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Sizing Solar Systems for Agriculture

Richard E. Phillips
Department of Agricultural Engineering
College of Agriculture

Current research data indicate that active solar systems are not economical for livestock facilities if initial cost and heat production are the major considerations. But other economic factors, such as investment credit and tax incentives, may make systems feasible for some operations.

The successful solar system requires attention to design and construction. Failure to comply fully with accepted practice will result in poor system performance or failure.

At the present time, three general uses of solar energy are feasible in livestock production.

1. Preheating ventilation air.
2. Supplementing water heating in floor heating systems.
3. Preheating water used for cleaning facilities or mixing feed.

General procedures for system design.

- Determine energy needs.
- Estimate collectable solar energy.
- Size the solar system.
- Adjust size as necessary to achieve better energy use or minimum cost.

Available Solar Energy

The intensity of solar energy or solar radiation decreases as the distance from the sun increases. The sun is not at the center of the earth's orbit, so the earth's distance from the sun varies during the year, as does the intensity of the radiation reaching the earth. The average value, called the *solar constant,* for solar radiation reaching the outside of the earth's atmosphere is about 430 Btu per hour per square foot. The actual amount of solar energy available to collectors on the earth's surface depends on the time of day, the time of year, latitude, the collector tilt angle, and weather conditions.

Clear day values for solar radiation at any location can be calculated using procedures outlined by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). A more useful value for design, though, is the long-term average values taken from weather bureau records. These values take into account normal weather patterns as well as anticipated reflected radiation from surface snow cover. Values for Columbia, Missouri, are tabulated and illustrated in Figure 1 and Table 1.

These values are acceptable for use in system design throughout the state of Missouri.

Ventilation Preheat

Systems, which partially warm outside air before it enters the livestock housing area, are effective in moduating daily temperature extremes and can offset some of the need for supplemental heat. These systems are most adaptable to swine farrowing and nursery buildings and to poultry brooding units. Proper use of thermal insulation can maintain desired temperatures in buildings designed for housing mature animals or for finishing.

Ventilation preheat systems are most effective when installed with some type of thermal storage. Most systems can be expected to provide an energy equivalent to about 2 gallons of LP gas per square foot of collector per year.

Analyzing your heat needs. An effective way to analyze heating needs for a building is to determine the requirements per degree of temperature difference between the inside and outside.

To calculate the conductive loss, $\mathbf{Q_c = \frac{A}{R.}}$

$\mathbf{Q_c}$ = Heat loss in Btu per hour
A = Area of component
R = R-value of component*

*"R" stands for resistance and is a measure of a given material's ability to resist the flow of heat. "R" value is an additive property—2 inches will have twice the resistance of 1 inch, and total "R" will be the sum of existing insulation "R" and the "R" value of the building material in the particular section.

Table 1. Solar radiation expected at the collector surface located in Missouri.

Month	Horizontal (0°)	4/12 (18°)	Latitude (39°)	Lat. + 15° (54°)	Vertical (90°)
	Columbia, MO (39.0° North Latitude) Collector tilt angle				
	Average total daily radiation, Btu/day-ft^2				
January	651	912	1124	1210	1153
February	941	1209	1402	1459	1288
March	1316	1536	1644	1624	1252
April	1631	1729	1689	1563	988
May	2000	1993	1829	1612	873
June	2129	2053	1820	1563	788
July	2149	2084	1857	1599	807
August	1953	1981	1846	1645	914
September	1690	1857	1869	1762	1158
October	1203	1455	1597	1598	1256
November	840	1126	1337	1405	1249
December	590	839	1039	1119	1056

Besides wall, ceiling, window, and door components, also evaluate conductive heat loss for slab edges. Multiply the length of the slab edge (perimeter) in feet times a factor based on whether or not there is edge insulation. The factors are .83 for uninsulated slabs and .45 for slabs with edge insulation.

When calculating the ventilation heat loss, the energy required to warm ventilation air per degree of temperature difference is $Q_v = 1.1V$.

Q_v = heat loss in Btu per hour
V = ventilation rate in cubic feet per minute (use minimum rate).

Example. Calculate the heat loss for a 20-sow farrowing house ventilated a minimum rate of 20 cubic feet per minute per sow. The building is 24 x 60 x 8 feet and is insulated with R = 24 in ceiling and R = 13 in sidewall. There are two exterior doors with R = 2.5, and the perimeter slab is insulated.

Conductive loss:

Wall

$$\frac{2(8 \times 24 + 8 \times 60)}{13} = 103$$

Ceiling

$$\frac{24 \times 60}{24} = 60$$

Doors

$$\frac{42}{2.5} = 17$$

Perimeter

$$2(24 + 60) \times .45 = 76$$

Conductive total ***256***

Ventilation loss:

$$20 \times 20 \times 1.1 = 440$$

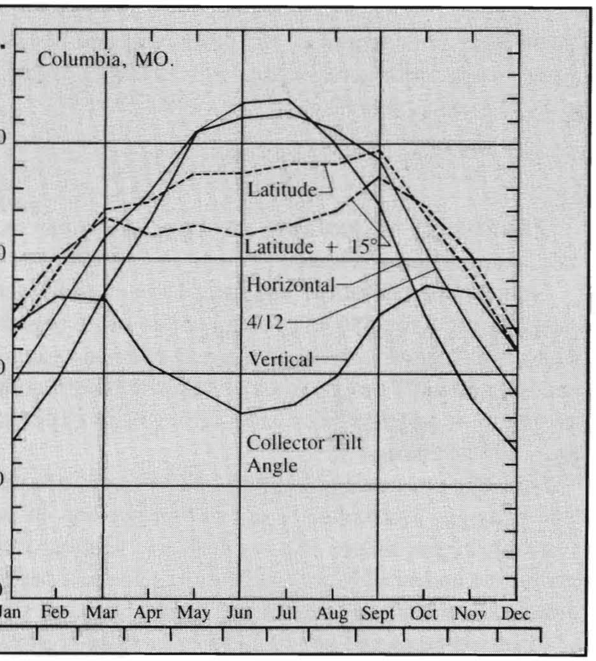
Building total ***696 Btu per hour***

Once you have determined heat loss per degree of

Table 2. Expected average outside temperatures for Missouri locations.

Month	Columbia	Kansas City	St. Joseph	St. Louis	Springfield
January	30	32	27	32	34
February	34	36	31	35	37
March	42	43	40	42	44
April	55	55	54	57	57
May	64	65	65	66	65
June	73	74	74	75	74
July	77	79	78	79	78
August	76	77	77	77	77
September	68	69	68	70	69
October	57	58	56	57	58
November	43	45	41	44	45
December	34	36	31	35	37

Figure 1.



temperature difference, you are in a position to evaluate total energy needs for the building. (See Tables 2 and 3.)

Total need = (Building total per degrees temperature difference x temperature difference) - animal heat production.

Because sensible heat production (see Table 3) varies throughout the day (normally, it's highest during daylight hours when outside temperature is highest), you need to apply an adjustment factor to average production in order to arrive at values for total heat needed, so the results are more nearly in line with actual performance. Use an adjustment of .50.

Example. Calculate the required daily supplemental heat for the farrowing house in our example. It is located in St. Joseph and is operated at a temperature of 60°F. Find heat needs for all months when it is required.

The general equation will be $\mathbf{Q_{tot} = ((696 \times (60 - T_o)) - .5\, Q_s) \times 24}$.

$\mathbf{T_o}$ = Average outside temperature (Table 2)
$\mathbf{Q_s}$ = Sensible heat production (Table 3)
= 20 x 600 = 12,000 Btu per hour
24 = Hours per day

Setting up a table sometimes helps in the analysis. (See Table 4).

Table 4. Sample analysis.

Month	Temperture difference	Btu per day
January	60 - 27	407,200
February	60 - 31	340,400
March	60 - 40	190,000
November	60 - 41	173,400
December	60 - 31	340,400

Estimating collectable solar energy. Table 1 tells how much energy you might expect to strike a solar collector. It does not tell how much it will capture. Collector efficiency and orientation gives us these values.

Since ventilation preheat has highest demands during winter, a vertically oriented collector is frequently selected. Ventilation preheat units generally operate at efficiencies of .40 to .50 when equipped with some type of storage. An efficiency of .45 and a vertical orientation result in the following estimates of solar availability for those months:

January	1153 x .45 =	518 Btu per ft^2
February	1288 x .45 =	579 Btu per ft^2
March	1252 x .45 =	563 Btu per ft^2
November	1249 x .45 =	562 Btu per ft^2
December	1046 x .45 =	470 Btu per ft^2

If you wanted to try a different orientation or year-round collection, you could make similar calculations.

Sizing the collector system. Two general procedures are used to determine an initial size for the collector. The first involves the physical constraints of the facility. For example, if a vertical sidewall collector is chosen, the practical size

Table 3. Sensible heat production for farm animals.

Species and size	Btu per hour
Dairy	
Adult per 1000 lbs.	2900
6 to 12-month calf	675
Poultry	
10 to 20-lbs. turkey per lb.	3.5
5-week-old broiler per lb.	7.5
Mature hen per lb.	3.2
Sheep	
Adult with fleece per lb.	2.0
Adult without fleece per lb.	3.8
Swine	
Sow and litter	600
50-lb. pig	620
100-lb. pig	310
150-lb. pig	400
200-lb. pig	460
250-lb. pig	520

Table 5. Heat supplied and energy needs in Btu.

Month	Daily heat needs	Heat supplied by collectors		
		1 ft^2	302 ft^2	480 ft^2
January	407,200	518	156,400	248,600
February	340,400	579	174,900	277,900
March	190,000	563	170,000	270,200
April		444	134,000	213,100
May		392	118,400	188,200
June		354	106,900	169,900
July		363	109,600	174,200
August		411	124,100	197,300
September		521	157,300	250,100
October		565	170,630	271,200
November	173,400	562	169,700	269,800
December	340,400	470	141,900	225,600

will be limited by the available south-facing wall area. It turns out that this is a fairly accurate estimate of size for ventilation preheat.

The second method involves the use of some proportaion of need during a particular month. Typically, December or January are chosen and the percentage value of 40 to 50 is used. Higher percentage values result in large amounts of unusable heat being collected during spring and fall months.

Use a percentage of 50 and apply it to the December needs for the farrowing house.

Solar Need = .50 x 340,400 = 170,200 Btu per day.

A vertical collector can be expected to supply 562 Btu/ft^2. Thus, **size = 170,200/562 = 302 square foot collector.**

Using energy. Collector size may be adjusted upward or downward depending on the designer's concept of how much energy is used versus how much energy is wasted during warmer parts of the year. Estimate this by plotting energy needs for the building and potential energy supplied by the solar system. (See Figure 2.)

Example. Use the 20-sow farrowing house and two sizes of collectors. One will be 302 feet squared as already determined. The other will be the entire south wall or 8 x 60 = 480 feet squared. See Table 5 for this data.

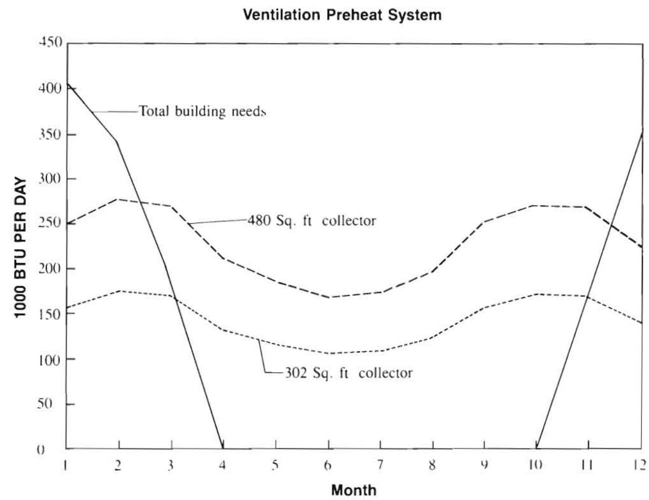


Figure 2. Heat required by example farrowing house versus heat supplied by two different sized solar collector walls.

Supplemental Heating of Water

Solar-heated water can be used to supplement conventional water heaters or boilers used to provide creep heat. The most commonly used system uses the solar collector to heat a water storage tank (about 3 gallons of water storage per square foot of collector). Whenever storage temperature is above the desired water circulation temperature, water is drawn from storage and circulated through the heating loop. If storage temperatures are below desired levels, the storage is bypassed and the conventional heater takes over.

Because these solar systems operate at temperatures considerably above outside air temperatures, they generally have lower collection efficiency. Values of .2 to .25 appear to be good for design purposes.

Determining heat needs. Most floor slabs are designed for operation at surface temperatures of 95 degrees F. According to ASHRAE, heat transfer upward from a horizontal-heated surface can be calculated by multiplying the temperature difference between floor and room by 1.63 to obtain heat loss in Btu per hour per feet squared of surface.

In actual practice, animals will be lying on some portion of the floor area, and this will reduce heat loss. If you assume 60 percent of the heated space as unoccupied, you will have reasonable heat loss values.

During winter months, inside temperature can be used for the calculation. During warmer months, use average outside temperatures as the room temperature value.

Example. The 20-sow farrowing house has 40 creep areas, each of which are 18 x 60 inches or 7.5 square feet. Determine the daily heat needs for each month of the year.

Daily Btu = **40 x 7.5 ft^2 x .6 use x 24 hours x temperature difference**
= **4320 x temperature difference.**

See Table 5 for creep heat needs.

Table 6. Creep heat needs.

Month	Temperature difference	Btu per day
January	95-60	151,200
February	95-60	151,200
March	95-60	151,200
April	95-60	151,200
May	95-65	129,600
June	95-74	90,700
July	95-78	73,400
August	95-77	77,700
September	95-68	116,600
October	95-60	151,200
November	95-60	151,200
December	95-60	151,200

Estimating collectable solar energy. See same section under **Ventilation Preheat.**

The desirable tilt angle for year-around use is approximately equal to latitude + 15 degrees. Using these values and an expected year-around efficiency of .20, you will obtain the following expectations for the sample water collector. See Table 7.

Table 7. Expected output from water collector tilted at latitude +15° - Missouri (Efficiency = .20).

Month	Btu Per Day
January	242
February	290
March	325
April	310
May	320
June	310
July	320
August	330
September	350
October	320
November	280
December	220

Sizing the collector system. Physical constraints of the facility may also limit the collector size with these systems. However, this is not usually the case, and systems are sized based on a percentage of heat supplied. Start by using a value of 50 percent of December needs.

Example. Size $= \frac{151{,}200 \times .50}{200} =$ 343 square feet.

Most agricultural collectors come in 40-square foot modules; thus, you would select nine units or a total of 360 square feet.

Using energy. See the same section under **Ventilation Preheat.** Table 8 shows the tabulation for the 360=square foot collector.

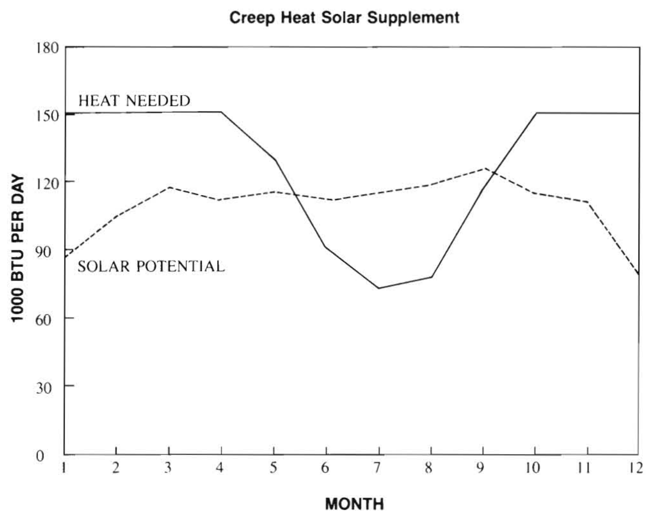


Figure 3. Heat required for example creep area versus heat supplied by 360 square foot collector.

Domestic or Service Water Heating

Water-based collectors can be effectively used to heat or preheat water for residential use, equipment cleanup, or mixing of liquid feeds. Although it is possible to heat water to normal service temperature (140 degrees F) with a solar

Table 8. Energy use for the 360 square foot collector.

Month	Creep heat needed BTU per day	Solar potential BTU per day
January	151,200	87,120
February	151,200	104,400
March	151,200	117,000
April	151,200	111,600
May	129,600	115,200
June	90,700	111,600
July	73,400	115,200
August	77,700	118,800
September	116,600	126,000
October	151,200	115,200
November	151,200	100,800
December	151,200	79,200