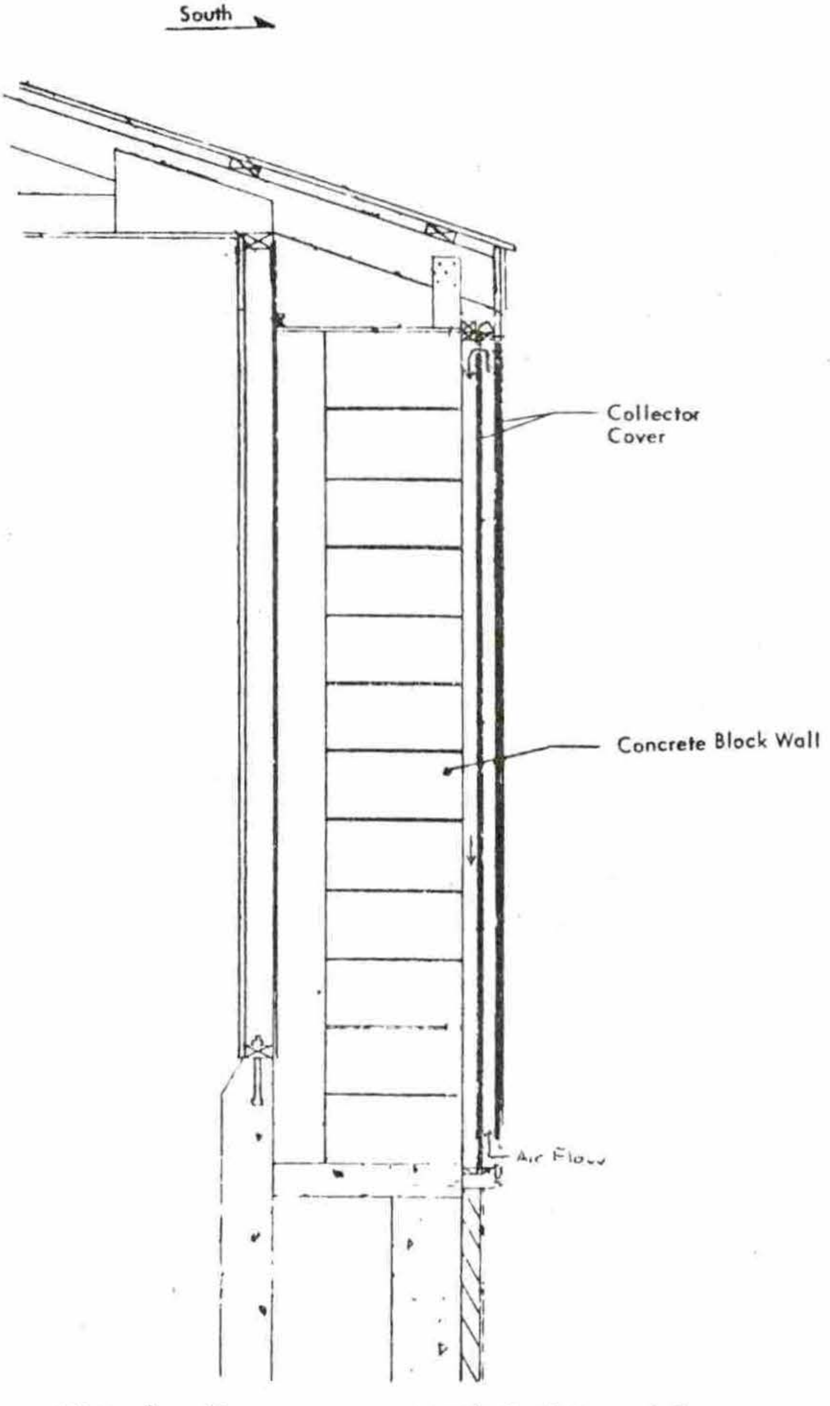

Fig. 4. Two cover suspended plate with storage (20)

used in a competing enterprise. The more competition there is for labor, the higher the value of labor usually is. Therefore, during planting and harvesting seasons, labor has a higher value than during slack times. Labor that has no competing uses is considered surplus labor and of little value.[1] It was assumed that this surplus labor is used in the construction of the collectors. Since no value is given to labor, it was assumed the required rate of return includes a return to labor.

Operational costs were considered minimal since ventilation air is used as the solar energy collection fluid. Maintenance costs were also considered to be minimal because of the nature of the materials used and some reduction in building maintenance since the southern wall is no longer exposed. Therefore, it was assumed the solar collector added no additional maintenance or operational costs to the swine system. The exception to this is the one-cover, covered plate where the cost of replacing the polyethylene film was taken into account in figuring annual returns to the collectors.

The operational life of the collectors is assumed to be fifteen years with no reduction in the efficiency of the collectors.

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[1] It is recognized that labor always competes with leisure and that leisure time has an economic value. Therefore, it is necessary to assume that leisure time was available in a sufficient amount such that, given diminishing returns, it takes relatively little to get the farmer to give up one hour of leisure for one hour of labor. Thus, a more precise definition of surplus labor is that time not employable in on-farm or off-farm income-making activities and is not desired for leisure activities. Therefore, it was assumed to have little value.

Estimated first costs are listed in Table 10. Appendix B lists estimated material costs and materials needed for each collector.

Table 10. Estimated first costs of collector installation (dollars)

Collector (ft^2)	Size (sq. ft.) 214	 289	 361
Type			
One cover	202	241	291
Two cover	438	560	690
Suspended	1,010	1,279	1,603
Duct work			104

Notation

The following notation is used through the rest of this study.

Swine systems

5 X SO - the farrowing unit only system where sows are farrowed five times per year on a solid floor

5 X SL - the farrowing unit only system where sows are farrowed five times per year on a slatted floor

6 X SO - the farrowing unit with nursery system where sows are farrowed six times per year. Both the farrowing unit and nursery have solid floors.

6 X SL - same as 6 X SO only with slatted floors in farrowing unit and nursery

8 X SO - the farrowing unit with nursery system where sows are farrowed eight times per year. Both the farrowing unit and nursery have a solid floor.

8 X SL - same as 8 X SO only with slatted floors in the farrowing unit and nursery.

Collectors

S1 - 214 ft^2 one-cover covered plate

S2 - 214 ft^2 two-cover covered plate

S3 - 214 ft^2 two-cover suspended plate

N1 - 289 ft^2 one-cover covered plate

N2 - 289 ft^2 two-cover covered plate

N3 - 289 ft^2 two-cover suspended plate

F1 - 361 ft^2 one-cover covered plate

F2 - 361 ft^2 two-cover covered plate

F3 - 361 ft^2 two-cover suspended plate

Annual Returns

The annual return to a collector is dependent upon the amount of solar energy used. The quantity of solar energy used is the lesser of the solar energy collected or the heating requirements of the swine unit that can be met by solar energy.

The quantity of solar energy collected is dependent on the amount of solar radiation available, the efficiency of the collector, and the size of the collector. Monthly averages were used for the amount of solar radiation available. The efficiency and size of the collectors were determined earlier; the more efficient and larger the collector the greater the amount of solar energy available.

The heating requirements of the swine unit were determined earlier. However, the extent to which the solar collector can meet heating requirements is dependent on the type of collector used. In estimating this amount, it was necessary to make the following assumptions.

One major assumption is that the nonstorage collectors could account for a maximum of 21 percent of the total heating needs of the buildings. There is an approximate 18° Fahrenheit average temperature differential between daylight high and nighttime low during the heating months (U. S. Weather Bureau data). Daylight hours are approximately 10 hours. Solar radiation is distributed in a bell-shaped curve around a peak reached at solar noon. The peak comes when building heat needs are the lowest. Thus, there will be periods during the daytime when the solar collectors cannot meet the heating needs (at the beginning and ending of the daylight period) and a period when the collectors may produce more heat than is needed (about solar noon). The periods at the beginning and ending of the daylight time are assumed to account for about one-third of the total heating requirements during this time. This background gives validity to the 21 percent assumption.

While it is possible to design a solar collection system to meet nearly all a building's heating requirements by using storage, the two cover suspended plate with storage used in this study is not designed for this. The cement block storage system was designed to provide a two to three hour lag between peak solar radiation and maximum temperature change of ventilation air. Further, the storage increases the amount of time solar energy is available from the ten hour collection period to a fifteen hour period[1] by increasing the distribution of the solar energy. This will provide for the utilization of solar energy during nondaylight hours, or at a time of increasing heating demand. Therefore it was assumed that the solar collector with storage used in this study could provide up to 50 percent of the heating needs of the buildings. There is no solar-noon heating loss of the nonstorage collectors and the concrete blocks store heat to be used later in the day and night.

The 21 percent and 50 percent figures are only estimates. Until actual data can be compiled, these estimates are considered sufficient for this study. It should be recognized that the actual percent of heating requirements may be less than this. Excess solar heat from the collectors (both storage and nonstorage) is considered unusable and vented through the building's ventilation system.

The amount of solar energy used was converted into gallons of LP gas equivalents. LP gas is used as equivalent units because it represents the cheapest, most accessible conventional form of energy for most swine producers. One gallon of LP gas contains about 93,000 BTUs. However, not all of this is available for use in heating, since the burning of LP gas is not 100 percent efficient. The efficiency of the LP gas heater depends on the type of heater and the condition of the heater. Typically, a LP gas heater will be around 90 percent

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[1] Based on preliminary Iowa State data.

efficient (19). Therefore, 83,700 BTUs of solar energy are assumed to be equivalent to one gallon of LP gas.

Annual costs of the collectors were considered to be minimal. Only one-half of the replacement costs of the polyethylene film on the one-cover covered plate (which needs replacing every other year) was used as an annual cost. While there will be maintenance and operational costs involved, the maintenance and operational costs for the swine production system were assumed to remain the same whether or not a solar collector was used. Therefore, no additional maintenance and operational costs were attributed to the solar collector.

Since the adoption of solar energy collection was looked at from a present value before tax standpoint, the effect of the various tax considerations given to solar energy collection systems were not included in the analysis. (Special tax considerations are mentioned in Appendix A.) By omitting taxes from the analysis, depreciation was also omitted. While depreciation expense will have an effect on the profitability of the solar collection system, the magnitude of that effect depends on the tax bracket of the producer. Further, by omitting special tax consideration and depreciation, the collector system was forced to pay for itself out of the energy savings it provided.

Annual returns were determined by the equation:

$$AR = \left(\frac{\text{BTUs of solar heat}}{83{,}700}\right) P_{LP} - AC$$

where AR = annual returns

P_{LP} = price per gallon of LP gas

AC = annual cost (for one-cover covered plate = 1/2 replacement cost of polyethylene film. Otherwise = 0)

It was assumed the cost of the polyethylene film (a petroleum based product) increased at the same rate as the LP gas price.

Table 11 lists the 21 percent and 50 percent of the heating requirements for each swine system. Table 12 lists the estimated output of the collector system per square foot of effective collector area. Table 13 lists the usable BTUs of solar heat for each swine system by size of collector system.

Present Value Under Inflation

The economic evaluation of the solar collectors was done under the assumption of inflationary conditions. In the absence of inflation, the general equation for determining net present value is:

$$NPV_1 = \sum_{t=1}^{n} \frac{AR_t}{(1+r)^y} - PC$$

where

NPV_1 = net present value in the absence of inflation

AR_t = the annual returns in the year t

r = weighted average of the real required annual rates of return to debt (r_d) and equity (r_e) capital ($r = w_d r_d + w_e r_e$)[1]

PC = present cost (or present value)

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[1] w_d represents the proportion of total capital invested that is debt capital and w_e represents the proportion of total capital invested that is equity capital. This notation is used again later in the text.

Table 11. 21 and 50 percent of heating requirements (1000 BTUs)

Swine system	Farrowing unit alone		Farrowing unit with nursery			
	5 farrowings/year		6 farrowings/year		8 farrowings/year	
Flooring material	solid	slatted	solid	slatted	solid	slatted
Supplemental heating requirements	84,121	31,064	122,933	53,434	197,699	87,436
Daytime heating requirements	18,005	6,466	26,320	11,214	41,925	18,250
50 percent of heating requirements	42,061	15,532	61,467	26,717	98,850	43,718

Table 12. Collector output per ft^2 (BTUs)

	One cover covered plate	Two cover covered plate	Two cover suspended plant
Percent efficiency	35	40	55
November	13,600	15,600	21,400
December	13,500	15,400	21,200
January	14,400	16,500	22,700
February	14,000	16,000	22,000
March	14,300	16,400	22,500
Total	69,800	79,900	109,800

Table 13. Usable solar collector output (1000 BTUs)

Unit	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/yr.		6 farrowings/year				8 farrowings/year			
			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
Flooring material	solid	slatted	solid	solid	slatted	slatted	solid	solid	slatted	slatted
214 ft^2										
one-cover	13,478	6,467	8,945	9,052	5,319	5,597	12,534	14,937	7,157	10,796
two-cover	14,784	6,467	8,977	10,379	5,319	5,894	12,599	17,099	7,157	11,093
suspended	22,964	15,257	16,105	14,253	12,304	10,217	12,964	23,498	16,145	19,462
289 ft^2										
one-cover	16,557	6,467	8,977	12,225	5,319	5,894	12,599	20,173	7,158	11,092
two-cover	17,499	6,467	8,977	14,017	5,319	5,894	12,599	23,092	7,158	11,092
suspended	29,546	15,532	20,154	19,248	12,826	11,919	27,871	31,733	17,188	24,207
361 ft^2										
one-cover	17,871	6,467	8,977		5,319		12,599		7,158	
two-cover	18,005	6,467	8,977		5,319		12,599		7,158	
suspended	34,327	15,532	21,433		12,826		29,843		17,188	
361 ft^2 w/duct										
one-cover				10,484		5,894		11,340		10,289
two-cover				12,498		5,894		14,621		10,972
suspended				14,069		10,079		8,815		13,842

n = number of years the asset is to be capitalized.

If the annual returns are constant in each period, then the equation for net present value can be written as:

$$NPV_1 = AR \sum_{t=1}^{n} \frac{1}{(1+r)^t} - PC$$

Inflation affects the annual returns to an investment. Although the annual returns may hold constant in real terms, nominally they could be increasing because of inflation. If the impact of inflation could be perfectly predicted, it could be built into the investment analysis. In the presence of imperfectly predicted inflation there will be a return to the investment solely attributable to inflation.

Likewise, if the investment is to be used as a substitute for an input in production whose cost is increasing faster than the general inflation rate, there will be a return attributable to inflation. To demonstrate this, assume the investment is a solar collector capable of replacing a specified quantity of fuel and assume that the fuel prices are increasing faster than prices in general. The amount of fuel replaced does not change, but the value of the fuel replaced would be increasing. Therefore, the returns to the collector would be increasing, not because the collector is producing more efficiently, but because the value of its output (i.e., the fuel replaced) is increasing. This return can be attributed to the price inflation of fuel.

To show the impact of inflation on investment decisions, certain assumptions will be made. The first assumption is that the investment substitutes for an input whose price is increasing faster than the general inflation rate. Second, it is assumed that the general inflation rate and the rate the price of the input is increasing are constant for every period. Third, it is assumed that the amount of input substituted for (i.e., real annual returns) is constant in every period.

Inflation, by increasing the cost of the input substituted for, acts as a growth factor on the annual returns of the investment by nominally increasing them in every period. Therefore, to show inflation's effect on the present value of an investment, the general growth model can be used. The general growth model estimates the value of an asset whose returns increase in every period. The general growth model equation is (13):

$$V = R \sum_{t=1}^{n} \frac{(1+g)^t}{(1+k)^t}$$

where

V = present value (or present cost)

R = returns per period (assumed to be constant)

g = growth factor by which returns are increasing

k = capitalization rate.

The similarity between the growth model and the net present value equations should be obvious. The general growth model equation can be modified to fit the net present value equation form. Then,

$$NPV_2 = R \sum_{t=1}^{n} \left(\frac{1+g}{1+k}\right)^t - V,$$ where NPV_2 is the net present value under inflation.

The capitalization rate in the general growth model is a weighted average of the required rate of return to debt (k_d) and equity capital (k_e), or $k = w_d k_d + w_e k_e$. The required rates of return to debt and equity capital reflects not only the real rates of return (r), but also the inflationary expectations (i) of the holders of debt and equity capital such that $k_d = r_d + i_d$ and $k_e = r_e + i_e$. Then, $k = w_d(r_d + i_d) + w_e(r_e + i_e)$. Assuming that the inflationary expectations are the same for both holders of debt and equity capital, then $k = w_d r_d + w_e r_e + i$. Since r was defined earlier as $w_d r_d + w_e r_e$, then the modified general growth equation can be written as:

$$NPV_2 = R \sum_{t=1}^{n} \left(\frac{1+g}{1+r+i}\right)^t - V$$

Assuming $1 > g \geq i > 0$, then $R \sum_{t=1}^{n} \left(\frac{1+g}{1+r+i}\right)^t > AR \sum_{t=1}^{n} \left(\frac{1}{1+r}\right)^t$

since R = AR by definition. Then, since PC = V (by definition) $NPV_2 > NPV_1$. Therefore, it is possible that an investment not meeting the net present value criteria (i.e., NPV > 0) in the absence of inflation, could when inflation exists.

Going back to earlier assumptions, g is the input inflation rate and i is the expected general inflation rate, so g > i.

LP Gas Price

The major assumption with respect to the price of LP gas is that it will be increasing relative to other inputs in agriculture. Although for the period 1920-1970, the price of energy was decreasing relative to other inputs, the more recent trend (1970-79) has been for the price of energy to increase relative to other inputs. How long this trend will continue is unpredictable, but it seems highly improbable that the price of energy will be decreasing relative to the price of other inputs.

In order to show the price of energy increasing relative to other inputs, the LP gas price inflator must be greater than the general price inflator. E. D. Cox, director of energy resources at Johns-Manville Corporation, in a meeting with the National Association of Purchasing Managers, estimated propane (e.g., LP gas) prices would probably be increasing at a rate of 2 to 4 percent above the general inflation rate (25). This estimate was used as the price inflator for LP gas. Trying to use historical data to predict future price increases proved difficult since price increases of LP gas in the last decade (1970-79) have varied from 5.3 to 57.8 percent, though most annual increases were near 10 percent.

The consumer price index (CPI) was used to estimate the general inflation rate. In the period 1973-79, the CPI has generally increased in the range of 6 to 10 percent annually (1979 was outside this range, as are predictions for 1980). A 7 percent annual rate is assumed to be the general inflation rate for the period of this study.

Based on Cox's predictions, the price inflator for LP gas was assumed to be 3 percent higher than the general inflation rate, or 10 percent per year. The initial price of LP gas was taken as $.60/gallon.

CHAPTER III. ANALYSIS

Net Present Value

The analysis of the systems defined in Chapter II was done under five determinations: net present value, internal rate of return, payback period, savings on heating costs, and fuel savings.

The net present value (NPV) of an investment is the net discounted value of future costs and returns. The net present value equation used was the modified equation that includes inflation, derived earlier:

$$NPV = AR \sum_{t=1}^{n} \frac{(1+g)^t}{(1+r+i)^t} - PC$$

where

NPV = net present value under inflation (or the earlier defined NPV_2)

AR = annual returns in the t^{th} period

g = fuel price inflator

r = real rate of return

i = general inflation rate

PC = present cost of collector

When using the NPV as the criteria for investment analysis, the NPV must be greater than or equal to zero for an investment to be undertaken. In a set of mutually exclusive investments, the highest NPV is the optimal investment, provided $NPV \geq 0$.

A mutually exclusive investment is an investment that once undertaken precludes the selection of any of the other investments. Such is the case here. The set of mutually exclusive investments is the different sizes and types of solar collectors available for each unit (i.e., farrowing or nursery). The selection of one collector makes it impossible to use any other collector on the unit.[1]

Therefore, by using the net present value criteria in the selection process, the optimal collector for each unit would be the collector with the highest NPV, provided NPV ≥ 0. The optimal collector combination for each swine system will have the highest combined NPV.

In using the NPV criteria, it is necessary to establish a minimum required rate of return which the investment must earn. The minimum required rate of return is generally considered as a weighted average of the minimum required rate of return to equity capital invested and the cost of using debt capital. The cost of using debt capital is easily determined since it is the interest rate of the borrowed money. However, determining the minimum required rate of return to equity capital is not so easy.

The minimum required rate of return to equity capital has to encompass both the opportunity cost to equity capital and the amount of risk[2] the investment places on the investor. The opportunity cost

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[1] The ductwork is an exception because it is a conditional investment. The ductwork can only be undertaken if the "F" (361 ft^2) collectors are used.

[2] Risk used in this text includes the concept of uncertainty.

to equity capital is the highest return the equity capital could receive in some alternative investment. Since the debt capital is usually secured, the majority of the risk of an investment lies with the investor of equity capital. The riskier an investment is, the more the investment should be required to return in order to compensate for assuming the risk, therefore, the minimum required rate of return to equity capital is usually higher than the cost of borrowing.

The cost of borrowing and the minimum required rate of return to equity capital includes inflationary expectations for over the economic life of the investment. For the purposes of this study, the inflationary expectations of both debt and equity capital were assumed to be the same. Therefore, the inflationary expectation factor was separated from the minimum required rate of return to investment. In other words, the minimum required rate of return (r) is viewed in "real" terms, as were the annual returns and costs.

In order to use the NPV criteria of analysis in the study, some assumptions were made regarding inflationary expectations and returns to investment. As explained under the heading Price of LP Gas in this section, the fuel price inflator (g) was taken as 10 percent and the general inflation rate (i) was taken as 7 percent. The minimum required rate of return was assumed to be 10 percent, i.e., the collectors must earn a minimum of 10 percent on their investment without inflation to be chosen as an investment alternative.

Under the method of selection using the NPV criteria, the optimal collector will be the collector which has the highest NPV provided NPV ≥ 0. If NPV > 0, then the collector has a greater than 10 percent real return to investment. If NPV = 0, then the collector returns exactly 10 percent. However, if NPV < 0, then the collector has a less than 10 percent real return and should not be chosen since a minimum of 10 percent is required.

The net present values of each collector for each system are listed in Table 14. The collectors were assumed to have an economic life of 15 years. (In order for the NPV to be used with a set of mutually exclusive investments, all investment alternatives must have the same economic life.)

As can be seen in the table, the highest NPVs for each system were:

System	Collector (Farrowing units listed first, followed by nursery)
5 X SO	F1
5 X SL	S1
6 X SO	S1-N1
6 X SL	F1-duct
8 X SO	N3-N1
8 X SL	F1-duct

The highest NPVs for each system were usually the one-cover covered plate collectors, either alone or in conjunction with the ductwork to transport surplus heat collection from the farrowing unit to the nursery.

The NPVs of the optimal collectors ranged from $330 to $1,093.

Table 14. Net present value (dollars)

	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/year		6 farrowings/year				8 farrowings/year			
Unit			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
Flooring	solid	slatted	solid		slatted		solid		slatted	
214 ft^2										
one-cover	677	201	369	376	122	141	613	777	247	495
two-cover	567	2	173	267	-77	-37	419	725	49	316
suspended	551	28	85	-41	-173	-315	552	588	88	313
289 ft^2										
one-cover	847	162	332	553	83	122	578	1,093	208	476
two-cover	627	-120	51	393	-199	-159	297	1,010	-73	194
suspended	730	-223	92	30	-407	-469	616	879	-110	367
361 ft^2										
one-cover	887	112	282		33		528		158	
two-cover	534	-250	-79		-329		167		-203	
suspended	674	-547	-145		-835		426		-434	
361 ft^2 w/duct[a]										
one-cover			891		330		1,195		754	
two-cover			766		-31		1,211		439	
suspended			707		-149		922		403	

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[a] Use of the ductwork is limited to 361 ft^2 collectors and precludes nursery collector.

Internal Rate of Return

The internal rate of return (IRR) is the rate of return which equates present and future costs to present and future returns. In other words, the IRR's rate of return which results in the net present value equaling zero.

The basic equation used to determine the IRR is the same as the one used in determining NPV, except that r is the variable and NPV is equal to zero.

In using IRR method for investment analysis, the optimal investment in a set of mutually exclusive alternatives is the investment with the highest IRR, provided the IRR is above a specified "cut off" rate. The cut off rate is the minimum required rate of return on investment which the investment must return for it to be acceptable.

An advantage of the IRR method over the NPV method of investment analysis is in the use of the minimum required rate of return. With the IRR method, the investments can be evaluated under different minimum required rates of return, without recalculating the IRR. Therefore, it is possible to refine the minimum required rate of return after IRR calculations have been made. Also, this allows for an investment to be analyzed under different capital allocation schemes (i.e., percentage make-up of r by debt and equity capital) without recalculations. With the NPV method, however, the NPV must be recalculated for each minimum required rate of return. It should be noted though that the calculations of the IRR are much more difficult than for the NPV.

The fuel price inflator and the general inflation rate were again assumed to be 10 percent and 7 percent, respectively.

The IRR for each system is listed in Table 15. The cut off rate was assumed to be 10 percent, the same as the minimum real required rate of return used in the NPV determination.

The optimal collectors for each system are:

System	Collector
5 X SO	N1
5 X SL	S1
6 X SO	F1-duct
6 X SL	F1-duct
8 X SO	S1-N1
8 X SL	S1-S1

While the IRR and NPV use the same basic equation and often give the same results, this is not always the case with mutually exclusive alternatives. Due to the implicit compounding effect of the rate of return used, it is possible for the collector with the highest NPV not to have the highest IRR. This depends on the size and timing of the returns and costs. In this study, the same collectors proved optimal by both the NPV and IRR method for the slatted floor swine systems, while different collectors were optimal under the two methods for the solid floor swine systems. This poses the problem as to which method is the best.

Generally, it is accepted that if the minimum real required rate of return can be well defined, the NPV is the better of the two methods. This is because the minimum real rate of return represents

Table 15. Internal rate of return (%)

Unit	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/year		6 farrowings/year				8 farrowings/year			
			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
Flooring	solid	slatted	solid		slatted		solid		slatted	
214 ft^2										
one-cover	53.3	24.5	35.1	35.5	19.3	20.6	49.5	59.0	27.5	42.6
two-cover	28.4	10.1	16.2	19.3	6.9	8.5	24.1	33.0	11.9	20.9
suspended	18.4	10.5	11.4	9.3	6.9	4.1	18.4	18.9	11.5	14.9
289 ft^2										
one-cover	55.2	20.2	29.5	40.8	15.5	17.9	42.0	67.2	22.8	36.8
two-cover	26.2	6.0	11.5	20.5	3.3	4.6	18.2	34.8	7.7	15.5
suspended	18.7	6.9	11.2	10.4	4.1	3.1	17.5	20.4	8.5	14.6
361 ft^2										
one-cover	49.6	16.0	24.2		11.9		34.9		18.4	
two-cover	21.6	3.2	8.1		0.5		14.0		4.5	
suspended	17.1	3.4	8.4		1.0		14.3		5.0	
361 ft^2 w/duct[a]				40.3		22.5		49.5		36.1
one-cover				22.5		9.3		31.3		18.5
two-cover				16.5		8.4		18.3		14.6
suspended										

[a] Use of the ductwork is limited to 361 ft^2 collectors and precludes nursery collector.

the cost of using capital in both methods. In the NPV method, the minimum real rate of return used is the actual (or close to) cost of using capital, while with the IRR method, the resulting IRR is implicitly the cost of using capital. For an IRR greater than the actual cost of using capital, the compounding effect of the rate of return used could cause an investment to be nonoptimal under the IRR method, while it may be optimal by the NPV method. With a greater difference between the IRR and the minimum required rate of return, the probability of an investment being optimal under the NPV method, while nonoptimal under the IRR method, increases. This is because the future returns and costs are significantly devalued compared to present returns and costs due to discounting by a capitalization rate greater than the cost of using capital.

Payback Period

Traditionally, the payback period has been defined as the number of years it takes for the initial investment costs to be recovered. Normally, the payback period is determined by dividing the initial investment costs by the estimated annual return. The problem with determining the payback period by this method is that no cost of using capital is taken into account. The exclusion of capital costs is especially a problem during inflationary periods because the capital costs account for more than just the opportunity cost to capital use. To alleviate this problem, the payback period will be viewed in a slightly different way.

For this study, the payback period will be defined as the number of years it takes to recover the initial investment while providing an acceptable rate of return to investment. In other words, the payback period is the number of years it takes to equate present and future costs with present and future returns while providing a specified rate of return.

In determining the payback period, the basic equation for determining the NPV is again used (with the net present value equal to zero, the rate of return equal to the minimum required rate of return, and solving for n).

For an investment to be acceptable under the payback period method, it must have a payback period less than or equal to a minimum acceptable payback period. In the study, the minimum acceptable payback period was considered to be the economic life of the collectors, fifteen years. The optimal investment in a set of mutually exclusive investments will be the investments with the shortest payback period.

However, this method, even when the cost of using capital is included, has a major fault; it ignores the returns and cost to the investment after the initial investment has been recovered. This is a problem because it could equate two investments with the same payback period, even though one investment may provide much higher returns after the payback period.

The payback period is useful in that it provides supplemental information to be used in conjunction with the other investment analysis methods. It provides an idea as to the riskiness of an investment, given that the quicker an investment returns its initial costs, the less risky it tends to be. Also, it can be a useful guide when a rapid return or a high amount of liquidity is needed.

The payback periods for each system are listed in Table 16.

The optimal collectors by the payback criteria were:

System	Collector
5 X SO	N1
5 X SL	S1
6 X SO	F1-duct
6 X SL	F1-duct
8 X SO	S1-N1
8 X SL	S1-S1

The one-cover covered plate collectors have the shortest payback periods for all systems. The payback periods of the optimal collectors ranged from 2.3 to 6.5 years.

Savings on Heating Costs

The three previous evaluation methods looked at the implementation of a solar collection system as a capital investment. While the solar collector should be viewed as a capital investment, the main objective of using a solar collector is to reduce the need for purchased fuels. In doing so, the goal is to reduce the costs of heating. This section will evaluate the solar collectors as a means of reducing the heating bill associated with swine production. The equation used in determining the percent cost savings is:

Table 16. Payback period (years)

	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/year		6 farrowings/year				8 farrowings/year			
Unit			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
Flooring	solid	slatted	solid		slatted		solid		slatted	
214 ft^2										
one-cover	2.4	5.8	3.9	3.9	7.6	7.1	2.6	2.2	5.1	3.1
two-cover	5.0	14.9	9.2	7.6	21.3	17.5	6.0	4.2	12.7	7.0
suspended	8.0	14.4	13.2	16.1	21.2	34.1	8.0	7.8	13.1	10.0
289 ft^2										
one-cover	2.3	7.3	4.7	3.3	9.6	8.3	4.2	1.9	6.3	3.7
two-cover	5.4	24.7	13.1	7.2	44.3	30.2	8.1	3.9	19.2	9.6
suspended	7.9	21.2	13.4	14.4	35.0	49.4	8.5	7.2	17.5	10.3
361 ft^2										
one-cover	2.6	9.3	5.9		12.7		3.9		8.0	
two-cover	6.7	47.4	18.6		∞		10.8		31.4	
suspended	8.7	40.2	17.7		∞		10.5		28.5	
361 ft^2 w/duct[a]										
one-cover			3.3		6.5		2.6		4.8	
two-cover			6.4		16.1		4.4		8.0	
suspended			9.0		17.6		8.1		9.9	

[a] Use of the ductwork is limited to the 361 ft^2 collectors and precludes nursery collector.

$$S = \frac{AR \sum_{t=1}^{n} (1+g)^t - n\left[PC \sum_{t=1}^{n} \frac{1}{(1+r+i)^t}\right]}{HC \sum_{t=1}^{n} (1+g)^t} \times 100$$

where

S = percent savings on heating costs over the life of the investment

AR = annual returns

PC = present costs

HC = heating costs without use of solar collector

g = fuel price inflator

r = real rate of return

i = general inflation rate

n = economic life in years

In the equation, $AR \sum_{t=1}^{n} (1+g)^t$ is the total revenue from the collector given the price of LP gas increasing by an annual percentage of g through the life of the collector; $n\left[PC \sum_{t=1}^{n} \left(\frac{1}{1+r+i^t}\right)\right]$ is the total cost of the investment where the present cost was annualized at a (r+i) rate of interest for the life of the collector; $HC \sum_{t=1}^{n} (1+g)^t$ is the total heating costs of the swine system, assuming the price of LP gas is increasing by an annual rate of g. The heating costs (HC) were estimated by taking the LP gas equivalent of the swine system's heating requirements multiplied by the price of LP gas. HC is the annual heating costs if no collector is used (i.e., heating requirements are met entirely by LP gas).

The percent savings on heating costs are listed in Table 17. The percent savings is for the swine system--not for the unit the collector is attached to.

The optimal collector under this evaluation is the collector with the largest savings. The optimal collectors for each system are: F3 for 5 X SO; S1 for 5 X SL; SI-NI for 6 X SO; F1-duct for 6 X SL; N3-NI for 8 X SO; and F1-duct for 8 X SL.

The savings to heating cost of the optimal collectors ranged from 10.1 to 16.4 percent.

Fuel Savings

The collectors were also evaluated for the total amount of fuel saved. The percent fuel saved is the amount of solar heat used divided by the total heating requirement for each system. Since the one-cover covered plate and the two-cover covered plate could only supply a maximum of approximately 21 percent of the total heating requirements, while the two-cover suspended plate with storage could supply a maximum of 50 percent of the total heating requirements, this method of evaluation is biased to the two-cover suspended plate. However, there is merit in evaluating the collectors under this method since one objective of the swine producer is to minimize the purchased fuel requirements of the swine system.

The optimal collector for all farrowing units was the F3 collector, except for the farrowing units in the 5 X SL and 6 X SL systems. The optimal collector for the nursery unit in all systems was the N3 collector. The N3 collector was also the optimal collector for the

Table 17. Percent heating costs savings

	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/year		6 farrowings/year				8 farrowings/year			
			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
Unit Flooring	solid	slatted	solid		slatted		solid		slatted	
214 ft^2										
one-cover	11.9	10.3	4.6	4.7	3.9	4.4	4.6	5.8	4.4	8.4
two-cover	10.7	3.0	2.7	3.8	-0.3	0.7	3.5	5.7	1.8	6.1
suspended	11.9	7.9	2.7	1.2	-0.7	-4.4	5.0	5.3	3.8	7.4
289 ft^2										
one-cover	15.0	8.8	4.3	6.8	3.1	4.1	4.4	8.1	3.9	8.1
two-cover	12.0	-1.7	1.5	5.5	-3.0	-2.0	2.7	7.9	0.1	4.4
suspended	15.6	-1.6	3.2	2.5	-5.7	-7.3	5.8	7.7	1.2	8.8
361 ft^2										
one-cover	15.8	6.9	3.8		2.0		4.1		3.2	
two-cover	10.8	-6.7	0.3		-5.9		1.9		1.6	
suspended	16.4	-14.0	1.0		-12.9		4.8		-3.2	
361 ft^2 w/duct[a]										
one-cover			11.0		10.1		9.0		12.9	
two-cover			9.1		2.2		9.6		8.9	
suspended			11.1		2.6		8.4		10.4	

[a] The use of ductwork limited to the 361 ft^2 collectors and precludes the use of nursery collector.

5 X SL and the 6 X SL systems farrowing unit.

The percentages of fuel saved for each swine system are listed in Table 18. Table 19 lists the percent of fuel saved for the individual units in each system.

If the fuel savings is to be used as a criteria, it is important to look at the economics of the optimal fuel savings collectors. The NPV, IRR, payback period and cost savings are listed for the most fuel savings collectors of each system in Table 20.

The collectors providing the largest reduction in purchased fuel are bad economic investments for some of the swine systems. The collectors failed to pass the other evaluation methods criteria test in the 5 X SL, 6 X SO, and 6 X SL. The collectors of the 5 X SO, 8 X SO, and 8 X SL met the other methods' criteria, so would be sound economic investments.

Optimal Collector for Each System

The optimal collector for each system depends on the type of method used to evaluate the collector options. An evaluation of the optimal collectors for each swine system is listed in Table 21.

If we assume the best collector to be the optimal collector that passes all the methods of criteria (i.e., NPV ≥ 0, IRR $\geq$ minimum acceptable time) while providing the greatest reduction in cost of heating, then the optimal collectors for each system are:

Table 18. Percent fuel savings for each swine system

Unit	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/year		6 farrowings/year				8 farrowings/year			
			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
Flooring	solid	slatted	solid		slatted		solid		slatted	
214 ft^2										
one-cover	16.0	20.8	7.3	7.4	10.0	10.5	6.3	7.6	8.2	12.3
two-cover	17.6	20.8	7.3	8.4	10.0	11.0	6.4	8.6	8.2	12.7
suspended	27.3	49.1	13.1	11.6	23.0	19.1	11.6	11.9	18.5	22.2
289 ft^2										
one-cover	19.7	20.8	7.3	9.9	10.0	11.0	6.4	10.2	8.2	12.7
two-cover	20.7	20.8	7.3	11.4	10.0	11.0	6.4	11.7	8.2	12.7
suspended	35.1	50.0	16.4	15.7	24.0	22.3	14.1	16.0	19.7	27.7
361 ft^2										
one-cover	21.2	20.8	7.3		10.0		6.4		8.2	
two-cover	21.4	20.8	7.3		10.0		6.4		8.2	
suspended	40.8	50.0	17.4		24.0		15.1		19.7	
361 ft^2 w/duct										
one-cover			15.9		21.0		12.1		20.0	
two-cover			17.5		21.0		13.8		20.7	
suspended			28.9		42.9		19.6		35.5	

Table 19. Fuel savings for each unit of each swine system (%)

Unit Flooring	Farrowing unit alone		Farrowing unit with nursery							
	5 farrowings/year		6 farrowings/year				8 farrowings/year			
			farrow	nursery	farrow	nursery	farrow	nursery	farrow	nursery
	solid	slatted	solid		slatted		solid		slatted	
214 ft^2										
one-cover	16.0	20.8	20.9	11.3	20.7	20.1	21.0	10.8	20.8	20.3
two-cover	17.6	20.8	20.9	13.0	20.7	21.2	21.0	12.4	20.8	20.9
suspended	27.3	49.1	37.8	17.8	48.0	36.8	38.5	17.0	47.0	36.7
289 ft^2										
one-cover	19.7	20.8	20.9	15.3	20.7	21.2	21.1	14.6	20.8	20.9
two-cover	20.7	20.8	20.9	17.5	20.7	21.2	21.1	16.7	20.8	20.9
suspended	35.1	50.0	47.0	24.0	50.0	42.9	46.7	23.0	50.0	45.6
361 ft^2										
one-cover	21.2	20.8	20.9		20.7		21.1		20.8	
two-cover	21.4	20.8	20.9		20.7		21.1		20.8	
suspended	40.8	50.0	50.0		50.0		50.0		50.0	
361 ft^2 w/duct										
one-cover				13.1		21.2		8.2		19.4
two-cover				15.6		21.2		10.6		20.7
suspended				17.6		36.3		6.4		26.1

Table 20. Optimal fuel savings collector values

System	Farrowing unit alone		Farrowing unit with nursery			
	5 farrowings/year		6 farrowings/year		8 farrowings/year	
Flooring	solid	slatted	solid	slatted	solid	slatted
Collector	F3	N3	F3-N3	N3-N3	F3-N3	N3-N3
NPV (dollars)	674	-223	-115	-876	1305	257
IRR[a] (%)	17.1	6.9	9.3	3.6	17.0	11.6
Payback period[a] (yrs)	8.7	21.2	16.2	42.2	9.0	13.9
Percent cost savings	16.4	-1.6	3.5	-13.0	12.5	10.0

[a] IRR and payback period are the weighted average value of the two collectors based on initial costs.

Table 21. Optimal collectors and values for each system

	Collector	NPV ($)	IRR[a] (%)	Payback period[a] (years)	Cost savings (percent)	Fuel savings (percent)
Farrowing unit alone, solid floor	N1	847	55.2	2.3	15.0	19.7
	F1	887	49.6	2.6	15.8	21.2
	F3	674	17.1	8.7	16.4	40.8
Farrowing unit alone, slatted floor	S1	201	24.5	5.8	10.3	20.8
	N3	-223	6.9	21.2	-1.6	50.0
Farrowing unit with nursery 6-farrowings/year solid floor	S1-N1	922	38.2	3.6	11.4	17.2
	F1-duct	891	40.3	3.3	11.0	15.9
	F3-N3	-115	9.3	16.2	3.5	33.1
Farrowing unit with nursery 6 farrowings/year slatted floor	F1-duct	330	22.5	3.3	10.1	21.0
	N3-N3	-876	3.6	42.2	-13.0	46.3
Farrowing unit with nursery 8 farrowings/year solid floor	S1-N1	1706	59.1	2.2	12.7	16.5
	N3-N1	1709	25.4	7.5	13.9	24.3
	F3-N3	1305	17.0	9.0	12.5	31.1
Farrowing unit with nursery 8 farrowings/year slatted floor	S1-S1	742	35.1	4.1	12.8	20.5
	F1-duct	754	36.1	4.8	12.9	20.0
	N3-N3	257	11.6	13.9	10.0	47.3

[a] IRR and payback period are weighted average values based on initial costs.

System	Collector
5 X SO	F3
5 X SL	S1
6 X SO	S1-N1
6 X SL	F1-duct
8 X SO	N3-N1
8 X SL	F1-duct

The optimal collectors provided a reduction in cost in the range of 10.1 to 16.4 percent and the reduction in needed purchased fuel ranged from 17.2 to 40.8 percent. The rates of return ranged from 17.1 to 38.2 percent. The payback periods ranged from 3.3 years to 8.7 years. The optimal cost savings collectors and their respective NPV, IRR, payback period, cost savings, and fuel savings values are listed for each system in Table 22.

Optimal Cost Savings Collectors Without Inflation

The optimal cost savings collector without inflation considerations is the collector providing the largest savings in heating costs for each system. Since inflation was not a factor, prices were assumed fixed at today's level (i.e., LP gas price at $.60/gallon).

Instead of determining the net present value, internal rate of return, and payback period for each collector, a linear programming minimization model was used. The linear programming model allows the consideration of many options and selects the collector or collector combination that will provide the greatest cost savings for any given price level. Since prices were assumed fixed, only one price level was used. (For details of linear programming see Beneke and Winterboer, Linear Programming Applications to Agriculture) (3).

Table 22. System optimal collectors and values

System	Farrowing unit only		Farrowing unit with nursery			
	5 farrowings/year		6 farrowings/year		8 farrowings/year	
Flooring	solid	slatted	solid	slatted	solid	slatted
Collectors	F3	S1	S1-N1	F1-duct	N3-N1	F1-duct
NPV (dollars)	674	201	922	330	1709	754
IRR[a] (%)	17.1	24.5	38.2	22.5	25.4	36.1
Payback period (yrs)	8.7	5.8	3.6	3.3	7.5	4.8
Percent heat cost savings	16.4	10.3	11.4	10.1	13.9	12.9
Percent fuel savings	40.8	20.8	17.2	21.0	24.3	20.0

[a] IRR and payback period are weighted average values based on initial costs.

It was necessary to convert present costs to an annualized cost in order to fit the linear programming model. (The linear programming model determined the annual savings.) The annualized present costs represent an equal distribution of the initial costs of the collector, plus a cost of using capital. In annualizing the present costs, a 10 percent cost of using capital was assumed as a discount factor. The 10 percent cost of using capital reflects a required 10 percent return on investment that was also assumed when inflation was considered.

The annual costs and returns were the same as for the inflation section with one-half of the replacement cost of the polyethylene film cover on the one-cover covered plate collector taken in each year. Since prices were assumed fixed, the annual costs and the annual returns were considered fixed and held constant over the economic life of the collectors. The economic life of the collectors was assumed to be 15 years.

The optimal cost saving collectors for each system are:

System	Collector
5 X SO	F1
5 X SL	S1
6 X SO	S1-N1
6 X SL	F1-duct
8 X SO	S1-N1
8 X SL	F1-duct

The rate of return and percent cost savings are listed in Table 23.

When inflation was not taken into account, the one-cover covered

Table 23. Systems optimal collectors (no inflation factor)

Swine system	Farrowing unit alone		Farrowing unit with nursery			
	5 farrowings/year		6 farrowings/year		8 farrowings/year	
Flooring	solid	slatted	solid	slatted	solid	slatted
Collector	F1	S1	S1-N1	F1-duct	S1-N1	F1-duct
Percent heating cost savings	12.9	5.0	8.4	3.7	10.9	9.0
Percent return to investment	27.5	5.9	17.4	3.8	36.1	15.1
Percent fuel savings	21.2	20.8	17.2	21.0	16.5	20.0

plate collector was the optimal collector for each system. When inflation was considered, the optimal collector was still the one-cover covered plate for four of the systems, but the two-cover suspended plate with storage proved optimal for the 5 X SO and 8 X SO systems.

The optimal collector, percent cost savings, and rates of return for both the evaluation under inflation and without inflation are given in Table 24. The percent cost savings when no inflation was considered ranged from 3.7 to 12.9 percent compared to the inflationary evaluation range of 10.1 to 16.4 percent. The rates of return of the no inflation evaluation ranged from 3.8 to 36.1 percent compared to the range of 17.1 to 38.2 percent for the inflationary evaluation.

While there was little variation in the optimal collectors chosen between the no inflation and inflation evaluations, there is a large difference between the estimated cost savings. The cost savings were less for the no inflation evaluation compared to the inflation evaluation. This was expected because the cost of heating the swine facilities was assumed to be increasing under the inflation evaluation and constant under the no inflation evaluation. The rates of return were also much less for the no inflation evaluation. This was also expected.

Although the two evaluation methods led to the same optimal collectors for four of the systems, a problem arises in noneconomic considerations. A collector may only provide an estimated 3.7 percent decrease in heating costs when inflation was not included. This may not be great enough for the producer to deem it worthwhile to

Table 24. Inflation versus no inflation--optimal collectors

Swine system	Farrowing unit alone				Farrowing unit with nursery							
	5 farrowings/year				6 farrowings/year				8 farrowings/year			
Flooring	solid		slatted		solid		slatted		solid		slatted	
Evaluation	infl.	no	infl.	no	infl.	no	infl.	no	infl.	no	infl.	no
Collector	F3	F1	S1	S1	S1-N1	S1-N1	F1-duct	F1-duct	N3-N1	S1-N1	F1-duct	F1-duct
Percent heating cost savings	16.4	12.9	10.3	5.0	11.4	8.4	10.1	3.7	13.9	10.9	12.9	9.0
Percent return to investment[a]	17.1	27.5	24.5	5.9	38.2	17.4	22.5	3.8	25.4	36.1	36.1	15.1
Percent fuel savings	40.8	21.2	20.8	20.8	17.2	17.2	21.0	21.0	24.3	16.5	20.0	20.0

[a] Return to investment and IRR, though not the same, are considered equivalent for comparison purposes.

implement the collector system. However, when inflation effects are included into the evaluation method, the estimated cost savings is 10.1 percent for the entire life of the collector.

Ignoring inflation could therefore lead to the selection of a less profitable collector (i.e., as in 5 X SO and 8 X SO) or its underestimation of returns may lead to nonimplementation when the implementation of the solar collector would be desirable.

CHAPTER IV. CONCLUSIONS AND SUMMARY

Conclusions

Solar energy is an economically viable alternative in meeting the heating needs of Iowa swine producers. A solar collection system can reduce the heat costs by 10 to 16 percent over the economic life of the collector. The collectors should recover their initial investment costs relatively quickly while providing a large return to investment.

The one-cover covered plate proved to be the best collector type for swine systems with facilities idle part of the year or systems with slatted floors where surplus heat could be used via duct work. They also proved to be the best collectors when inflation was not accounted for. In systems requiring large amounts of heat, the two-cover suspended plate with storage was the better collector choice. The two-cover suspended plate with storage was also a viable alternative for a system that continually uses the facilities (i.e., no idle time), even when the heating requirements were not great.

The addition of a second cover to the one-cover covered plate proved not to be economical. While it did increase the efficiency of the collector, it tended to decrease the returns to the collector. Generally, the NPV, IRR and cost savings were greater for the one-cover covered plate when compared to the two-cover covered plate. The main reason for this is probably because the additional cover was greenhouse grade fiberglass which is more expensive than a polyethylene film. However, part of the reason is also because the one-cover covered plate was able to meet daytime heating requirements.

Generally, it was more beneficial to increase the size of the collector than to improve its efficiency. This is because the next size one-cover covered plate often had a higher NPV value or IRR value than the same size two-cover covered plate or two-cover suspended plate with storage. It was also more beneficial to increase the size of the farrowing unit collector and duct the surplus heat to the nursery than to use a collector on the nursery for the slatted floor systems.

The addition of storage to the collector system, while reducing the need for purchased fuel, generally did not decrease the cost of heating by any more than the one-cover covered plate did.

The inclusion of inflation in the investment analysis did not significantly vary the selection from the optimal collector types. Only the optimal collectors for the solid floor farrowing unit only and continuous farrowing with nursery systems (5 X SO and 8 X SO) had different optimal collectors under the no inflation evaluation as compared to the inflation evaluations.

The fact that two of the six swine systems had different optimal collectors under the inflation and no inflation evaluations gives credence to the argument that inflation expectations should be taken into account in investment decision making. Especially since the method using an inflation factor chose the more expensive, more efficient collector compared to the cheaper, less efficient collector that was optimal when no inflation factor was considered. The exclusion of the inflation factor would have led to the selection of collectors providing fewer returns for the entire period for the 5 X SO and 8 X SO systems.

The inclusion of inflation should provide for a more accurate estimate of the reduction in heating costs and the rate of return to an investment. The exclusion of inflation would underestimate both of these, possibly leading to erroneous conclusions. Underestimating the returns to an investment may make the investment undesirable, when in fact it could be very beneficial.

There is a margin of error built into the procedures needed in this study that could have an impact on the optimal collector selection. The rates of inflation used, the use of average monthly temperatures, and the use of the 21 percent and 50 percent estimates of maximum building heat requirements that can be provided by solar collectors all provide a measurement of error. However, the selection of the optimal collector should not vary significantly given the degree of difference there was between the optimal collector and the next best collector. Therefore the margin of error should have no effect on the optimal selection, unless this margin of error is greater than expected.

Summary

The purpose of this study was to do an economic evaluation of solar energy collection with regard to Iowa swine production. The evaluation was done under the assumption of multi-inflationary pressures on the economy, where the price of purchased fuels is increasing more rapidly than prices in general. Liquid petroleum gas (LP gas) was used as equivalent units in determining the value of the heat collected by the solar systems. LP gas was used because, to the majority of swine producers, it represents the cheapest, most readily available form of purchased fuel in heating swine facilities.

The collector system evaluated was a simple south-wall collector based on Kansas State University's design. Three types of collectors were evaluated: a one-cover covered plate, a two-cover covered plate, and a two-cover suspended plate with storage. Only solar energy used to preheat ventilation was evaluated.

The one-cover covered plate and two-cover covered plate could only supply heat during the daytime hours. The daytime heating requirements were estimated to be about 21 percent of the total heating requirements. The two-cover suspended plate with storage was assumed to be able to supply heat for a longer period of time, with a two-hour lag time between maximum heat collection and maximum heat release from storage. The two-cover suspended plate was assumed to be able to meet up to 50 percent of the total heating requirements.

The collectors were evaluated under six different swine systems. The swine systems included systems in which the weaned pigs remained in the farrowing unit and systems with separate farrowing and nursery units. Under the farrowing unit with nursery systems, two sizes of operations were used. One called for the facilities to be empty part of the winter while the other called for continuous use. Both slatted floors and solid floors were examined in the study.

The facilities were assumed to be totally confined units and in excellent condition. They were assumed to be well-insulated.

The evaluation of the collectors was done under five methods: net present value, internal rate of return, payback period, percent heating cost savings, and percent purchased fuel savings. The optimal collectors were assumed to be the collectors providing the highest percent heating cost savings while still meeting the acceptance criteria of the other methods.

While the majority of the study was an evaluation including inflation, a linear programming minimization model was run to select the optimal heating cost savings collectors without inflation considerations for comparison purposes. Both methods selected the same collectors as optimal for all but two of the swine systems. The two systems with differing optimal collectors had large heating requirements.

The optimal collectors for all but the solid floor farrowing unit only (5 X SO) and solid floor continuous farrowing with nursery (8 X SO) systems were the one-cover covered plate collectors. For the 5 X SO and 8 X SO systems, the two-cover suspended plate with storage was optimal. The two-cover suspended plate with storage would also be beneficial to a system continuously using the facilities, even when heating requirements are not great.

Generally, it was more beneficial to increase the size of the collector than to improve its efficiency. The addition of a second cover to the one-cover covered plate, while increasing the efficiency, tended to decrease the returns to the collector. The addition of energy storage decreased the need for purchased fuel, but did so without increasing returns to the collector. Generally, the net present value and the internal rate of return were higher for the next size larger one-cover covered plate collector than for the more efficient same sized collector.

Solar energy proved to be a viable alternative for reducing the purchased fuel requirements of Iowa swine producers. It is not necessary to have a complex solar energy collection system for solar heat to work. A simple south-wall collector used to preheat ventilation air can reduce purchased fuel requirements by up to 21 percent. The addition of storage can reduce purchased fuel requirements by up to 50 percent, but does little in reducing the costs further.

Since the heating requirements were assumed to be minimized and to be maintainable at low levels, swine systems with higher heating requirements would find it even more beneficial to adopt solar energy technology. Also, since the returns to the collectors were based on an average winter, a colder than normal winter would increase the returns to the collector. Conversely, a milder than normal winter would decrease the returns to the collector.

Generally, an eight-foot high collector 30 to 40 feet long was best suited for slatted floor systems, systems where the facilities set idle part of the winter, and systems where ducting surplus heat was not possible. An eight-foot high collector fifty feet long was best suited for solid floor systems in continuous use and systems where ducting surplus heat was possible.

This study only looked at the economic feasibility of a simple south-wall solar collection system used to preheat ventilation air in swine production. More work needs to be done on the feasibility of using more complex systems and on using solar energy in other livestock enterprises. Further work should put emphasis on the feasibility of using other sources of energy to replace conventional energy sources. The majority of this work was based on theoretical data, so refinement may be needed as experimental data is accumulated.

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APPENDIX A

The issue of taxes and their effect were not dealt with in the study. It was felt that the feasibility of solar collection should be evaluated in the absence of special tax considerations. Therefore, the tax issue was separated out. However, this area should not be overlooked, for it may have an impact on the economic desirability of adopting solar energy technology. Since solar energy proved to be economically feasible, the special tax considerations will be discussed only briefly.

The Energy Act of 1978 provides up to a 10 percent investment credit for "alternative energy property."[1] Six types of energy property are listed as qualifying, of which solar-wind energy property is one. Solar-wind energy property is defined as any equipment which uses solar or wind energy to generate electricity or to heat or cool or provide hot water for a structure.

This 10 percent maximum energy investment credit is in addition to the regular investment credit. To qualify for the 10 percent energy credit, the alternative energy property must be new depreciable property with a minimum useful life of three years. The credit can be used to offset 100 percent of the tax liability. The credit is allowed until December 31, 1983.

Since the collectors used in the study were assumed to be capital assets with an economic life of 15 years, they would qualify for the

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[1] Section 301, Energy Act of 1978.

full 10 percent energy investment credit. They would also qualify for a 10 percent regular investment credit. Since the investment credit can be used to offset 100 percent of tax liability, it in essence reduces the cost of installing a solar collector system by 20 percent.

Applying this 20 percent investment credit to all the collectors evaluated in the study should not significantly change the results. It would, however, make the more expensive two-cover suspended plate with storage more economically desirable, but probably not enough to cause a change in the optimal collector selection. The exception to this may be the 8 X SO nursery and the 8 X SL system where the two-cover suspended plate with storage was economically viable, but not the optimal collector choice.

APPENDIX B

Materials list[1]

	Quantity per collector		
	214 ft^2	289 ft^2	361 ft^2
Wood			
2" X 4" studs (8' long)	18	24	30
1/2" plywood (4' X 8' sheets)	3	4	5
2" X 4" redwood (board feet)	20	27	34
1" X 2" pine (8' long)	15	20	25
Paint			
Flat black (gallons)	2	2	2
White (gallons)	1	1	1
Screws and bolts			
3" #10 flatheads (100/box)	1	1	2
1 1/2" #10 flatheads (100/box)	3	4	5
1/2" bolt and nut (12" long)	7	9	11
2" X 1" angle iron brace	64	84	104
Greenhouse grade fiberglass (ft^2)	240	320	400
Polyethylene film (8' X 100' roll)	1	1	1
8 penny galvanized nails (lb)	3	3	3
Concrete (for storage of energy)			
Block (8" X 8" X 16"	540	720	900
Ready mix 3000 psi (yd^3)	1	1	1 1/4

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[1] Based on Kansas State University's experimental collector.

Material price list[1]

Wood	
2" X 4" studs (8' long)	$ 2.70
1/2" plywood (4' X 8' sheets)	14.00
2" X 4" redwood (board feet)	1.25
1" X 2" furring strips (8')	.55
1" X 2" pine (8')	1.20
Paint (gallon)	15.00
Screws and bolts	
3" #10 flatheads (100/box)	6.85
1 1/2" #10 flatheads (100/box)	3.00
1/2" bolt and nut (12" long)	1.55
2" X 1" angle iron brace	.35
Polyethylene film (8' X 100' roll)	15.75
Greenhouse grade fiberglass (ft^2)	.80
8 penny galvanized nails (lb)	.65
Concrete	
Block (8" X 8" X 16")	.80
Ready Mix--3000 psi (yd^3)	41.50
Small-load charge	15.00

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[1] Prices quoted by local suppliers, March 1980.