SOLAR HEATING OF ON-FARM LIVESTOCK STRUCTURES

Demonstration Project

Final Report

Sponsored by:

Cooperative Extension Service
University of Nebraska-Lincoln

Department of Agricultural Engineering

with assistance from:

Department of Animal Science

Department of Agricultural Economics

in cooperation with:

United States Department of Agriculture
and
United States Department of Energy

cooperating farmers:

Alvin Paus and Sons	Logan Valley Swine
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Craig Buescher	Galen Stevens
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Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Leo E. Lucas, Director of Cooperative Extension Service, University of Nebraska, Institute of Agriculture and Natural Resources.

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PROJECT OVERVIEW

This project was one of nine sponsored by the U.S. Department of Agriculture (U.S. Department of Energy pass-thru monies) to demonstrate the technical and economical potential of utilizing solar energy to reduce dependence on fossil fuels for operation of livestock production facilities. The University of Nebraska project was directed by faculty members in the Department of Agricultural Engineering having appointments with the Nebraska Cooperative Extension Service.

Cooperators were selected based on their willingness to work with the University of Nebraska. In each case the cooperator also had to be willing and able to make a financial commitment in a solar system the performance of which, for the most part, was unproven under commercial farm operation and management regimes.

The University of Nebraska, Cooperative Extension Service and Department of Agricultural Engineering are deeply indebted to each of the cooperators for his participation in this project. Although some difficulties and problems were encountered, overall the project must be considered a success. Only through unselfish sacrifices and risks by people such as the dedicated cooperators involved in this project can the University of Nebraska Cooperative Extension Service succeed in its educational mission.

PROJECT PHILOSOPHY

The potential benefits of a demonstration project are enhanced by cooperator sites which are widely dispersed geographically. Such an arrangement makes the sites "visible" to more producers, allows evaluation of the several designs under a wider range of climatic conditions and should enhance the image of the sponsoring institution. At the same time widely separated sites severely complicate the management of construction and data collection. These drawbacks of widely scattered sites could in large part be offset if adequate funding were available to allow employment of a full-time individual with freedom from class schedules and other obligations. Other requirements would be a funding level to cover required travel costs and to allow simultaneous monitoring of all sites.

Contractor and/or producer skill and familiarity with construction techniques and solar technology influenced construction cost variations between projects. In two projects (Paus and Stevens) extensive and thorough advance planning minimized construction site decision making and thus labor costs. Having demonstrated that system costs can be controlled, it is likely that as solar construction technology becomes more widespread among farm builders, additional opportunities to control or reduce system costs will become evident.

ECONOMIC FEASIBILITY OF SOLAR LIVESTOCK HEATING

The nature of this project did not lend itself to an accurate measurement of the economic benefits or savings from the investment in solar equipment. Since it was set up as a series of demonstrations, rather than a research project, there were no "control" or "conventional" systems with which to compare the solar systems. Also, gas, electricity and other inputs were generally not metered or measured separately for the solar-heated facilities. Therefore, only simple payoff tests have been calculated. The type of data available were not conducive to a more sophisticated economic analysis.

Since factors such as income tax and interest rates affect the outcome of an evaluation, but were not considered in the payoff tests, an example (See Table 1) is presented to show the impact of these factors. This example is based on an investment in solar equipment of $1,000. The farmer is in a 30 percent marginal tax bracket (state and federal) and the nominal interest rate is 14.3 percent. The investment in solar equipment qualifies for both the 10 percent investment tax credit and the 15 percent business energy tax credit. Under current depreciation guidelines (accelerated cost recovery system) the investment will be depreciated to zero value in five years.

The example in Table 1 shows that the tax savings can reduce the present value of the cost of $1,000 worth of solar equipment to $547.79. How much of a net savings per year would the solar equipment have to yield in order to break-even? Table 2 was calculated using the same interest rate (14.3 percent) and tax bracket (30 percent) as in the example presented in Table 1. It shows savings per year which would be required for the solar equipment to break-even in 5, 10 and 15 years.

The figures in Table 2 can be used as a guideline in evaluating systems where energy cost savings are estimated or collected. For example, a $7,000 investment in solar equipment would need to generate a savings of $623 ($89 x 7) per year in order to yield a pre-tax return of 14.3 percent, or an after-tax return of 10 percent over a 10 year period.

Table 1. Five-year economic analysis of solar equipment investment (example, per $1,000).

Year	Equipment Cost	Depreciation	Tax Savings From Depreciation	Tax Savings From ITC[1]	Tax Savings From BETC[2]	Net Cash Flow	Present[3] Value of Net Cash Flow
0	($1,000)					($1,000)	($1,000)
1		$ 150	$ 45	$100	$150	295	268.18
2		220	66			66	54.55
3		210	63			63	47.33
4		210	63			63	43.03
5		210	63			63	39.12
Total		$1,000	$300			($450)	($547.79)

[1]All of the solar equipment should qualify for the 10 percent investment tax credit. This does not reduce the basis for depreciation under current tax law, although this was changed in the tax law of August, 1982.

[2]This investment should qualify as solar energy property for the business energy tax credit. The rate was 10 percent from 10-1-78 through 12-31-79. It is 15 percent from 1-1-80 through 12-31-85. This credit is taken in addition to the regular investment tax credit.

[3]A pre-tax discount rate of 14.3 percent was assumed. Given the marginal tax bracket of 30 percent, an after-tax discount rate of 10 percent was used to discount the cash flows to their present value.

Table 2. Net annual savings required to break-even on solar investment (example, per $1,000).

Years	Required Net Savings Per Year
5	$145
10	89
15	72

SOLAR HEAT STORAGE

Use of solar heat storage in all of the solar collector systems was beneficial, except in the case of the grain drying mode of operation of the one vertical solar wall (Lay, NE-2). Storage of excess daytime solar heat allowed that heat to be released at night, when the heat was required because of lower outdoor ambient temperatures. The vertical solar walls provided the majority of their heat, and benefits to the livestock buildings, at night. The Solar MOF Nursery IFHDS systems effectively stored the excess daytime solar heat and moderated the floor temperatures to provide almost all of the heat required by the nurseries under normal operating conditions.

In development of solar collector system designs for the various systems, an effort was made to devise techniques to achieve the generally recommended storage mass and airflow rate to collector area ratios. Specifically, the goal was designs which would provide 2 ft^3 of thermal storage mass (standard density concrete, or equivalent) and an airflow rate of 2 cfm per ft^2 of collector. Although these specific goals were realized to varying degrees in the various systems designed and installed, the necessity of thermal storage as part of a system has been clearly demonstrated.

DATA COLLECTION AND ANALYSIS

Campbell Scientific CR5 Digital Recorders were used to monitor temperature and solar radiation data at the various sites. Cooper-constantan thermocouples at each site were wired to bus bars in junction boxes. Wires ran from these bus bars to 24 point TRW cinch plugs in the side of the junction boxes. Wires from the input terminals of the S250 50-channel scanner in the CR5 digital recorder connected these terminals to 24 point TRW cinch plugs mounted in the side of the Campbell recorders. Twelve-pair connector cables with a 24 point TRW cinch plug on each end served as extension/connection cords between the Campbell digital recorder and the junction boxes. This was our method of achieving mobility of the data loggers, since insufficient funds were made available to provide a data logger at each site.

Solar radiation levels were measured with Eppley Black-and-White Model 8-48 Pyranometers. These pyranometers were connected to A101MV millivolt integrator modules in the Campbell digital recorders. The pyranometers were not moved from site to site but were kept at the Solar MOF Nursery sites (Projects NE-1 and NE-10) since this system is unique to the Nebraska contribution towards this project.

Hourly recordings of the temperatures and solar radiation were placed on Scotch 835/2 Certified Digital Cassettes by the Campbell R235 CR5/Cassette Interface module. Once every two to four weeks, the tapes were changed and data were entered into the IBM 370 computer at the University of Nebraska with a Campbell A235 Cassette/Terminal Interface.

Two accessory items we found desirable with the Campbell digital recorders were a printer disabling switch and a powered take-up roll. The printer disabling switch allows disconnection of the printer module when data are being recorded on cassette tapes but allows personnel (either farm management or University) to easily spot-check all data points. The powered paper take-up roll prevented the fan-folded paper for the printer from being caught in and jamming the printer.

PROBLEMS

Several methods were used in an effort to determine airflow for mass flowrates through the solar collector systems. Static pressure differences were so low as to be negligible, except for the Solar MOF Nursery active solar collector systems. Air velocities were so low (less than 200 fpm) that hot wire anemometer readings were not precise. Vane anemometer readings at the outlet of the ventilation fans did not give satisfactory measurements of airflow through the vertical solar walls. Other, permanently mounted and recording airflow measuring devices such as a Thomas-meter were too expensive and time consuming to fit within budget and time constraints of the project. Consequently, mass flowrate and collected heat calculations were based on estimates of the airflow rate through the solar collector systems. To the extent possible, mass flowrate data were also based on manufacturer's fan performance data. However, the use of fans not subjected to AMCA testing makes the accuracy of these data questionable. Overall accuracy of airflow estimates could easily vary by ±30 to 50 percent. Thus, care must be exercised in use of performance data.

Lack of adequate budgeting for the projects resulted in having fewer data loggers than project sites. This prevented simultaneous data monitoring for all systems and prevented accurate comparisons between systems.

High interest rates and low hog prices at the beginning of the project resulted in several of our initial cooperators being unable to continue cooperation because of the cash-flow problems associated with installation of the solar collector systems. This forced us to locate other cooperators and delayed the system design and construction phase of the project. Lack of economic feasibility led to a decision by all dairy and poultry producers to stop consideration of solar heating systems for their production facilities. These problems resulted in a high turn-over of project cooperators, and increased design time and cost, as well as a delay in construction of some systems. Time constraints for the project did not allow collection of data for two heating seasons on many of these systems.

Cooperators themselves caused a few problems. One cooperator changed his mind regarding system design so frequently that he became dissatisfied with project personnel's inability to effectively meet all the changing design criteria. This cooperator was subsequently dropped from the project because of his dissatisfaction. Another cooperator had so many "irons in the fire" that he was unable to provide the management and labor required for his solar heated livestock building. In this instance the result was a total lack of operational data from that solar collector system.

Although an effort was made to "bridge the gap" between the Cooperative Extension Service and engineers engaged in consulting practices, a lack of solar system design expertise on the part of the consultants soon became evident in time delays and project cost over-runs. Several cooperators found it difficult to communicate with the consultants. The overall result was this aspect of the project became an unpleasant experience for nearly everyone involved.

SUGGESTIONS

In many cases knowing more about less is better than knowing less about more. With the same level of funding each state could have been asked to provide information on four or five sites instead of ten. This would have allowed better instrumentation, simultaneous and continuous data collection--except for the ever-present system malfunctions--and much more confidence in the accuracy of the data produced. While this may seem on the surface to be more in the line of research than demonstration we feel the overall results of the project would have been more beneficial and rewarding.

The formal agreement between the sponsoring university and the cooperator is a good start at ensuring cooperation. Choosing of cooperators may need to be a careful selection process. In some instances county Extension agents might have sufficient familiarity with their producers to enable them to recommend farmers interested in the program, limiting recommendations to those believed to have the financial means and management skills to fulfill the cooperator's part of the program. The prospective cooperator and project manager or project team members then need to visit to assure that all personnel involved in the project are aware of the problems the farmer wishes to solve by cooperation in the project. The potential cooperator must also be made aware of his obligations to the project success. The project manager can then suggest solutions and determine the farmer's response to those suggestions. A visit by the project manager and/or project team members to each prospective cooperator's farm would be helpful for the project manager to assess the cooperator's management, labor and economic capabilities. It might be helpful for project personnel to visit with the prospective cooperator's banker to allow input from the banker regarding the financial capabilities of the farmer and his bank. The cooperators can then be chosen from the list of prospective cooperators. However, our experience suggests that even such thorough and complete screening procedures cannot guarantee success in the selection process. Problems such as animal or producer health, abrupt changes in market prices and similar events all comprise over-riding uncontrollable circumstances.

PROJECT UTILIZATION

1) Plan No. NE 10.726-37 was prepared from the successful Solar MOF Nursery (Projects NE-1 and NE-10). Over 300 copies of this plan have been sold. At least three of the nurseries are operating in Nebraska. Solar MOF Nurseries have also been built in eight other states in the USA. Pork producers in China and Korea are planning to construct Solar MOF Nurseries in their countries.

2) A 1:20 scale model of the Solar MOF Nursery has been built and used for displays at pork producer meetings, field days and fairs. The model visually depicts the Solar MOF Nursery and the features of the design.

3) A 1:20 scale model of a farrowing house with farrowing pens (Project NE-2) and crates (Project NE-5) with the slant solar wall and water heating option (Project NE-5) was constructed. This model also has been used at pork producer meetings, field days and fairs in the state.

4) Much of the design and performance knowledge gained from this project by University of Nebraska agricultural engineers was used in design of solar heated swine facilities (80 sow farrow-to-finish) at the University of Nebraska's Energy Integrated Farm Extension Demonstration Project. Aspects from the Solar MOF Nursery and vertical solar walls have been included and are on display. The "Energy Farm" is located at the University's Field Lab near Mead, NE.

5) Drafts of NebGuides (four page informational pamphlets for state-wide distribution) on Solar Collectors and the Nebraska Solar MOF Nursery are in final stages of review and preparation.

6) Three slide tape sets are being planned. Topics addressed will be: 1) Solar MOF Nursery; 2) vertical solar wall; and 3) overall demonstration project.

7) Knowledge gained from the project was included in an in-service training program for county Extension agents on the topic of solar energy for agriculture. Phase I final reports were given to the training session participants. A tour of four project sites was also part of the session.

8) Various installations associated with this project have been featured in at least six state and/or national swine trade and solar magazines.

9) A number of technical papers and articles have been prepared in which one or more of the demonstration project systems has been discussed. Papers prepared and presented are:

   a) Bodman, G.R., J.A. DeShazer, M.F. Kocher and J.A. Lamb. 1980. In-floor storage of solar heat. Technical Paper No. 80-4514. American Society of Agricultural Engineers, St. Joseph, MI.

   b) Bodman, G.R., J.A. DeShazer, M.F. Kocher and D.D. Schulte. 1981. Concrete floors for storage and distribution of solar heat. In Modelling, Design and Evaluation of Agricultural Buildings, Proceedings of CIGR Section II Seminar, Aberdeen, Scotland.

   c) Bodman, G.R., M.F. Kocher, J.A. DeShazer and J.A. Lamb. 1982. In-floor solar heat for swine nurseries. In Livestock Environment II, Proceedings of the Second International Livestock Environment Symposium, American Society of Agricultural Engineers, St. Joseph, MI.

d) Bodman, G.R. 1982. Swine nursery design--challenges and opportunities. In Proceedings George A. Young and Twenty-Second Annual Nebraska SPF Conference, University of Nebraska--Lincoln.

e) Kocher, M.F., G.R. Bodman and M.R. Lay. 1981. Solar grain drying and farrowing house heating with a multi-use collector. Technical Paper No. 81-4554. American Society of Agricultural Engineers, St. Joseph, MI.

f) Kocher, M.F., E.J. Veburg, G.R. Bodman, J.A. DeShazer and D.D. Schulte. 1981. Solar energy and swine confinement operation. 1981 Nebraska Swine Report E.C. 81-219. University of Nebraska-Lincoln.

g) Kocher, M.F. and J.A. DeShazer. Thermal performance of an in-floor solar heat distribution-storage system. (Proposed paper for the 1983 Summer ASAE Meeting. American Society of Agricultural Engineers, St. Joseph, MI).

PROJECT MANAGEMENT

Work on this report was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

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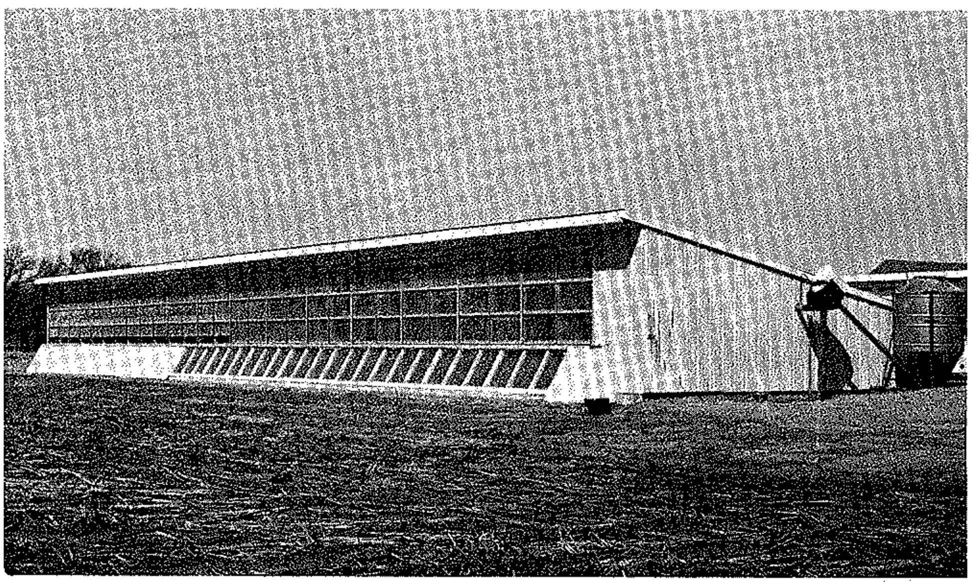
MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Alvin Paus and Sons, Art and Doug
Glenvil, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-1



550-head Solar MOF Nursery building with active/passive solar collector system and in-floor heat.

MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Alvin Paus and Sons
Glenvil, NE

THE FARM

Alvin Paus and his sons, Doug and Art, own and operate the farm with the recent addition of the solar nursery. The farm (40°24'N, 98°11'W) is located in south central Nebraska's Clay County. The farming operation consists of working 880 acres, raising beef cattle and managing a 150-sow farrow-to-finish operation. The young pigs are weaned at about 4 weeks of age (15 lb) and are placed in the nursery until they reach a weight of approximately 60 lbs. At that time they are moved into a modified-open-front (MOF) growing-finishing unit. The Pauses produce approximately 2500 market hogs per year.

The Paus family has cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting, and monitoring this system. This report includes a description of the nursery, a description of the solar collector system and the cost of the system. Some performance results, suggested modifications of the system and details on where to obtain plans for construction of a building similar to this one are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Solar Nursery

The 22-pen, 550-head nursery incorporates several energy conserving features besides the solar heating system. The 23 x 116 ft building has a mono-slope roof, is non-mechanically ventilated and is well insulated (See Table 1 for recommended R values). The solar heating system uses in-floor heat for zone heating--heating the floor of the sleeping area and allowing the warm floor to heat the pig's immediate environment. Insulated hovers are used to help retain heat within the pig's environment. The in-floor heat and insulated hovers are located in the rear 40 percent of each pen. Feeders in the pen partition walls are located in the middle portion of each pen. Manure is removed from the building via an open flush gutter located along the south end of the pens and equipped with a dosing siphon flush tank(See Figure 1).

B. The Solar Collectors

Supplemental heat for the nursery building is supplied by a combination of active and passive solar collectors. The passive collector system consists of 8 x 6 ft windows along the south wall. Solar energy passing through these windows is absorbed by the 3 in. concrete floor which is insulated from the underlying soil. The passive windows are approximately 3 ft above exterior grade level, allowing room for the active collector beneath them.

The single-pass, 3 ft-3 in. x 108 ft active collector is sloped 60 degrees from the horizontal to allow maximum winter solar energy collection. The active collector heats air which travels through the collector, through the heat storage, and returns to the collector in a closed loop arrangement (See Figure 2). The airflow rate through the active collector system is approximately 2.3 cfm per ft^2 of collector.

The In-Floor Heat Distribution-Storage (IFHDS) system for the active collector consists of a layer of concrete blocks laid on edge with the cores aligned to provide air channels along the length of the building (See Figure 3). The heat storage is five 2-core 8 x 8 x 16 in. (nominal) blocks wide with a 7 to 10 in. sand layer above the blocks and a 3 in. concrete floor above the sand. The IFHDS system is insulated to prevent excessive heat loss to the soil below the building. The resultant storage capacity is approximately 2 ft^3 per ft^2 of collector.

C. Non-Mechanical Ventilation

The non-mechanical ventilation system is another energy-saving feature of the nursery. Fall, winter and spring ventilation is achieved through adjustment of the openable passive collector windows and an air outlet near the top of the south wall. Openable panels along the north wall facilitate increasing airflow through the animal space during warm weather. Airflow under all weather conditions is augmented by the 3:12 roof slope.

D. Model

To aid producers in visualizing various components of the system a 1:20 scale model of the facility was constructed. All aspects of the field unit are illustrated in the model. The model has been used extensively at producer meetings, fairs and field days.

COST

The passive and active collector and the IFHDS system added a total cost (materials and labor) of $6,945.92 to the cost of the building. The passive panels cost $2,739.80 for 672 ft^2 or $4.08 per ft^2. The 351 ft^2 of active collector and the IFHDS system cost $4,206.12 or $11.98 per ft^2 of collector. The owner estimates the glazings on the active collector will last 10 years with the remainder of the system lasting 15 to 20 years.

The total cost of the building, including the solar heating system, was $30,000.00. A non-solar MOF nursery would have cost $30,000.00 less the $6,946.00 for the solar heating system. However, additional costs would have included approximately $1,500.00 for a curtain or similar covering for the front opening (where the passive windows are now located) and a minimum of $500.00 for a forced warm air furnace system for a total of $25,054.00. The solar collector system therefore added 16.5 percent to the basic cost of the building. Despite the added cost for the solar collector system, the total cost of the facility at $54.55 per pig was less than two-thirds the cost of a conventional raised deck style nursery at the time of construction.

PERFORMANCE

A. Thermal

The Pauses have been pleased with the performance of the building. Under their expert management, the building has functioned to provide an environment conducive to good performance of young pigs--and has done so at low cost--since the building was occupied in October 1979.

Some aspects of the thermal performance of the solar heated nursery are presented in Table 2. During the months noted, the total quantity of solar heat delivered to the surface of the solar heated floor (top of the IFHDS system) ranged from 1.70×10^6 Btu to 4.09×10^6 Btu with an average of 2.94×10^6 Btu per month. This solar heat, plus the heat from the pigs themselves, kept monthly average air temperatures under the hovers between 73 and 82°F with an average of 77°F.

The thermocouple used to measure the air temperature beneath the hover was under the middle of the hover of the first pen in the building (east end). The smallest pigs were kept in this pen since the air from the collector, having just entered the IFHDS system at this location was hot enough to keep the floor surface temperature between 90 and 95°F most of the time.

The thermocouple used to measure the indoor ambient temperature was in the middle of a pen near the midpoint of the building. This thermocouple was 5 ft above the floor (not in the pig zone). Temperatures at this point (human "eye level") averaged 7F° cooler than temperatures in the pig zone under the hover. This demonstrates the advantage of hovers and in-floor heat in energy savings since the whole building interior need not be heated to the high temperature required by the young pigs. This design reduces conductive heat losses through building surfaces while meeting the thermal needs of the young pigs. The use of hovers over the heated floor, a cooler open feeding area, and a cooler flush gutter area also allowed pigs to choose between three micro-environments to fit their thermal needs.

The total solar heat transferred to the floor surface as presented in Table 2 was calculated on an hourly basis from the temperature loss of the air going through the IFHDS system and a collector system airflow rate based on AMCA certified airflow data at the measured static pressure drop across the fan. Heat losses to the soil around the IFHDS system as calculated from temperature differences in the soil were then subtracted from the heat input to the IFHDS system to determine the quantity of solar heat transferred to the floor surface. The hourly heat transferred to the floor surface was accumulated to obtain the monthly totals. Dividing monthly totals by the number of days in the month and the collector area yielded the average daily heat input to the floor per square foot of collector area. This value divided by the average daily solar insolation incident on the collector yielded the percent of solar energy actually transmitted to the floor surface. This percentage was about 20 percent for normal conditions, with a decrease to about 13 percent in cold weather.

During the first three years of operation solar heat provided 100 percent of the supplemental heating needs of the building except for four weeks during late December 1981 and early January 1982. During this time period heat lamps were used in pens occupied by newly weaned pigs to maintain warm temperatures during the cold cloudy weather (Table 3).

It is not known whether all of the heat supplied by the solar system in the "100 percent solar heated" months was needed. If excess heat was added to the building by the solar heating system it was removed from the building with increased ventilation. With a non-mechanically ventilated building, accurate comparison of the supplied solar heat and heat actually required is not possible.

In February of 1980, the temperature of the air leaving the solar collector regularly peaked at 140°F on sunny days (See Figure 4). The temperature of the air entering the collector during this same time period normally peaked at about 78°F. Outdoor temperatures for the period were between 15 and 50°F. Indoor ambient temperatures during this period were between 45 and 75°F.

Although the indoor ambient temperature fluctuated, the temperature of the floor surface in pen 2, occupied by the smallest pigs, remained nearly constant at about 90°F (See Figure 5). This constant floor temperature reflects the temperature moderating and heat storage effects of the

IFHDS system. The moderating and storing effects can be seen by comparing the relatively constant temperature of the floor surface at 90°F to the periodic temperature pattern of the air passing through the air passageway in the concrete blocks. The air passing through the IFHDS system at this location reached a peak temperature of about 127°F during sunny hours and cooled to about 85°F overnight.

Note that the temperature of the air at the far end of the building (pen 21) just before the air leaves the IFHDS system and returns to the collector does not have a large temperature rise associated with sunny hours. This air has travelled the length of the IFHDS system and has already transferred much of its heat to the storage mass. There is enough heat at this location from the IFHDS system, and from the larger pigs (40-60 lbs) themselves, to keep the environment in this pen warm enough for these larger pigs.

B. Economic

An engineering heat balance was performed for this building. Estimated annual heating costs were $1540 if petroleum-based fuels and conventional whole-building space heating techniques were used. This cost is based on a propane price of $0.56 per gallon. During the heating seasons of '79-'80 and '80-'81 (September thru April) the only supplemental heat added to the building was solar heat. The operational cost of the solar system was equal to the cost of electricity to run the fan in the active collector. This cost came to $10 and $20 for the respective heating seasons. During late December 1981 and early January 1982 low solar insolation levels made it necessary to add heat lamps to the first five pens for newly weaned pigs. The operating costs for these heat lamps over a 30-day period resulted in an increase in unit operating costs for the heating season of '81-'82 to approximately $55. Nearly two-thirds of this operating cost was for electricity used by heat lamps.

Assuming the $1540 per year conventional heating costs and using the $6,945.92 cost for all of the solar components, the simple payback period can be calculated at 4.6 years. This payback period can be reduced to between 3 and 5 years with tax credits, a time-value-of-money approach to calculating the payback period and with current propane prices.

C. Ventilation System

All ventilation openings are manually adjusted. During three years operation this control technique has been found to be both efficient and effective. Automatic controls were determined to be unsatisfactory due to freezing of the panels. Openings are usually adjusted as needed during morning and evening checks of the facility and animals. The manually adjusted openings in combination with the three micro-environments within each pen have served to allow ventilation rates to be varied to meet the needs of various size pigs.

Adjustment of the south wall air inlets (passive solar windows) is accomplished by a hand crank and winch system. Groups of panels along each third of the building can be independently adjusted. The air outlet along the top of the south wall stays open except for extreme winter weather. North wall panels are opened and closed as necessary.

D. Maintenance

The solar heating system does require some maintenance. Dust must be washed off the active collector glazings about once a month, especially when peak solar heating is required (i.e., when a group of newly weaned pigs enters the building). The solar collector fan bearings must be greased and belt tension checked. Glazings must be checked for damage after bad storms or, just generally, about twice per year. The active collector must be covered at the beginning of the summer to prevent overheating the building and the collector. The wood on the exterior of the collector should be kept protected with paint. Joints in the collector system should be inspected occasionally to be sure they are tightly caulked to prevent air leaks. Attempts by rodents to enter the system should be repaired.

E. Problems

Most of the problems encountered in this building were related to data gathering as contrasted to problems with the building. Several pigs escaped from their pen one day and chewed through several thermocouple wires. The thermocouple under the hover was also subjected to pig chewing. From these experiences, it is suggested that thermocouple wiring in places where the pigs might conceivably gain access to the wire should be in conduit, pipe or junction boxes. If the sensing end of a thermocouple must be in a pig zone, run the thermocouple wire down a conduit with holes or slots. This allows airflow over the sensing end without allowing pigs to chew on the wire.

Thermocouples weren't the only things that had problems. Moisture, dust and the generally corrosive atmosphere in the building necessitated removal of the data logger every two or three months for cleaning, calibration checks and repairs. The plugs connecting the thermocouples to the data logger corroded and several connectors had to be replaced after severe errors were identified in the data.

One problem with the active solar collector system, noticed from the data early in the project, was a large temperature drop (30F°) in the solar heated air between the outlet from the collector and the inlet to the IFHDS system. A similar temperature drop was noticed at the other end of the collector, between the outlet from the IFHDS system and the inlet to the collector. These problems occurred during collector operation. Doors in the ends of the collector allowing access to the collector for instrumentation, inspection, etc. were caulked shut to reduce air leaks. This measure reduced the large temperature drop, but did not completely solve the problem. We believe increasing the level of insulation from R 4 to R 15 for all surfaces of the transition boxes between the solar collector and the PVC pipes will reduce the temperature drop at these locations to a reasonable level of about 10F°. Be sure to use a high temperature insulation in these locations.

Other problems noticed from the data were gradual overnight temperature decreases at the active collector inlet and outlet, and at the inlet and outlet of the IFHDS system. These temperature drops occurred overnight, whereas the previously mentioned problem occurred while the collector was operating. These overnight temperature decreases paralleled the outdoor ambient temperature, with the collector outlet temperature between the floor inlet (air passageway, pen 2) and outdoor temperatures (See Figure 6). Additionally the temperatures are higher at the outlet end of the collector than at the inlet end. We believe natural convection currents at each end of the building are set up by the density differences between the warm air at the IFHDS system and the cold air at the collector. The convection currents are causing the temperature decreases in the air at the IFHDS system. To prevent these convection currents and the associated heat loss from the IFHDS system, we recommend placing back-draft dampers at the outlet ends of the PVC pipes. The recommended back-draft dampers are pieces of plastic that can withstand temperatures as high as 200°F without deforming (See Figure 7). A layer of high temperature fiberglass insulation should be attached to the plastic sheet to reduce conductive heat transfer from the air in the IFHDS system to the air in the PVC pipes during these overnight periods.

COMMENTARY

A. Construction Suggestions

1) Plan No. NE 10.726-37 Solar MOF Nursery is available from the University of Nebraska Agricultural Engineering Plan Service for $5.00 and provides information needed to construct one of these buildings. The plan packet includes guidelines regarding construction techniques and materials, solar energy, equipment selection and system management. One specific construction procedure is to completely seal the active collector system against air leaks during construction. Collector performance is highly dependent on having an airtight system. It is much easier to build properly the first time than to repair air leaks. Use only high quality, long-life caulking materials. Clear silicone caulk is recommended.

2) Care should be taken to prevent creasing of the Tedlar® glazing during construction of the active collector. The Tedlar® does not crease easily, but will crease if a heavy object is laid on a fold. The creases are weaknesses in the Tedlar® sheet and tearing might occur as the Tedlar® shrinks in very cold weather.

3) Glazing material for the collector should be chosen to withstand ultraviolet light degradation and to have good solar energy transmission characteristics.

4) Install the fan and back-draft dampers in a manner that allows for servicing and repair. The fan and transition should be placed in an "empty pen" to allow easy access, proper heat delivery to the floor of the first pen with small pigs, and space for equipment storage.

5) Use a high temperature fiberglass insulation board in the active collector behind the absorber plate to prevent "failure" of this insulation. Plastic foam insulations in this location will "melt".

Normal fiberglass insulation in this location will experience decomposition of the organic binder or "glue" holding the fibers together. This decomposing binder will give off a gas that will "cloud" the inside of the glazing and reduce transmittance of solar energy to the absorber plate.

6) Placement of the fan to provide a suction at the collector outlet is recommended. In this arrangement, leaks allow cold air into the collector. Alternately, with the collector under pressure from the fan, a leak near the collector outlet could result in warmed air being pushed outside. Cold air leaking into the collector is more easily detected with temperature sensing equipment than is warm air leaking out.

7) With the recommended fan placement, the fan must be constructed so that its motor is remote from the airstream. Hot air from the collector will be passing through the fan, but most electric motors are not built to take the high temperatures from these solar collectors. A belt driven fan is almost mandatory in this situation.

8) The remote sensing bulb for the thermostat that controls the collector fan should be located in a shady spot near the collector outlet. The suggested location is in the upper half of the collector height and one to two inches from the edge of the solid cover used to form the transition.

9) When building the transitions from the collector to the PVC pipe (or equivalent) ducts, and from the PVC pipe (or equivalent) through the fan to the concrete blocks, be sure to insulate the transitions well. Insulation at these locations will reduce heat loss and prevent the fan motor from being overheated. High temperature insulation should be used.

10) The ventilation openings along the top of the south wall must be equipped with baffles or other devices to allow partial closure during extreme winter weather. The closure devices are especially needed during periods of low temperatures and strong north or south winds. North winds tend to over-ventilate the nursery by drawing warm air out the openings while south winds force excess amounts of cold air in through the openings.

B. Suggested Modifications

1) Use back-draft dampers at the outlet ends of the PVC pipe air ducts to prevent convection currents removing heat from the IFHDS system at night. A small flap of plastic that can withstand temperatures as high as 200°F (See Figure 7) can act as a gravity shutter to provide this back-draft damper. Attach a piece of high temperature insulation to the plastic sheet to reduce conductive heat losses.

2) The optimum collector and IFHDS system length seems to be in the 50 to 75 ft range. Multiples of these lengths are suggested for longer buildings with small pigs in the 15 to 30 lb category.

3) Buildings with lengths of 100 to 150 ft with pigs ranging from 15 to 50 lbs may need only one active collector loop. The smaller pigs may be kept above the solar IFHDS system. The smallest pigs should be kept in the pens where the air in the solar IFHDS system is warmest (i.e., pens closest to the place where the hot air from the collector enters the solar IFHDS system). As the pigs grow they should be moved through the building towards the area where the air in the solar IFHDS system is cool (i.e., pens closest to the place where the air leaves the solar IFHDS system and returns to the collector). The rest of the building need not have the active collector system but research results indicate heat storage may be beneficial. This insulated thermal storage can be identical to the solar IFHDS system except the concrete blocks are not needed because no air will pass through this heat storage. The insulated thermal storage mass will help store heat released from the animals at night as they lie on this storage area. Some of this heat is slowly released to the air during the day. The remainder of the heat stored in this area is used to maintain or slightly increase the average floor temperature above this heat storage. The research data referred to herein were reported in a technical paper (No. 80-4514) of the American Society of Agricultural Engineers.

4) Provisions to allow placement of heat lamps above the sleeping area in one-fourth of the pens are recommended. These heat lamps should be provided for the pens in which the smallest pigs will be located (i.e., closest to the place where hot air from the collector enters the solar IFHDS system) on an "as needed" basis. Experience with this unit has shown that use of these heat lamps was all the auxiliary heat required during the fourth coldest January on record (January 1982) in Nebraska. This cold weather was accompanied by low solar insolation levels during the months of December and January.

5) Caution should be taken in constructing a unit of this design in locations outside Nebraska. Certain features may need to be modified to accommodate local climatic conditions. For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this report was performed by the University of Nebraska Department of Agricultural Engineerng. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

Table 1. Recommended types and levels of insulation for the Nebraska Solar MOF Nursery (Paus).

Insulation Location	Insulation Type	Insulation Level
Ceiling/roof	Fiberglass batt	R-19
Stud Wall	Fiberglass batt	R-11
Insulated concrete sandwich panel	Rigid foam board	R-13
Foundation perimeter	Extruded foam board	R-8
Beneath feeding floor	Extruded foam board	R-4
Around IFHDS system	Extruded foam board	R-8
Around solar collector air ducts	Fiberglass Batt	R-11
Behind solar collector absorber plate	High temperature fiberglass*	R-8
Transitions between air ducts (PVC pipe) and collector outlet and inlet	High temperature fiberglass*	R-15
Transition between air ducts and fan	High temperature fiberglass*	R-12
Transition between fan and IFHDS system	High temperature fiberglass*	R-12
Outlet end of air ducts (back-draft damper)	High temperature fiberglass*	R-4

*High temperature fiberglass is necessary to prevent this insulation from degrading at the temperatures attainable in the collectors.

Table 2. Thermal performance results for the Solar MOF Nursery (Paus).

	1980			1981						1982
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	OCT.	NOV.	DEC.	JAN.
Total solar heat transferred to floor surface, 10^6 Btu	4.09	3.56	2.35	3.01	1.91	3.94	3.64	2.95	2.21	1.70
Avg. daily radiation incident on collector, $Btu/ft^2 \cdot day$	1798	1622	1082	1622	1565	1435	1366	1237	1118	1149
Avg. daily heat input to floor surface, Btu/ft^2 collector area·day	376	338	215	276	194	362	334	281	203	156
Avg. temp under hover, °F	82	77	75	78	NA	NA	NA	73	83	84
Avg. inside temp, °F	75	70	70	70	67	62	70	67	59	57
Avg. outside temp, °F	47	38	33	30	21	36	42	38	17	8
Solar energy transmitted to the floor surface, percent	20.9	20.8	19.9	13.3	12.4	25.3	24.5	22.7	18.2	13.6
Heat supplied by solar, percent	100	100	100	100	100	100	100	100	83.7	43.1

NA--not available

Table 3. Weather data near the Paus unit.

	1981			1982		
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Average monthly temperature, °F	49	41	26	15	22	35
Departure from normal average monthly temperature, F°	-4	2	-3	-9	-4	0
Heating degree days, F°·days	461.5	712	1218.5	1549	1200.5	928
Normal heating degree days[1], F°·days	326	780.5	1146.5	1271	993.5	837
Percent possible sunshine[2]	50	57	39	40	61	50
Normal percent possible sunshine[1]	67	57	52	57	59	59

Source: Data from NOAA Climatological Data for Nebraska for the Weather Station at Clay Center, NE, 12 miles northeast of the unit.

[1]Taken from Climatic Atlas of the United States, 1968.

[2]NOAA data for the weather station at the airport in Lincoln, NE. Solar radiation at the two sites is consistently similar.

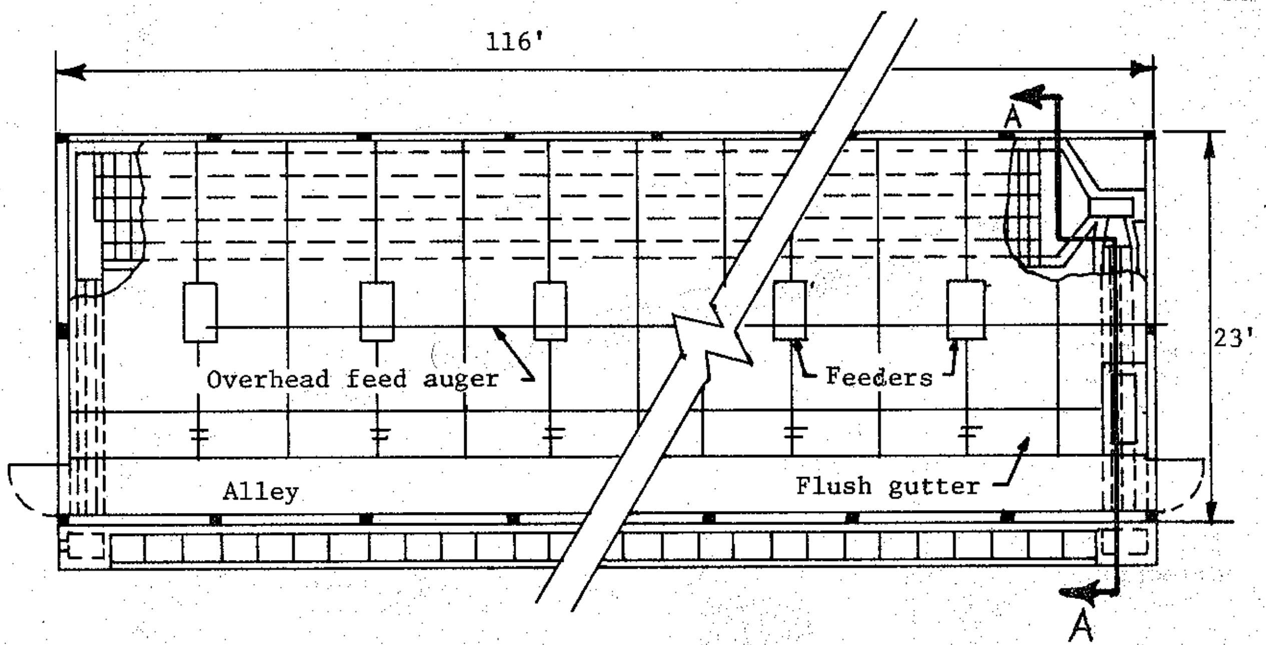


Figure 1. Solar MOF Nursery floor plan (Paus).

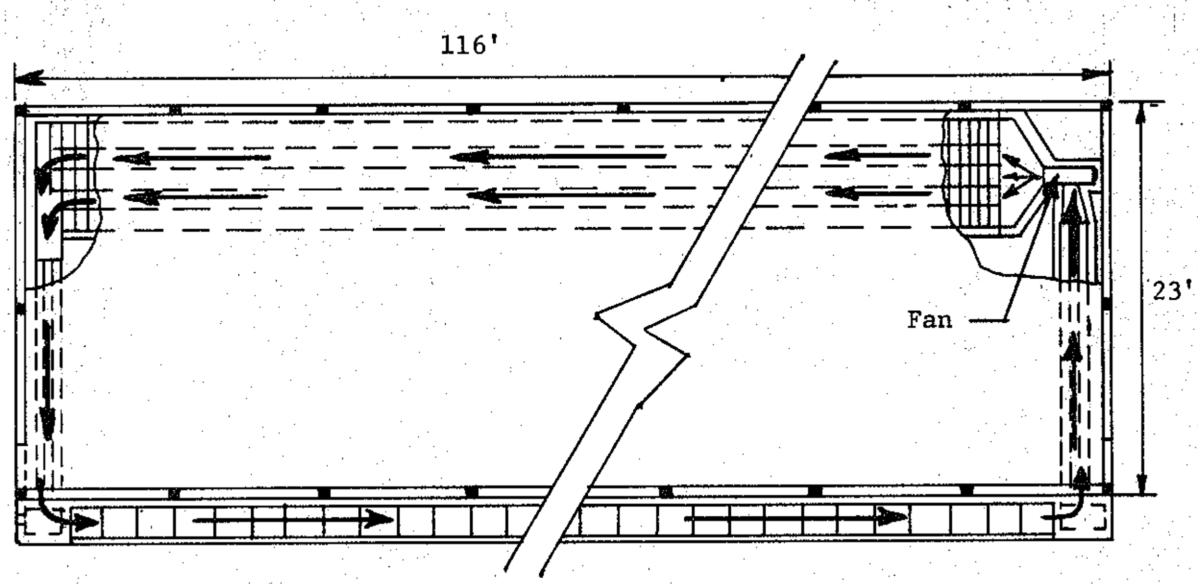


Figure 2. Fluid flow through the active solar collector system (Paus).

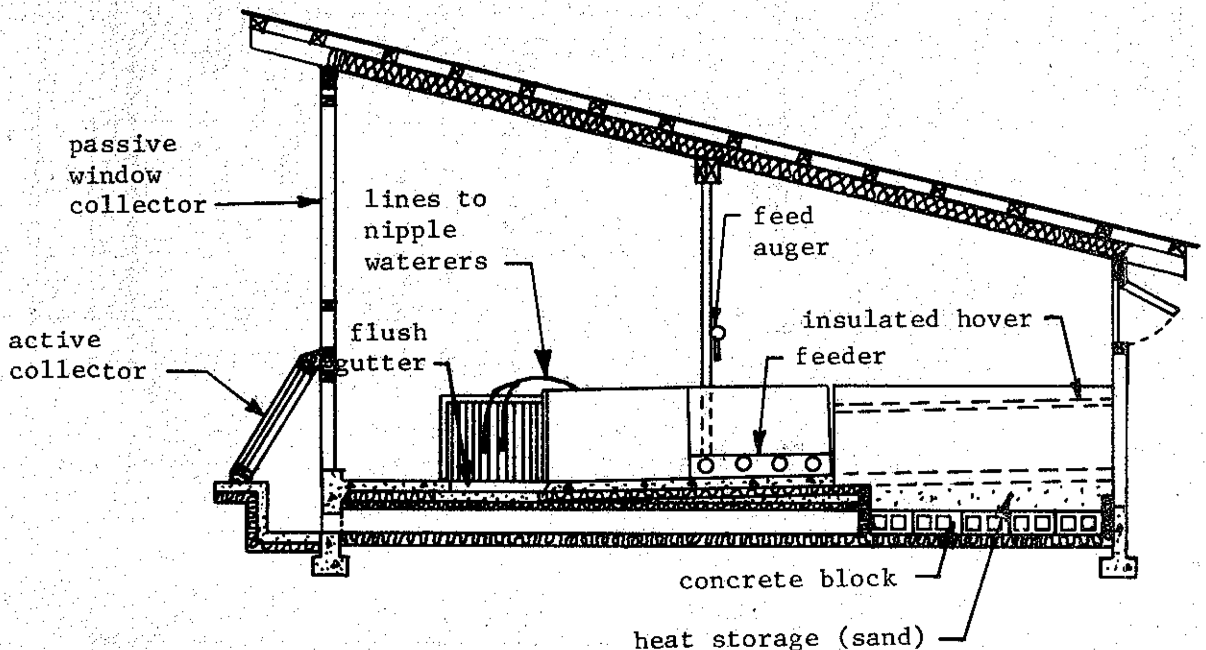


Figure 3. Solar MOF Nursery cross section (Paus).

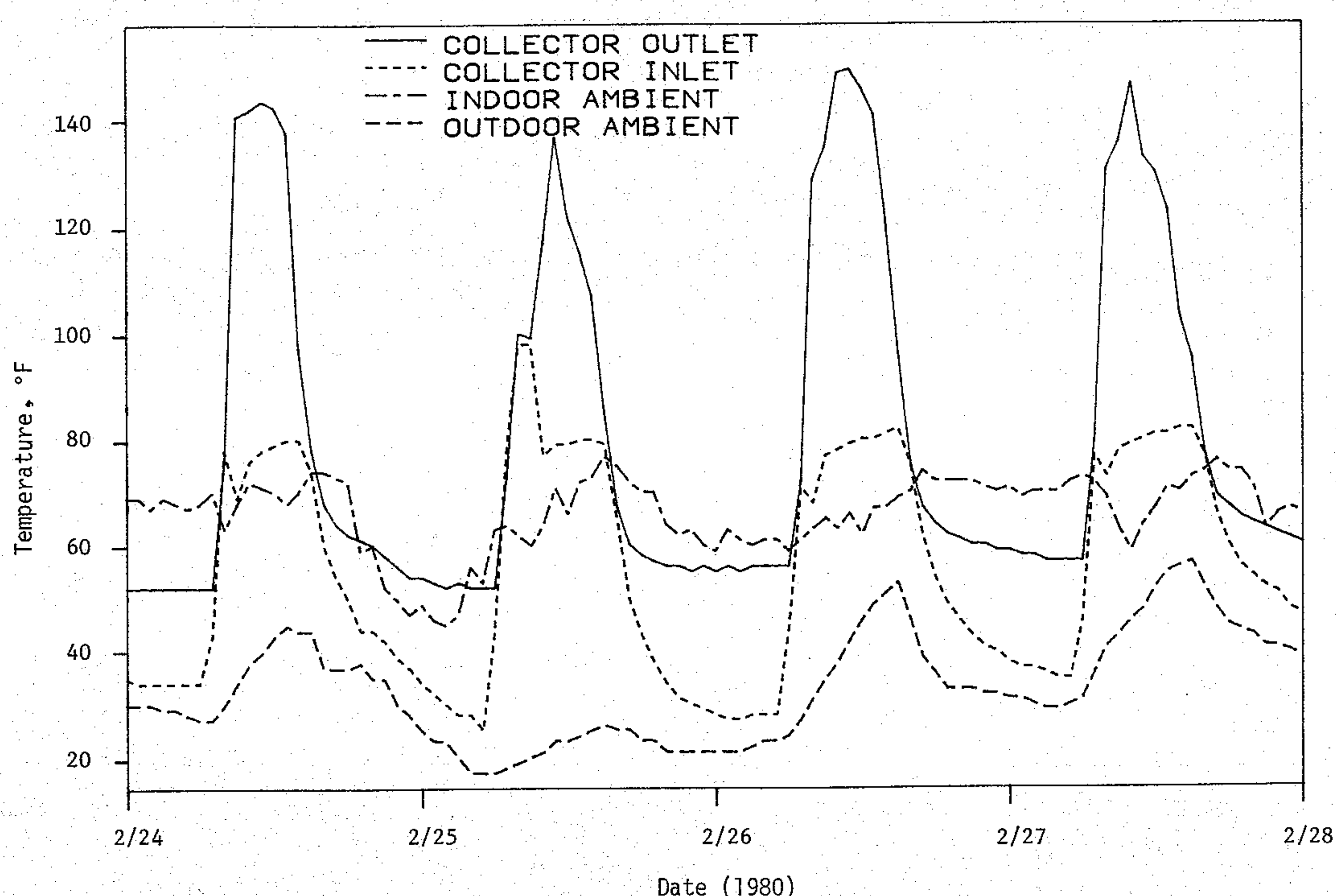


Figure 4. Collector and ambient temperatures at the Solar MOF Nursery in February 1980 (Paus).

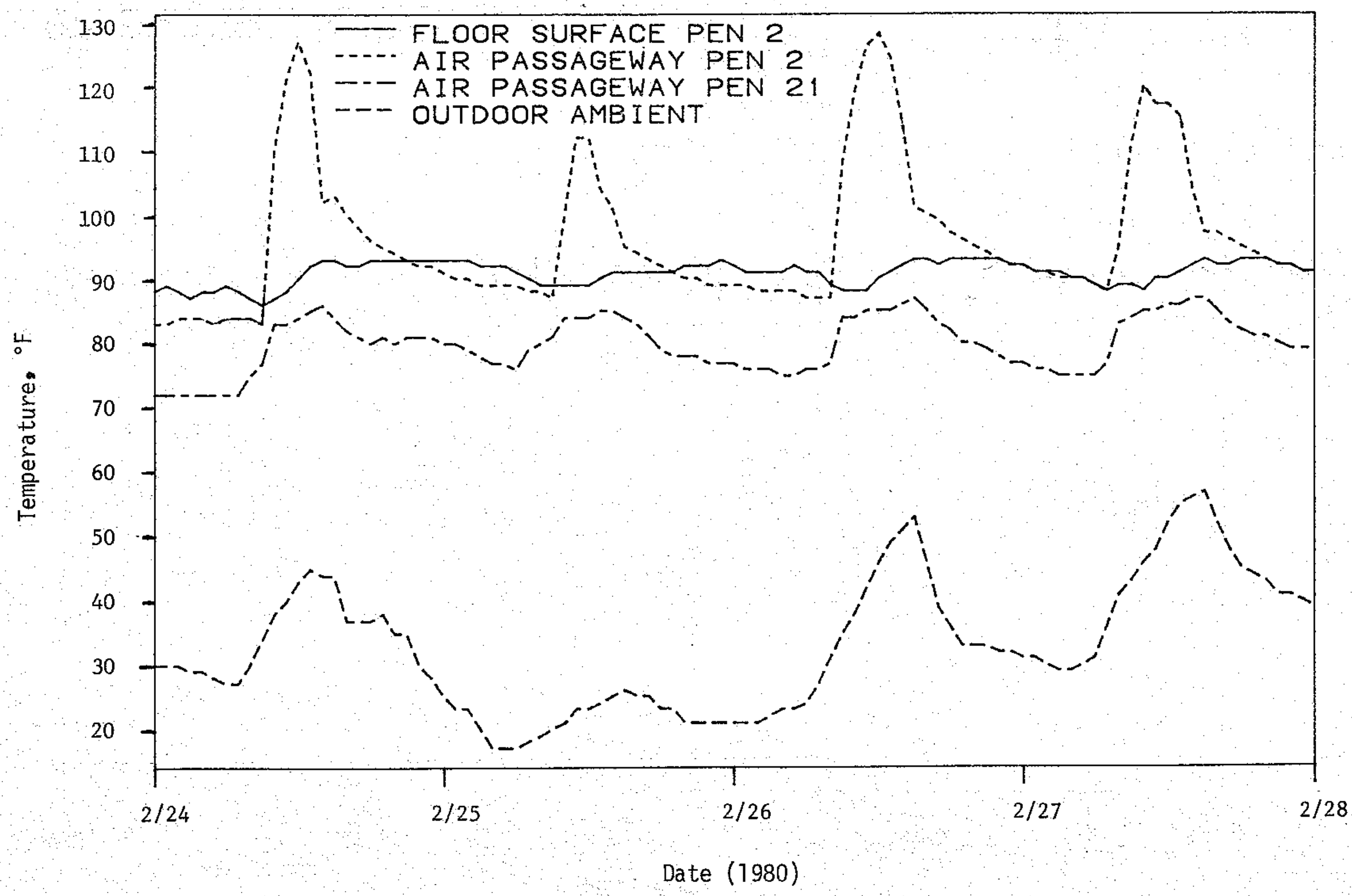


Figure 5. Temperatures at locations in the in-floor solar heat distribution-storage system in February 1980 (Paus).

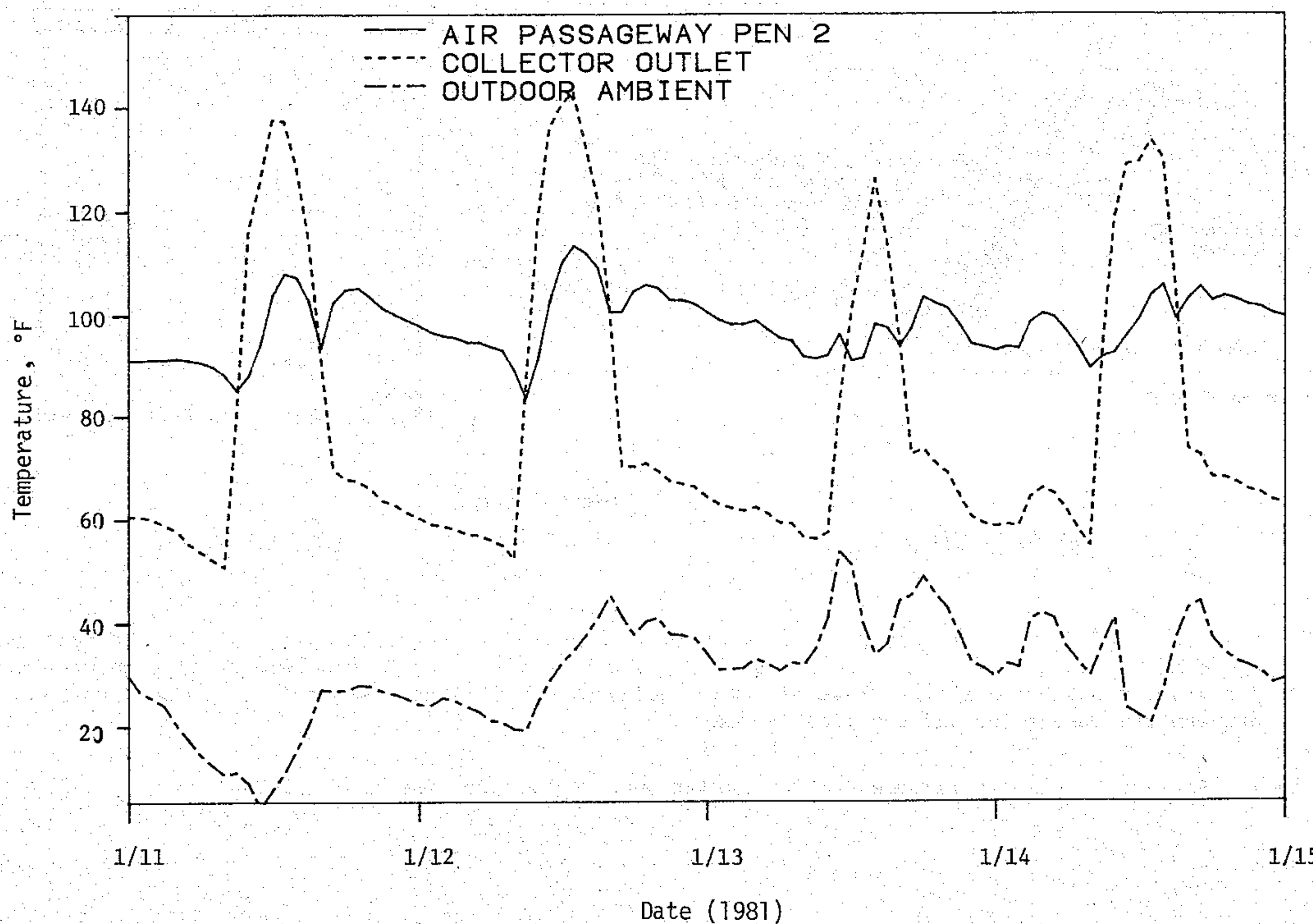
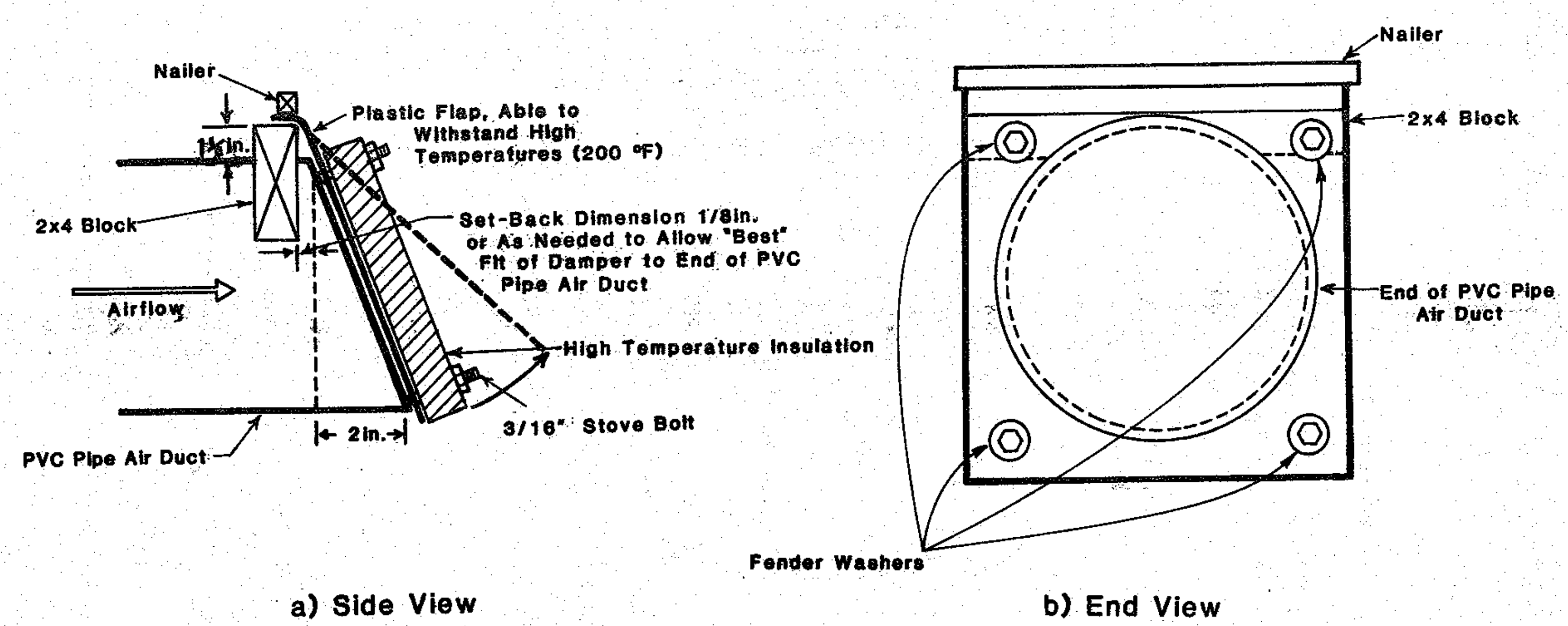


Figure 6. Temperatures in the in-floor solar heat distribution-storage system at the outlet end of the active solar collector (Paus).



NOTE: Use clear silicone caulk "adhesive" between the 2 x 4 block and the PVC pipe air duct to hold the block in place. Also use a bead of silicone caulk on either side of the plastic flap between the 2 x 4 block and the nailer. Place silicone caulk between the washers and the plastic flap and between the insulation and the plastic flap.

Figure 7. Back-draft dampers recommended for outlet ends of PVC pipe air ducts (Paus).

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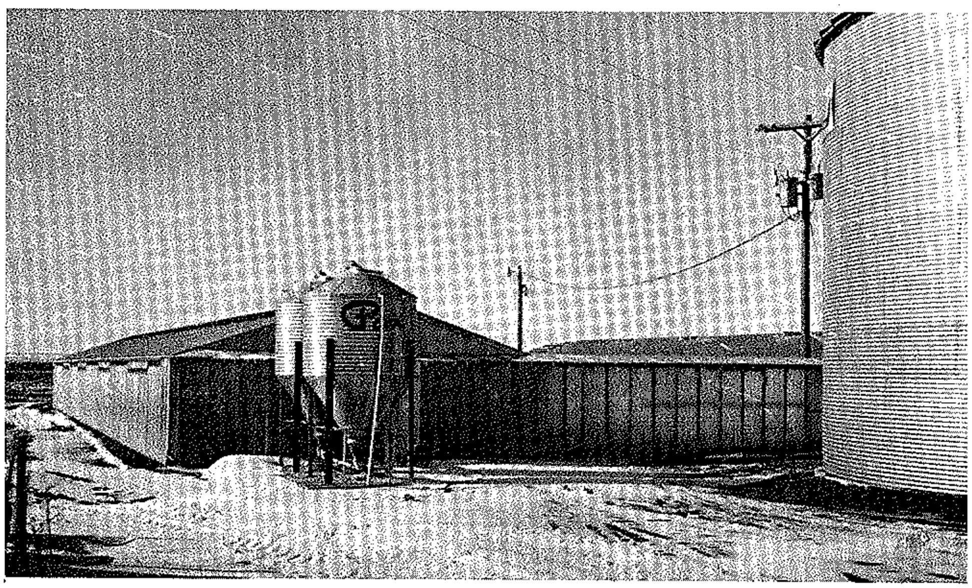
SWINE FARROWING-NURSERY BUILDING WITH VERTICAL SOLAR WALL

Merlyn Lay
Glenvil, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-2



Farrowing-nursery building (2-25 pen rooms) and gestation room (50 sows) with solar collector to preheat ventilation and grain drying air.

SWINE FARROWING-NURSERY BUILDING WITH VERTICAL SOLAR WALL

Merlyn Lay
Glenvil, NE

THE FARM

Merlyn Lay owns and operates the farm on which this demonstration facility is located. The farm (40°29'N, 98°20'W) is located in south central Nebraska's Adams County. The farming operation consists of working approximately 900 acres, raising a few cattle and raising Specific Pathogen Free (SPF) pigs. The Lays have been involved in the SPF swine program for approximately 25 years. With the recent addition of two 25-sow farrowing-nursery units and a 50-sow gestation unit (occupied January 1, 1979) the breeding herd has been increased from 50 to 120 sows. Most of the pigs produced are finished to market weight. Pigs in excess of the capacity of a growing-finishing unit are sold for breeding and/or as feeder pigs.

The Lays have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting, and monitoring this system. Presented in this report is information on a solar system used to preheat ventilation air for the farrowing-nursery rooms during the winter, cool ventilation air during the summer and warm air for grain drying in the fall. The information includes a description of the farrowing house, the grain drying system, and the solar collector. Guidelines for operating the system, suggested system modifications and typical results of the system performance evaluation are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing-Nursery Building

The two 24 x 59 ft farrowing-nursery rooms are connected end-to-end with the gestation room within one building. The building has a gable roof and each room is individually mechanically ventilated. Each farrowing-nursery room has twenty-five 4 ft-6 in. x 10 ft pens with the rear 6 ft of each pen floor being slats or woven wire over a deep pit designed to allow periodic "flushing" of manure into a nearby lagoon. The front 4 ft of each pen is a solid concrete floor creep area with in-floor warm water lines to provide a warm floor creep area for the young pigs. Heat lamps are used for the first few days after farrowing to provide additional heat for the newborn pigs and to attract the newborn pigs to the warm creep area.

Ventilation consists of over-the-wall slot inlets with three AMCA rated variable speed exhaust fans in each room located in a bank centered along the north wall (See Figure 1). The winter ventilation fan runs continuously and pulls air down through the slats where it moves across the manure in the pits before being exhausted from the building. Spring/fall ventilation follows a similar flow path (See Figures 2 and 3). The summer ventilation air is not drawn through the pits. Instead it is moved across the animal space and exhausted directly from the building rooms (See Figures 4 and 5). This arrangement provides for control of pit odors and gases while providing cooling of the sow.

B. The Solar Collector System

The solar collector consists of a vertical wall of dry-stacked concrete blocks with two glazing layers (Filoplate® #556). The blocks are 8 x 8 x 16 in. (nominal) concrete blocks placed so the long dimension is perpendicular to, and 15 in. away from, the south wall of the building. A 3/8 in. vertical gap between adjacent blocks allows airflow through the block wall. The south side of the block wall is painted black to increase the absorption of solar energy. Overall collector dimensions are 6 ft-8in. x 140 ft (932 ft^2).

The slots and gaps in the collector glazings and blocks are designed so winter ventilation air enters the collector between the glazings, travels across the warm black surface of the block wall, filters through the gaps between the blocks, and goes into the building through the ventilation air inlets. The ventilation fans exhausting moisture, gases, and odors continually pull ventilation air through the collector into the building. In this way, the building ventilation fans provide the power to move air through the collector instead of having a separate fan perform this function. The concrete blocks act both as absorber plate and heat storage. The blocks used to form the collector-storage were FHA blocks which are three quarters solid concrete. The indentions in the blocks in the east half of the collector were filled with sand to provide added heat storage capacity. The blocks in the west half of the collector do not have sand in the indentations.

The system is constructed so the collector can preheat winter ventilation air as well as cool summer ventilation air. Assuming a 35 cfm per sow normal winter ventilation rate, the collector airflow rate is 2.25 cfm per ft^2. During the fall, ventilation air can bypass the collectors through openings over the collector. This allows the collector to be used to heat air for use in grain drying (See Figures 4 and 6).

C. The Grain Drying Operation

A 27 ft-9 in. diameter grain bin with a full-perforated floor is used for drying grain. Corn at 26 to 28 percent moisture (wb) is loaded into the bin to a depth of approximately 4 ft. Drying air moves through the collector into a plenum between the concrete block wall and the farrowing-nursery building wall. The air exits out the east end of the plenum and moves down an enclosed walkway to the air inlet of the grain bin fan. The enclosed walkway is covered with a single layer of corrugated glazing (Filoplate® #556) so the walkway itself acts as a solar collector. A 26 in. diameter, 13 hp fan pulls the warm air from the walkway and pushes the air under the drying floor and up through the corn to be exhausted at the top of the grain bin. After the corn is dried to 18 percent moisture (wb) it is moved to another bin for completion of drying and storage and another 4 ft layer of corn is loaded into the drying bin. This procedure is repeated until the harvest and grain drying are complete. A propane burner downstream from the drying bin fan is used to add heat to the grain drying air until it reaches a temperature of 120°F.

COST

The materials and labor cost for the collector system, including the walkway to the grain bin used for drying, was $10,385.55 for 932 ft^2 or $11.14 per ft^2 of collector area. This can also be calculated as $207.71 per sow space. On this basis, had the collector been integrated into the unit at the time of construction it would have represented approximately 15 percent of the total construction cost. These costs are in 1979 dollars. No interest or opportunity costs are included in the figures.

PERFORMANCE

A. Thermal

The main purpose for the solar collector system was to provide preheating of the winter ventilation air. Additional anticipated uses were preheating air for grain drying and cooling ventilation air for the farrowing house during the summer. All of these uses for the solar collector system have been realized.

Typical data from the winter ventilation air preheating mode of operation for the solar collector system are presented in Figure 7. Outdoor ambient temperatures during that time period ranged from a high of 38°F to a low of -4°F. Temperatures at the collector outlet point ranged from 57 to 16°F during this same time period for an average temperature rise of 16°F.

The benefit of having heat storage as part of the collector system is evident in the continued ventilation air temperature increase through the night. In fact, a larger quantity of heat was transferred to the ventilation air during the nights than during the days. Thus, solar energy collected during the day was stored for subsequent release to the ventilation air. This delayed release of collected heat is highly desirable since heating needs are greater overnight. The result is increased utilization of collected solar energy.

Data from the grain drying mode of solar collector system operation are presented in Figure 8. Interpretation of these data and attribution of performance characteristics to specific parts of the system are complicated by some confounding features built into the system. One of these confounding factors is that air can enter the grain drying system at a number of points between the air inlet to the collector and the air inlet to the fan. Air enters along the walkway because the gaps between the ridges of the corrugated glazing and the walkway framing members are open. (Except during grain drying, this is desirable for odor and temperature control within the walkway, especially during warm weather). Additional air infiltration can occur between joints in the walkway and the duct leading to the fan inlet.

Besides this air infiltration, solar radiation can be collected by the vertical collector and also by the walkway. Yet, while the walkway can serve as a solar energy collector, it can also serve as an energy dissipator because the glazing on the walkway has a low thermal resistance, or R value, and can conduct heat to the cold environment outside the walkway.

The sensing accuracy of the thermocouple used to monitor air temperature in the walkway/duct is also open to question since it is close to the walkway wall to minimize interference with animal and personnel movement between the farrowing-nursery and growing-finishing buildings. This thermocouple may be in a boundary layer of air near the wall that has a higher or lower temperature than the rest of the air moving through the walkway. The combination of these circumstances makes it difficult to reason through the "why's" of the performance data.

The data do allow a few conclusions to be reached, however. One conclusion is that the walkway serves as a collector. The walkway, on the east side of the building and available for collection of morning solar radiation, experiences large and rapid temperature increases (Figure 8) as would be expected of a solar collector with no storage medium. In the early afternoon the building shades this part of the walkway resulting in early daily temperature declines. The northern part of the walkway at the air inlet to the grain bin fan is not shaded by the building and its temperature peak comes an average of two hours later in the day.

The south-facing block wall collector shows the characteristics of a collector with storage in that the temperature at the collector outlet does not increase or drop off as quickly nor exhibit the temperature extremes noted in the walkway. The temperature of the air leaving the collector is the highest temperature in the system during the nighttime hours which demonstrates that the storage in the vertical solar wall is providing heat to the system overnight.

A computer program was used to average the temperature rise between the inlet to the grain drying fan and the outdoor ambient temperature. The program was also used to average the outdoor ambient temperature for the grain drying season of October 14 through November 13, 1981. The average temperature rise for this time period was 4F° with an average outdoor ambient temperature of 36°F.

The use of the propane burner to maintain a "constant" temperature of air entering the bin results in the solar collector having minimal effect on actual drying time. The benefit of the collector is to increase the temperature of air entering the fan thereby reducing the quantity of propane necessary to achieve the desired drying bin air input temperature of 120°F.

The solar collector actually performed no net cooling of summer ventilation air. Instead it provided a moderating effect to lower the high daytime air temperatures and raise the cooler nighttime temperatures (See Figures 9 and 10). During August of 1980 the daytime cooling total was 4.3×10^6 Btu, while the nighttime heating total was 9.6×10^6 Btu. In August of 1981 the daytime cooling total was 1.2×10^6 Btu, while the nighttime heating total was 1.3×10^6 Btu. Based on performance of other similar systems (e.g., Project NE-4) covering the collector probably will not allow a balancing of these two quantities despite no solar energy being added directly to the collector because of the conductive heat flow from the building to the collector and through the collector cover. However, the maintenance of higher indoor ambient temperatures through heating of the nighttime ventilation air could produce deleterious effects on the animals since relief from high daytime temperatures is minimized or eliminated. This factor must be very carefully considered when using this collector system in conjunction with housing for lactating or breeding age animals.

B. Economic

During the year of operation prior to construction of the solar collector, the farrowing building required 5866 gal of propane for the heating season (7189 F°·days). During the first year of operation following installation of the solar collector, propane usage in the farrowing building was 3900 gal for the heating season with a load of 5526 F°·days. This converts to a savings of 0.11 gal/F°·day or \$0.062/F°·day (propane at \$0.56/gal). These fuel requirements are based on information from fuel delivery tickets.

Using the AGNET computer model DRY CROSSFLOW, 19.5 hours of drying time was required to dry a batch (1970 bu) of corn. This required

1.21 MBtu of energy or 15.1 gal of propane energy equivalent. With propane costs at $0.56/gal and 50,000 bu of corn harvested in 1981, the estimated cost of the energy provided by the collector during the grain drying season was $215. This converts to $0.0043 per bu.

With an average annual farrowing house heating load of 5973 F°·days and a grain drying load of 50,000 bushels, the use of the solar collector can save approximately $585 per year. Since no summer ventilation cooling would be used if the solar collector did not exist and no clear cut benefits were derived from its use in this mode, no energy savings can be attributed to this aspect of the solar collector system. If benefits in terms of better animal production can be clearly shown to exist from such cooling, the dollar value of those benefits should be included in the annual savings from the solar collector.

With the collector cost of $10,385.55 and an annual savings of $585, the simple payback period is calculated to be nearly 18 years. Replacement of the glazing may be necessary every five years. Even with inflation, increasing energy costs, interest and opportunity costs used with the time-value-of-money approach to estimate the life cycle costs for this collector, the design is considered to be a non-economical investment. However, the availability of government cost-sharing money to reduce the operator's investment could result in an economical system for the producer while reducing the use of fossil fuels.

C. Problems

Adding the collector under an existing eave was difficult. Extending the eave to provide full cover for the collector was also a problem.

Dust accumulating on the glazing layers is slowly decreasing the transmission of solar energy to the absorber. No easy way exists to clean the inner glazing.

Measurement of airflow through the collector was attempted with a manometer to determine the static pressure against which the fans were operating and with a hot wire anemometer. No consistency was attainable, and in many cases, the air velocity was so low (less than 200 fpm) that accuracy of the instruments was questionable.

COMMENTARY

A. Construction Suggestions

1) Be sure to seal the collector carefully. This will help ensure proper airflow through the collector. Air leaks have appreciable adverse effects on collector performance. Joints are much more easily sealed during construction than as a repair operation. Use only high quality, long-life caulking materials. Clear silicone caulk is recommended.

2) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

3) Provide enough overhang so rain and snow do not drip or blow into the collector inlet. Do not make the overhang wider than necessary since doing so could result in shading part of the collector.

4) When painting blocks, be sure to protect them from rain. Failure to do so results in leaching of minerals from the concrete and formation of a white deposit on the outside of the paint.

B. Suggested Modifications

1) Other blocks may be substituted for the FHA blocks. When substituting other blocks be sure to provide proper spacing between the blocks for airflow. Allow between 3 and 5 ft^2 of open area in the block wall per 1000 cfm of ventilation air.

2) The FHA blocks, even when filled with sand to achieve the equivalent mass of an 8 x 8 x 16 in. solid block, do not meet the generally recommended storage mass to collector area ratio. Consideration should be given to alternate designs which provide 2 ft^3 of storage mass per ft^2 of collector.

3) The collector design described in this report allows all winter and spring/fall ventilation air to be pulled through the collector. It may be desirable to warm only the winter ventilation air. This can be accomplished by installing motorized shutters in the ends of the collector. These shutters should be wired in parallel with the spring/fall fan so they open whenever the spring/fall fan operates. This will occur when the building temperature is high enough so heating is not required but when spring/fall ventilation rates are necessary to effect some temperature control. Air from the outside is pulled through the shutters into the plenum behind the blocks. From there the air is pulled into the building for ventilation. Under this operational mode a very minimal airflow will occur through the collector. The collector can then "stagnate" with very low airflow and solar radiation can be stored in the blocks until heat is needed during cool nights or days. This arrangement reduces ventilation loads and increases the utilization of solar energy. Thus, overall system efficiency is improved.

4) Solar collectors will not be helpful for all grain drying operations and in some instances can actually be detrimental. All components of the grain drying operation must be matched to avoid grain quality losses and to achieve reasonable operational efficiencies.

5) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

Table 1. Winter ventilation preheating data for the farrowing house (Lay).

	1980			1981	
	OCT.	NOV.	DEC.	JAN.	NOV.
Total heat required, 10^6 Btu	0.30	21	22	30	7.8
Total heat supplied by solar, percent	100	80	60	66	100
Average indoor ambient temperature*, °F	62	59	48	52	58
Average outdoor ambient temperature, °F	44	21	15	14	32

*This thermocouple was located in the middle of the east farrowing room, about 5 ft above the floor (not in the pig zone). The control panel with the east farrowing room ventilation fan controls was also in this location.

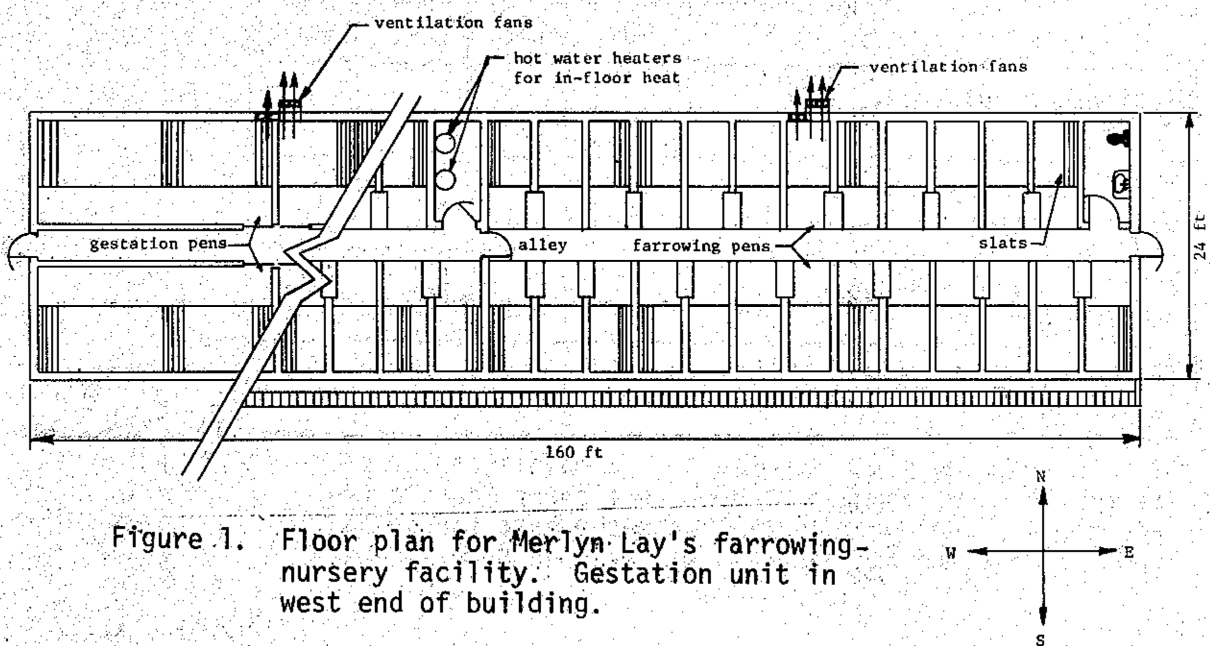


Figure 1. Floor plan for Merlyn Lay's farrowing-nursery facility. Gestation unit in west end of building.

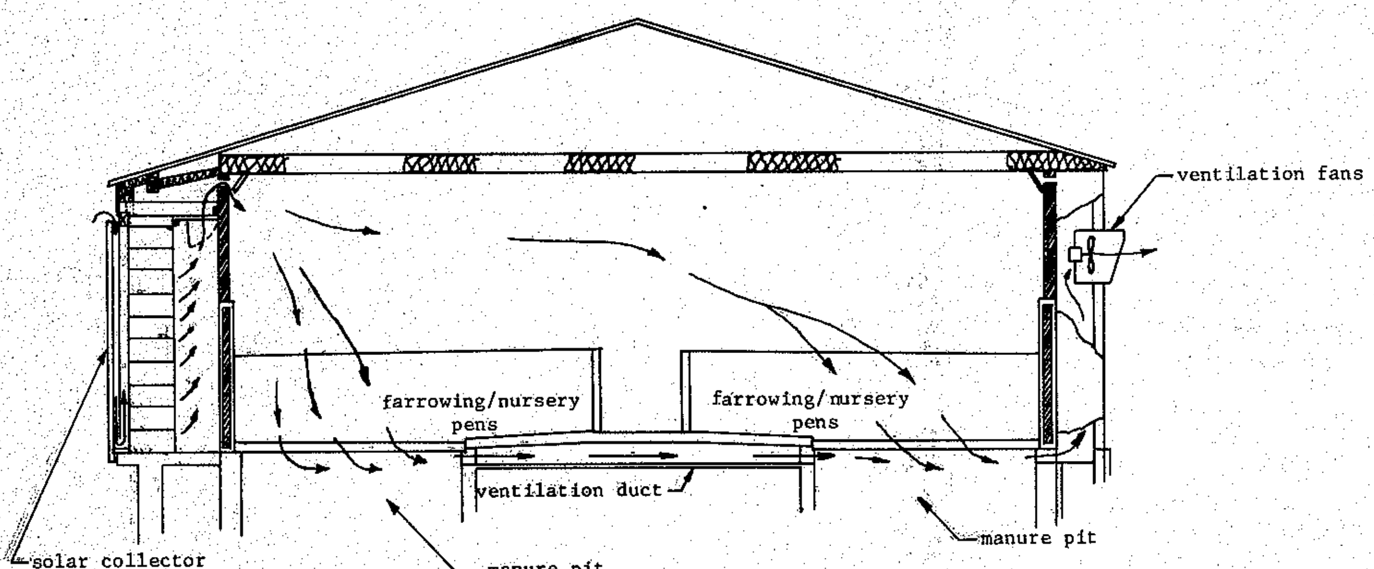


Figure 2. Building cross section schematic showing winter ventilation air movement (Lay). Minor details omitted for clarity.

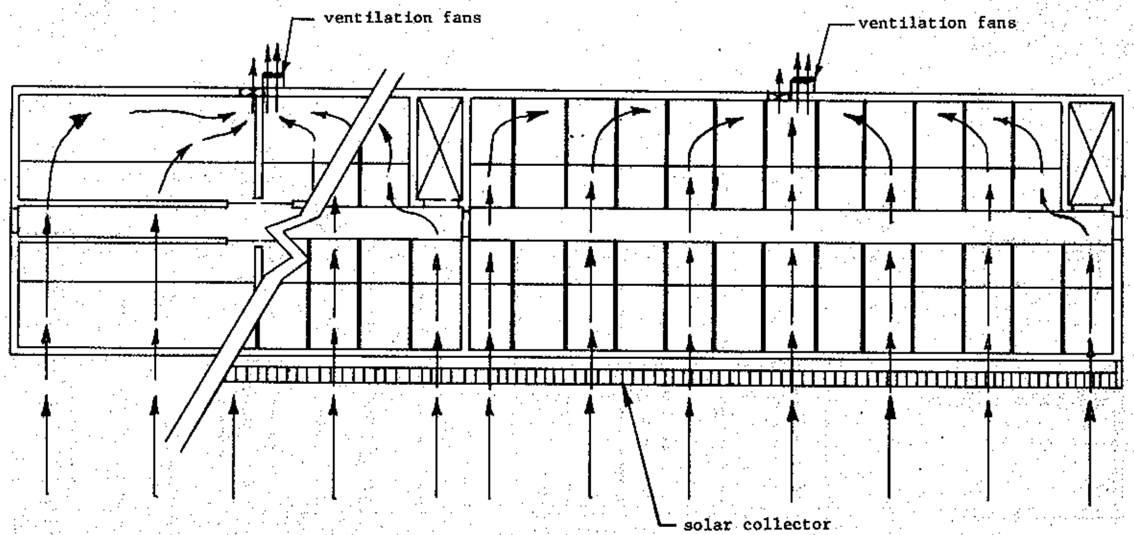


Figure 3. Floor plan schematic showing winter ventilation air movement (Lay). Minor details omitted for clarity.

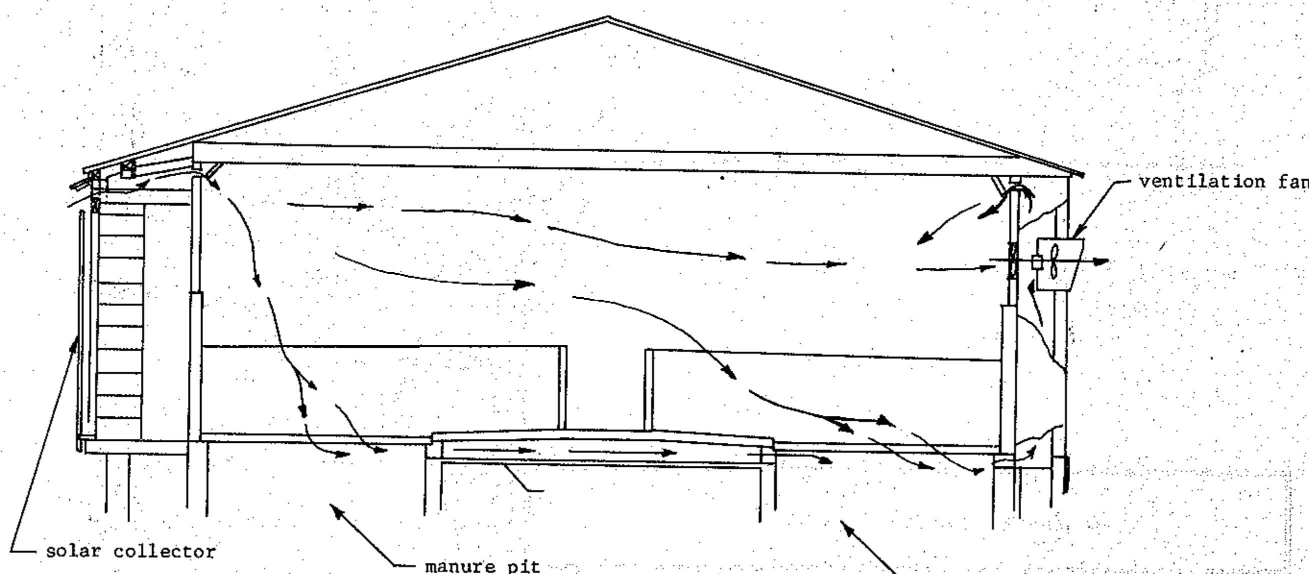


Figure 4. Building cross section schematic showing summer ventilation air movement (Lay). Minor details omitted for clarity.

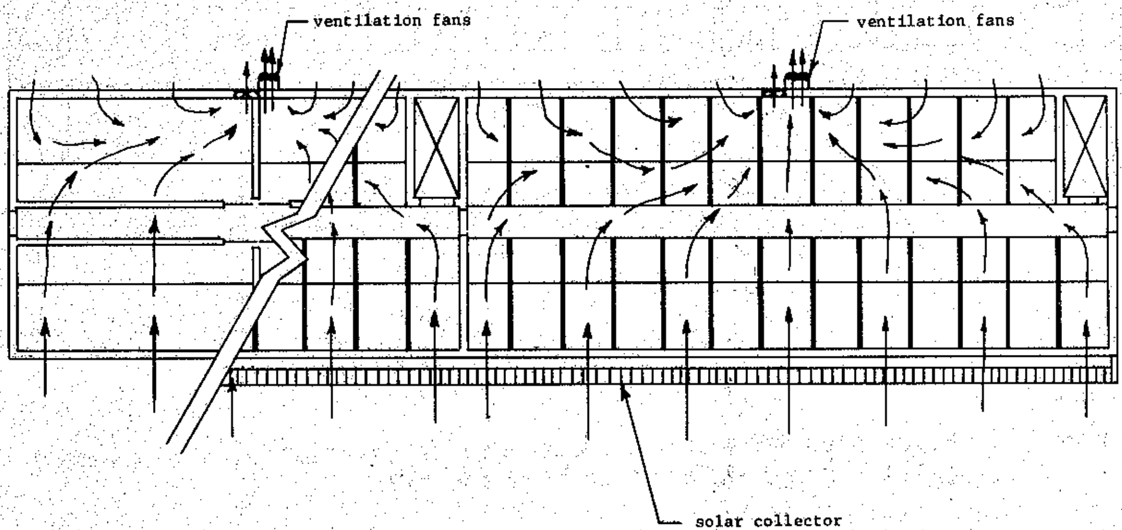


Figure 5. Floor plan schematic showing summer ventilation air movement (Lay). Minor details omitted for clarity.

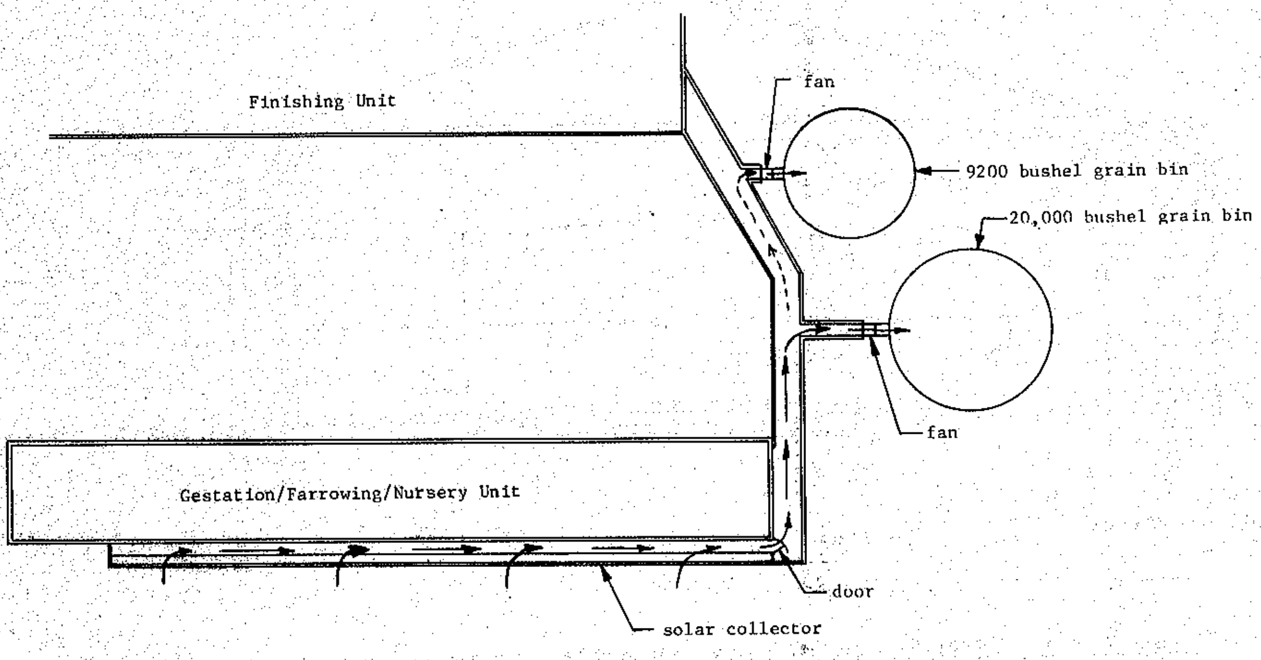


Figure 6. Site plan showing grain drying airflow paths (Lay). Details omitted for clarity.

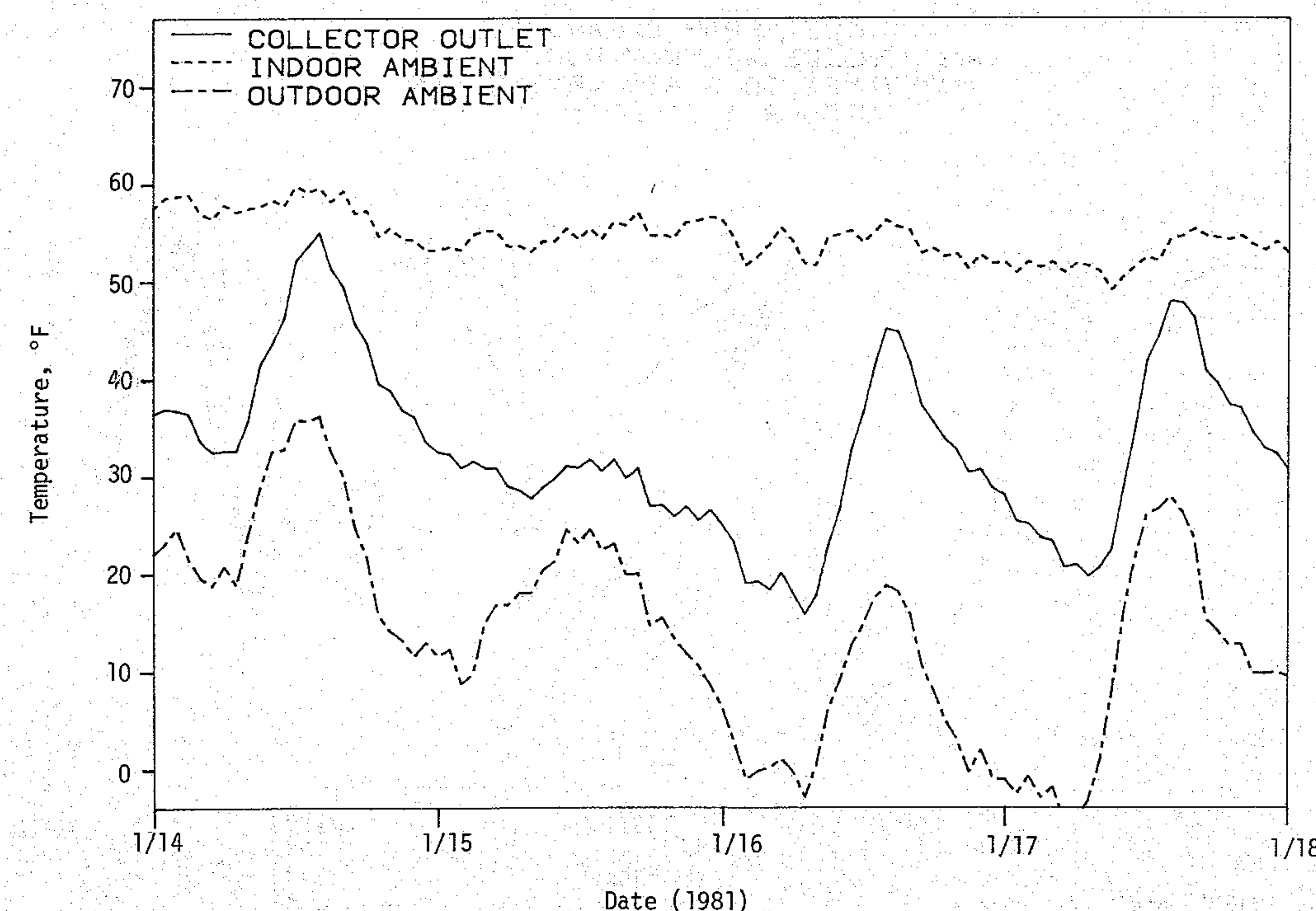


Figure 7. Farrowing house winter ventilation preheating temperatures with the vertical solar wall (Lay).

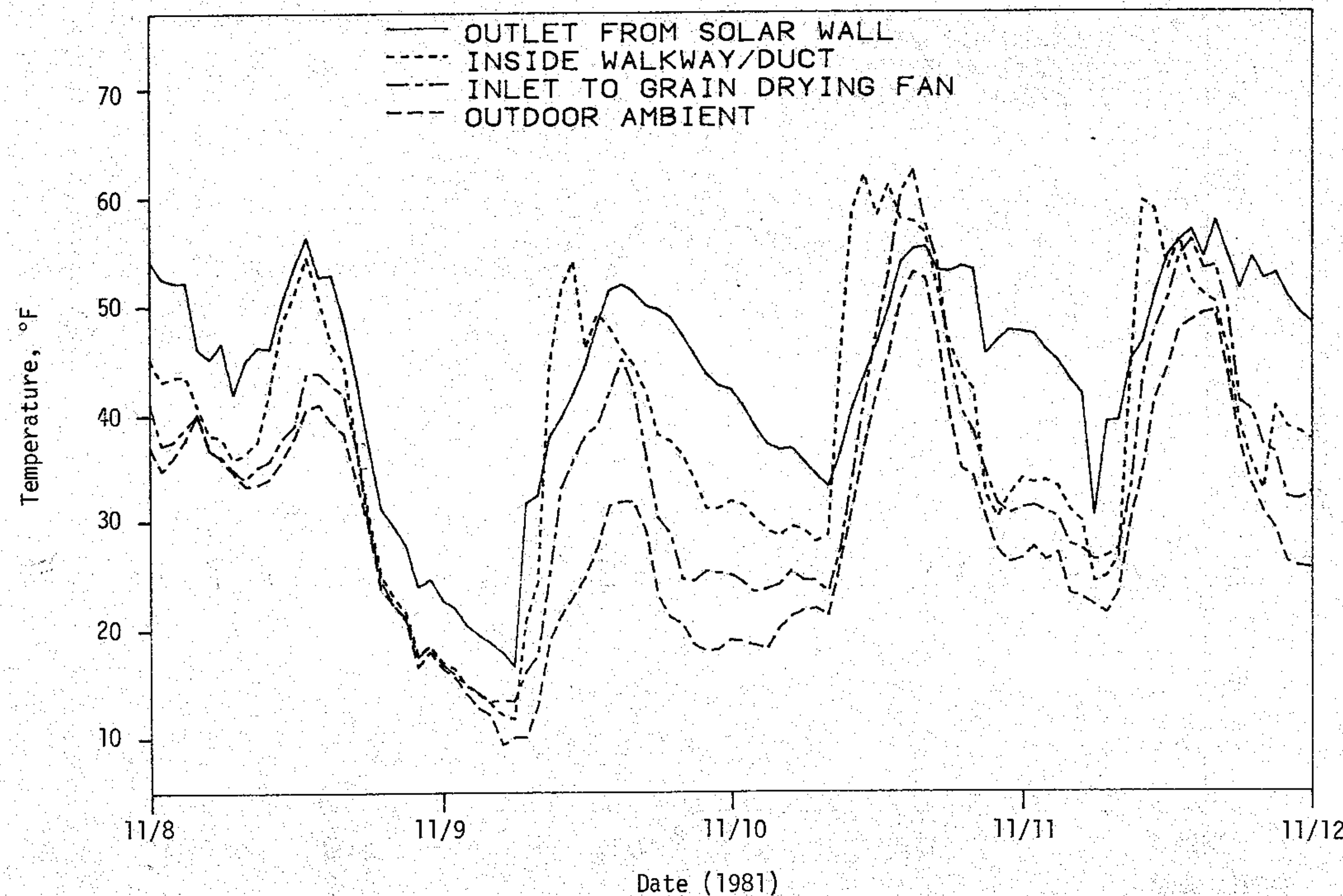


Figure 8. Grain drying air preheating with the vertical solar wall and walkway/duct (Lay).

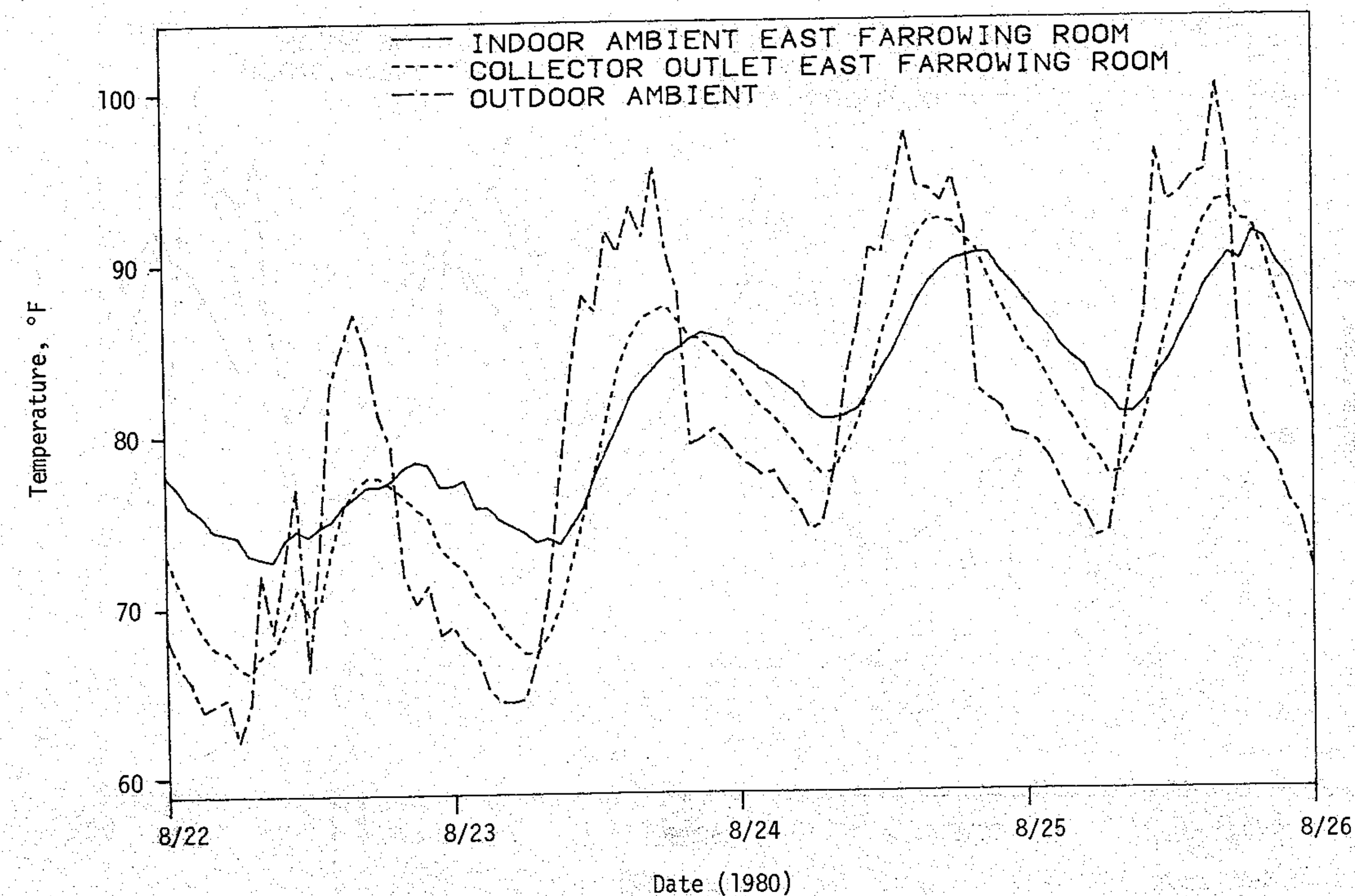


Figure 9. East farrowing room summer ventilation cooling temperatures with the vertical solar wall (Lay).

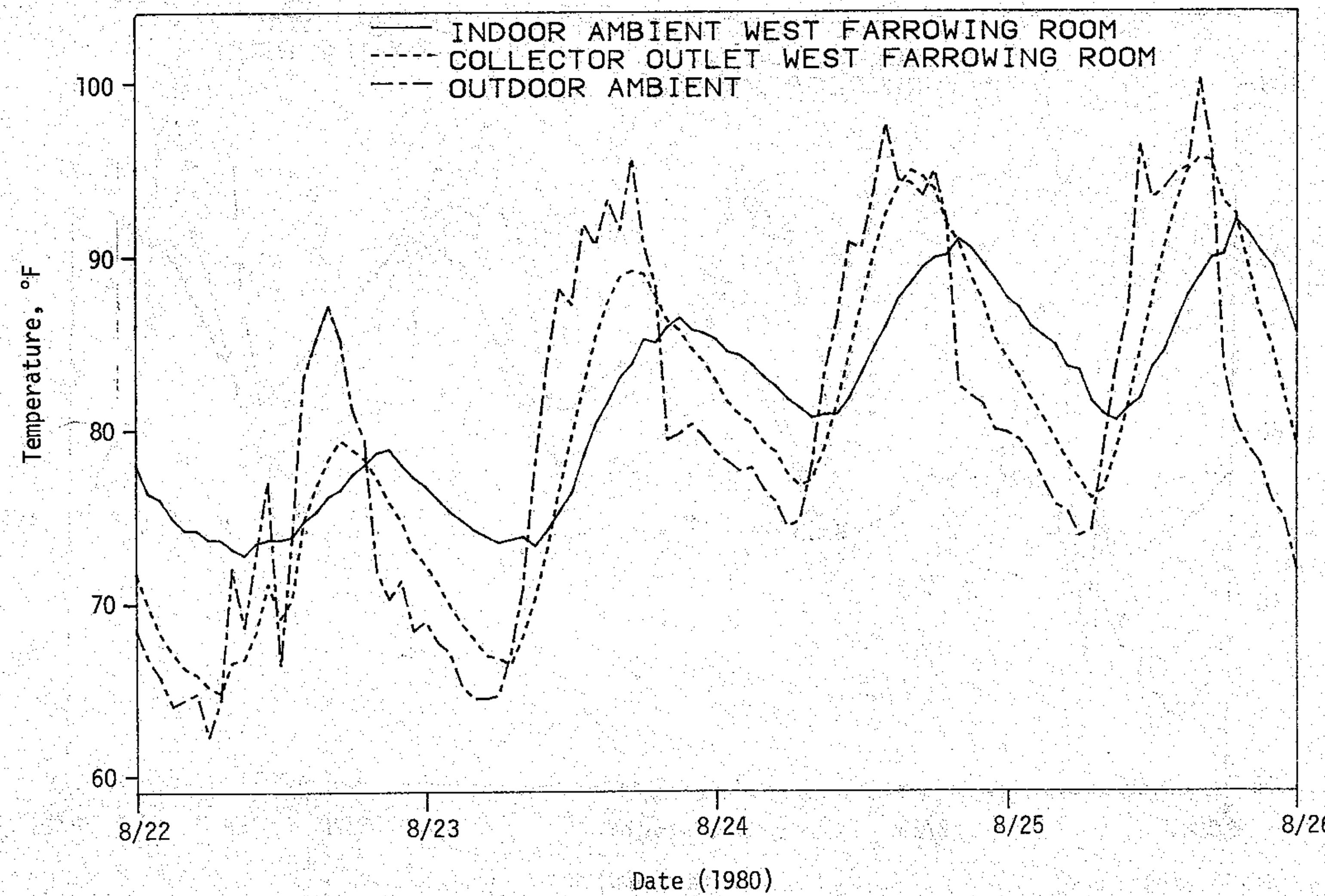


Figure 10. West farrowing room summer ventilation cooling temperatures with the vertical solar wall (Lay).

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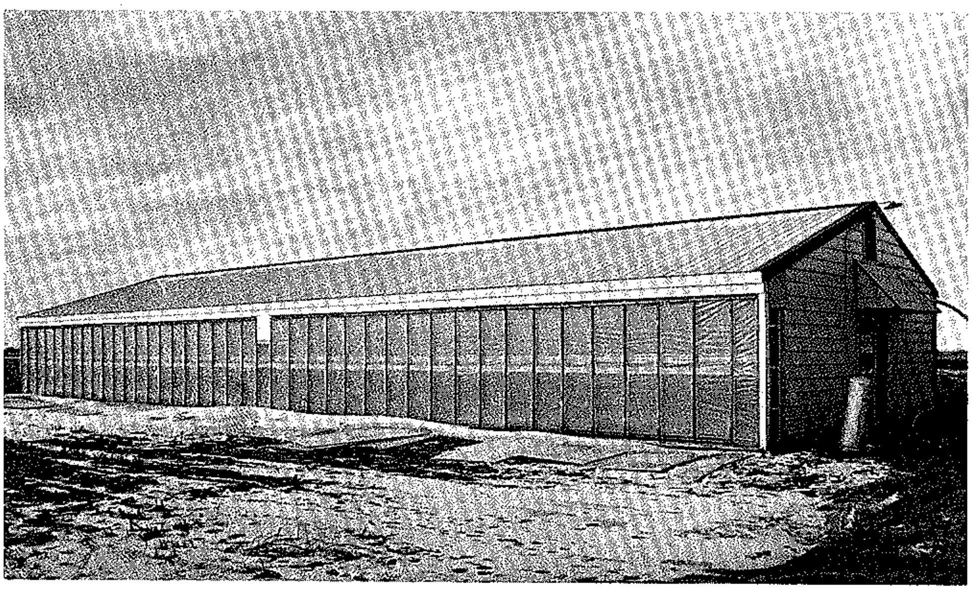
COMBINATION SWINE FARROWING-NURSERY BUILDING WITH A VERTICAL SOLAR WALL

Craig Buescher
Deweese, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-4



12-sow farrowing-200 pig nursery building with solar collector for ventilation air preheating or cooling.

Cooperative Extension Service
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

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... VERTICAL SOLAR WALL

COMBINATION SWINE FARROWING-NURSERY BUILDING WITH A VERTICAL SOLAR WALL

Craig Buescher
Deweese, NE

THE FARM

Craig Buescher owns and operates the farm on which this demonstration facility is located. The farm (40°23'N, 98°10'W) is located in south central Nebraska's Clay County. Dryland crops include approximately 12 acres of alfalfa, 100 acres of wheat, 200 acres of sorghum and 35 acres of soybeans. Alfalfa and sorghum are grown on 12 and 100 acres of irrigated cropland, respectively. Livestock operations on the Buescher farm include a cow-calf herd of about 20 cows and a 70-sow farrow-to-finish operation. Annual swine production is approximately 1100 market-weight hogs. Craig also sells York and Landrace gilts as breeding stock. The swine facility that Craig had been using was destroyed by fire thus necessitating the construction of the new solar farrowing-nursery unit.

The Bueschers have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, instrumenting, and monitoring this system. This report includes a description of the building, a description of the solar system and the cost of the solar system. Guidelines for construction of this system, some system performance results and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing-Nursery Facility

The farrowing-nursery facility has three basic areas. A 12 x 70 ft farrowing room exists side-by-side with a 12 x 70 ft nursery room. Across the end of those two rooms is a 12 x 24 ft work area, including an office, feed storage and a sow wash (See Figure 1). The building has a gable roof and is mechanically ventilated with two insulated ducts, one on each side of the wall dividing the two rooms, supplying fresh ventilation air and exhausting warm moist air (See Figures 2 and 3). The farrowing room has 12 crates above a flushing gutter (See Figure 4). The flushing device for the farrowing room is a tipping bucket. Auxiliary heat for the farrowing room is provided by heat lamps when the solar collector system cannot provide enough heat.

The 200-pig nursery room has twelve 5 ft x 9 ft-6 in. pens with fenceline feeders in the back portion of the pens. A 30 in. wide open flush gutter is located in the front of each pen (See Figure 4). This flush tank uses a dosing siphon to discharge the flush water. Auxiliary heat for the nursery room is provided by a vented unit heater.

B. The Solar Collector System

The 590 ft^2 solar collector is a concrete block wall with two Tedlar® glazing layers on the 82 ft long south side of the building. The collector system was constructed based on plans obtained from Kansas State University. The block wall is not of typical construction but consists of 8 x 8 x 16 in. (nominal) solid concrete blocks placed so the long dimension is perpendicular to the building. A 9 in. space between the block wall and the south wall of the farrowing room forms a plenum for airflow behind the block wall.

The blocks in the collector are dry stacked (no mortar) with 3/16 in. vertical gaps between adjacent blocks. These gaps allow airflow through the block wall. The south side of the block wall is painted black to increase the absorption of solar energy allowing the blocks to act both as absorber surface and heat storage material (1.3 ft^3 of thermal storage mass per ft^2 of collector).

The slots and gaps in the collector glazings and blocks are designed so ventilation air enters the collector between the glazings, travels across the black surface of the block wall and filters through the gaps between the blocks into the 9 in. plenum behind the blocks. Once in the plenum the air travels down the length of the plenum (towards the west) to the cross duct that conveys air to the supply side of the divided ventilation ducts. The ventilation fans exhausting moisture, gases and odors continually pull exhaust air from the building into the exhaust side of the divided ducts, and discharge it out of the building. This creates a slight vacuum inside the building which draws the fresh air from the supply side of the divided ventilation ducts into the building (See Figures 2 and 3). In this way the building ventilation fans provide the power to move the air through the collector instead of having a separate fan perform this function.

The system is constructed so the collector can preheat winter ventilation air (2.3 cfm per ft^2 of collector) for both the nursery and farrowing rooms (See Figure 2). During the summer, ventilation air for the nursery is pulled directly from outdoors into the nursery room through a duct located in the work area (See Figure 5). Ventilation air for the farrowing room is pulled through the collector year-round. During the summer the collector is covered to reduce solar radiation on the blocks and to provide cooling for the farrowing room ventilation air. On summer nights a fan in the middle of the collector is turned on to exhaust air from the plenum to the outdoors (See Figure 6). This increases the amount of cool nighttime airflow through the blocks, thus increasing the cooling of the blocks to provide additional cooling capacity during the following day. During summer days this fan does not operate and only the ventilation fans in the farrowing room pull air through the collector, thereby cooling ventilation air before it is introduced into the farrowing room (See Figure 5).

COST

The cost for the materials and labor for the collector system was \$7,601.57 for 590 ft^2 or \$12.88 per ft^2 of collector area. These costs are in 1981 dollars. The materials and labor cost for the building was \$30,000. The materials and labor cost for the solar collector system added 25 percent to the building cost.

PERFORMANCE

A. Thermal

The vertical solar wall has been used successfully to preheat winter ventilation air for the farrowing and nursery rooms since October 1981. During a 10 day period in January 1982 the building required 6.48×10^6 Btu of supplemental heat. This heat requirement was calculated from the "best estimate" ventilation rate, building heat loss factors, and the temperature differences between air inside the farrowing and nursery rooms, and air outside the building. The solar collector provided approximately 54 percent (3.49×10^6 Btu) of this load, as calculated from the temperature rise of the air and a "best estimate" of the airflow rate through the collector. During these 10 days the average indoor temperature for both rooms was 71°F while the average outdoor temperature was 24°F (range was 1 to 41°F).

For 16 days in February 1982 the building required 16.5×10^6 Btu of supplemental heat. Approximately 45 percent of this quantity (7.5×10^6 Btu) was provided by the solar collector. The average indoor and outdoor temperatures were 69°F and 14°F, respectively. The range of outdoor temperatures was -8 to 40°F.

Examples of typical outdoor, collector outlet, and indoor air temperatures for the farrowing and nursery rooms are presented in Figures 7 and 8, respectively. The temperature of the air at the collector outlet remained higher than the temperature of the air entering the collector, especially at night. This demonstrated the effect of the concrete blocks as heat storage. The storage allowed a portion of the solar heat gathered during the day to be stored for release during the night. The storage of solar heat was also demonstrated in the time lag between the rapid rise in outdoor air temperature and the increase in temperature of the air leaving the collector.

The cooperator has used the solar collector to "cool" summer ventilation air for the farrowing room. Data collected for 23 days in July of 1981 showed that the collector provided 41.8×10^6 Btu of heating during the nighttime and 31.7×10^6 Btu of cooling during the daytime for a net heating gain of 10.1×10^6 Btu. Despite the covering of the collector and the use of additional energy to operate the cooling fan the net effect of passing summer ventilation air for the farrowing room through the collector was to add heat to the farrowing room. However, the collector did have a temperature moderating effect on ventilation air entering the farrowing room. The temperature of the air entering the farrowing room was lower than the daytime outdoor air temperature and higher than the nighttime outdoor air temperature (See Figure 9). The data did not allow a complete evaluation of possible benefits of this moderating effect from an animal performance standpoint. Research to date has not fully addressed the influence on sow productivity (milk production and breed-back efficiency) of a moderated temperature range versus higher daytime and lower nighttime temperatures.

While the summer ventilation air for the farrowing room passed through the solar collector a separate air inlet allowed outside air to be drawn directly into the nursery. Air temperature in the nursery remained at reasonable levels for these pigs, as can be seen in Figure 10. Pig performance was judged to be quite satisfactory though data, per se, were not available.

B. Economic

Extrapolating from the winter heating data, the solar collector should save an average of 45 percent of the annual heating load for the building. Using an average annual heating load of 5973 degree days requiring 149×10^6 Btu of heat the solar collector should save 67.0×10^6 Btu or 729 gal of propane.

With a propane price of $0.56 per gal, the estimated annual fuel savings would be $408. The collector cost of $7,601 divided by $408 savings per year yields a simple payback period of nearly 19 years. This includes no economic returns from the "cooling" aspect of the solar collector system, and makes none of the assumptions required for the time-value-of-money approach for life-cycle cost analysis. The omission of economic benefits from "cooling" are considered valid since the net effect was really heating. Further, elimination of the collector-cooling system would not have necessitated incorporation of a separate cooling system.

The solar collector life is expected to be 20 years, except for the glazing material. Current estimates of glazing life are 5 to 10 years. Without subsidy, this collector cannot be considered cost-effective.

C. Maintenance

Periodic maintenance of the ventilation system (including the fan for summer cooling of the blocks) will keep the majority of the solar collector system in good condition. Glazings should be checked periodically for damage, especially after storms. Check the collector system joints for cracks that need to be caulked. Check the air inlet to the collector periodically to be sure they are free from dust. Wash the outer glazing of the solar collector when it becomes dirty. Maintenance of the remainder of the collector system will be similar to maintenance of the exterior of the building.

COMMENTARY

A. Construction Suggestions

1) Glazing materials for the collector should be chosen to withstand ultraviolet light degradation and to have good solar energy transmittance characteristics.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places can greatly affect collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long life caulking materials. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire screening to prevent birds from entering the solar system and the building.

4) The nursery ventilation air inlet for summer should be covered with 1/2 x 1/2 in. wire screening and a hood to prevent birds and rain from entering the ventilation duct.

5) Provide enough overhang so rain and snow do not blow into the collector inlet, but don't put in too much overhang or shading of the collector will result.

6) Install all fans and shutters in a manner which allows access and/or removal for servicing and repairs.

B. Operation suggestions

1) Sometime during the fall (management decision as to when) the divider panel that goes into the divided ducts should be removed. This is the duct divider panel shown in Figures 5 and 6. Remove the covers from the face of the solar collector at this time.

2) When the duct divider panel is removed (See preceding point) the nursery ventilation air inlet for summer ventilation should be covered with an insulated door to reduce heat loss in this location and to prevent introduction of large quantities of cold infiltration air into the building.

3) Sometime during the spring (management decision as to when) the insulated door should be removed from the nursery ventilation air inlet. The duct divider panel should be installed to divide the ducts for independent summer ventilation. Cover the collector at this time.

C. Suggested Modifications

1) The 8 x 8 x 16 in. solid concrete blocks do not have the full storage mass of 2 ft^3 per ft^2 of collector area as generally recommended. Other blocks may be substituted for the solid concrete blocks. The "trick" to substituting other blocks is to provide proper spacing between the blocks for airflow. Allow between 3 and 5 ft^2 of open area in the block wall per 1,000 cfm ventilation air (maximum airflow rate through collector is normally summer ventilation rate).

2) The building design described in this report requires the central duct work for good ventilation. It is easier to accommodate proper ventilation without duct work by using end-to-end room construction as opposed to side-by-side. This eliminates the need for the divided central ducts and allows use of over-the-wall slot inlets for ventilation and ventilation fans centered in a group along the north wall of the building. In all cases, fans must be protected from direct discharge into the wind.

3) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

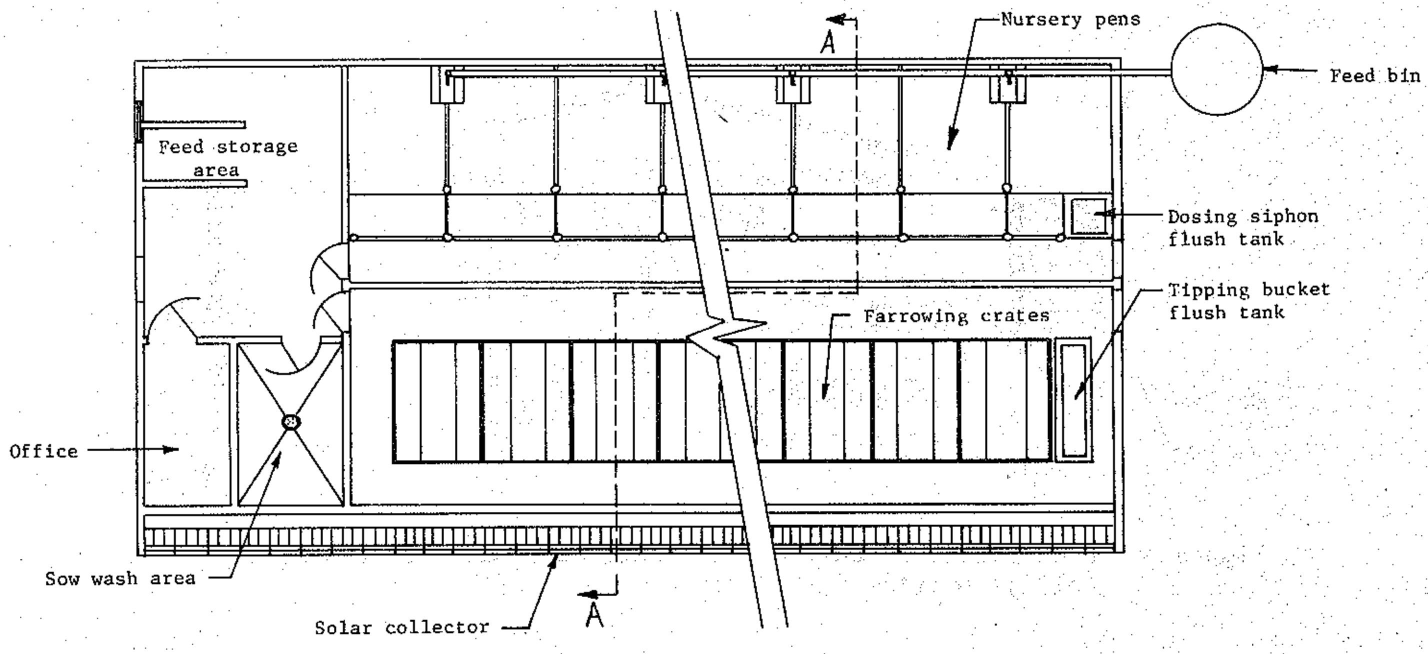

Figure 1. Floor plan of the 12-sow farrowing/200-pig nursery building (Buescher). Details omitted for clarity.

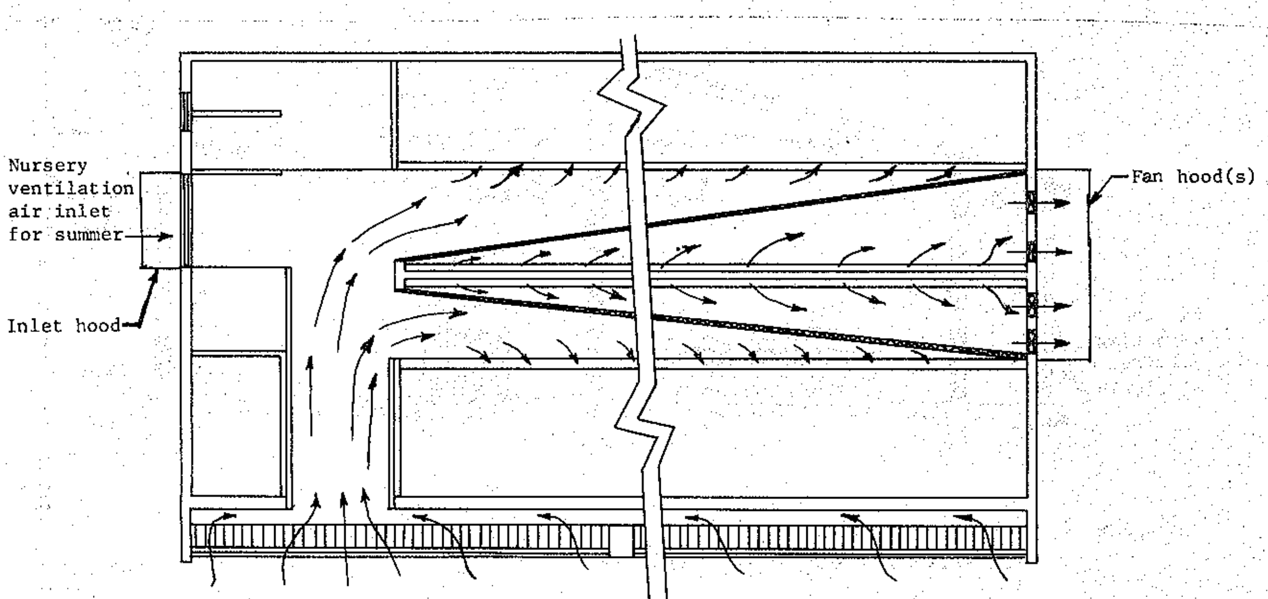

Figure 2. Floor plan schematic of winter ventilation airflow in the collector and ventilation ducts (Buescher). Details omitted for clarity.

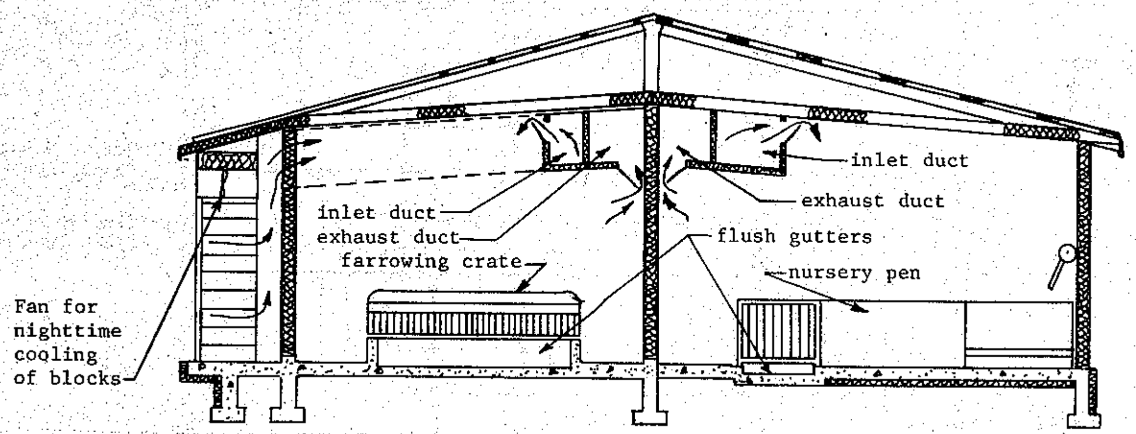

Figure 3. Cross section schematic of ventilation airflow (Buescher). Details omitted for clarity.

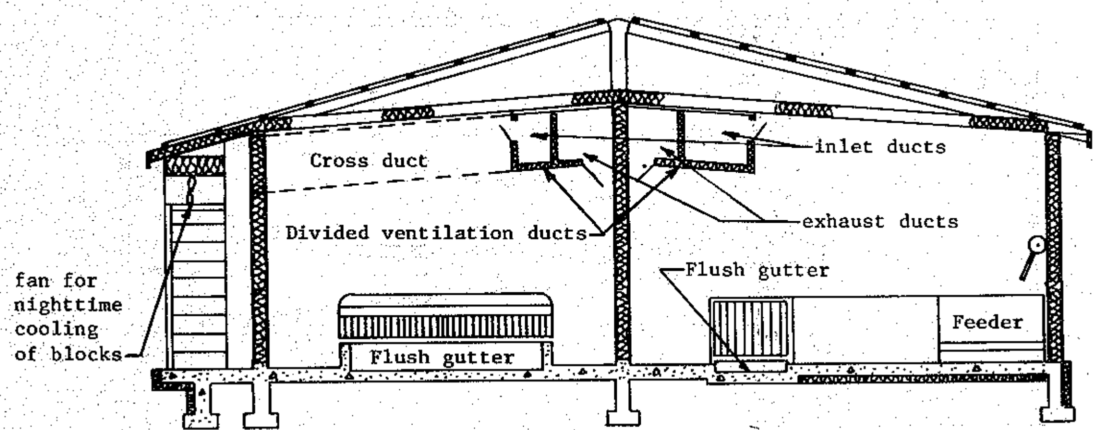

Figure 4. Partial cross section of the building (Buescher). Details omitted for clarity.

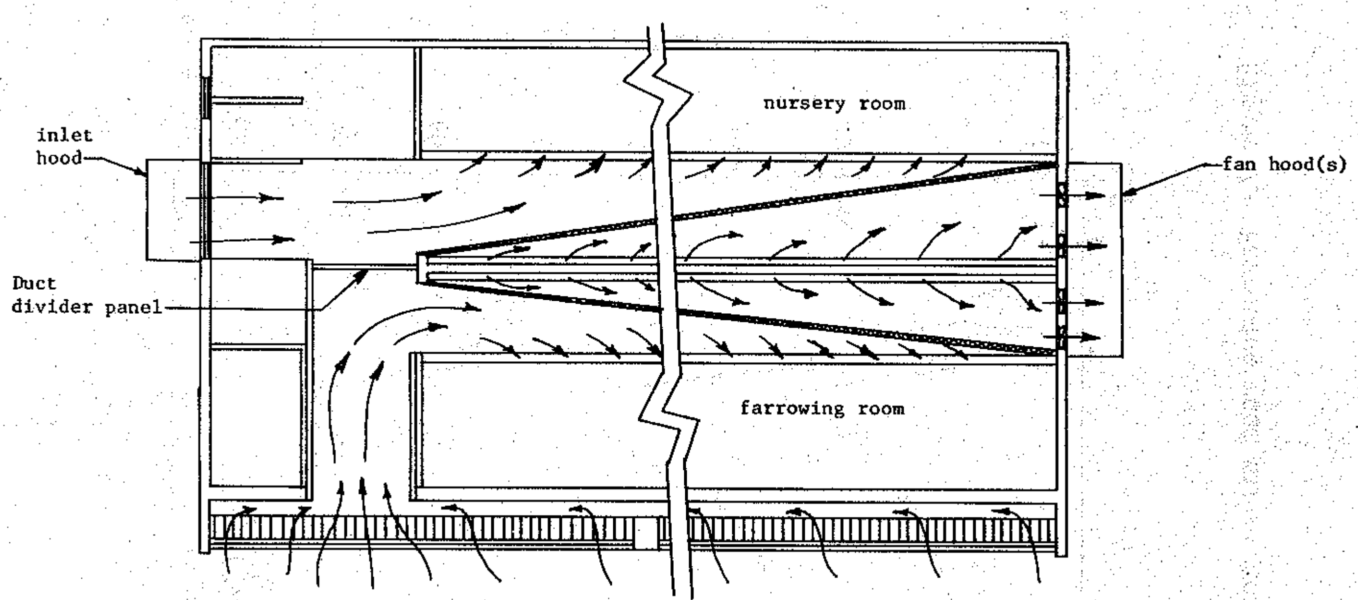

Figure 5. Floor plan schematic of summer daytime ventilation airflow in the collector and ventilation ducts (Buescher). Details omitted for clarity.

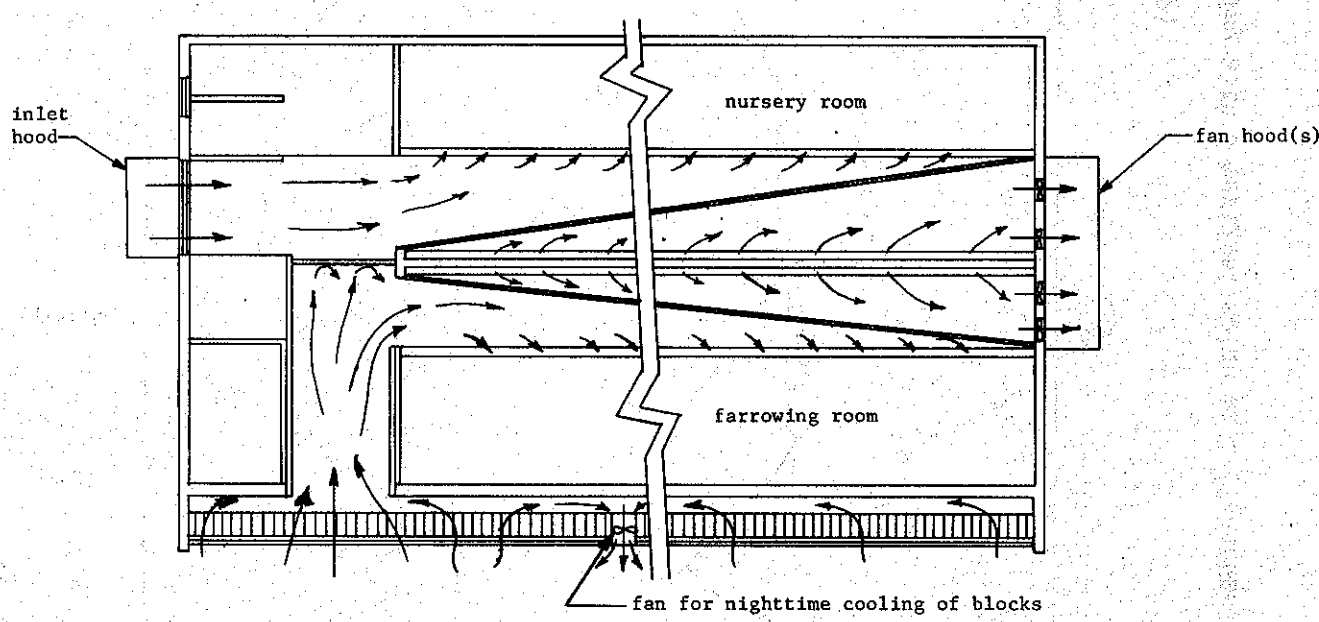

Figure 6. Floor plan schematic of summer nighttime ventilation airflow through the collector and ventilation ducts (Buescher). Details omitted for clarity.

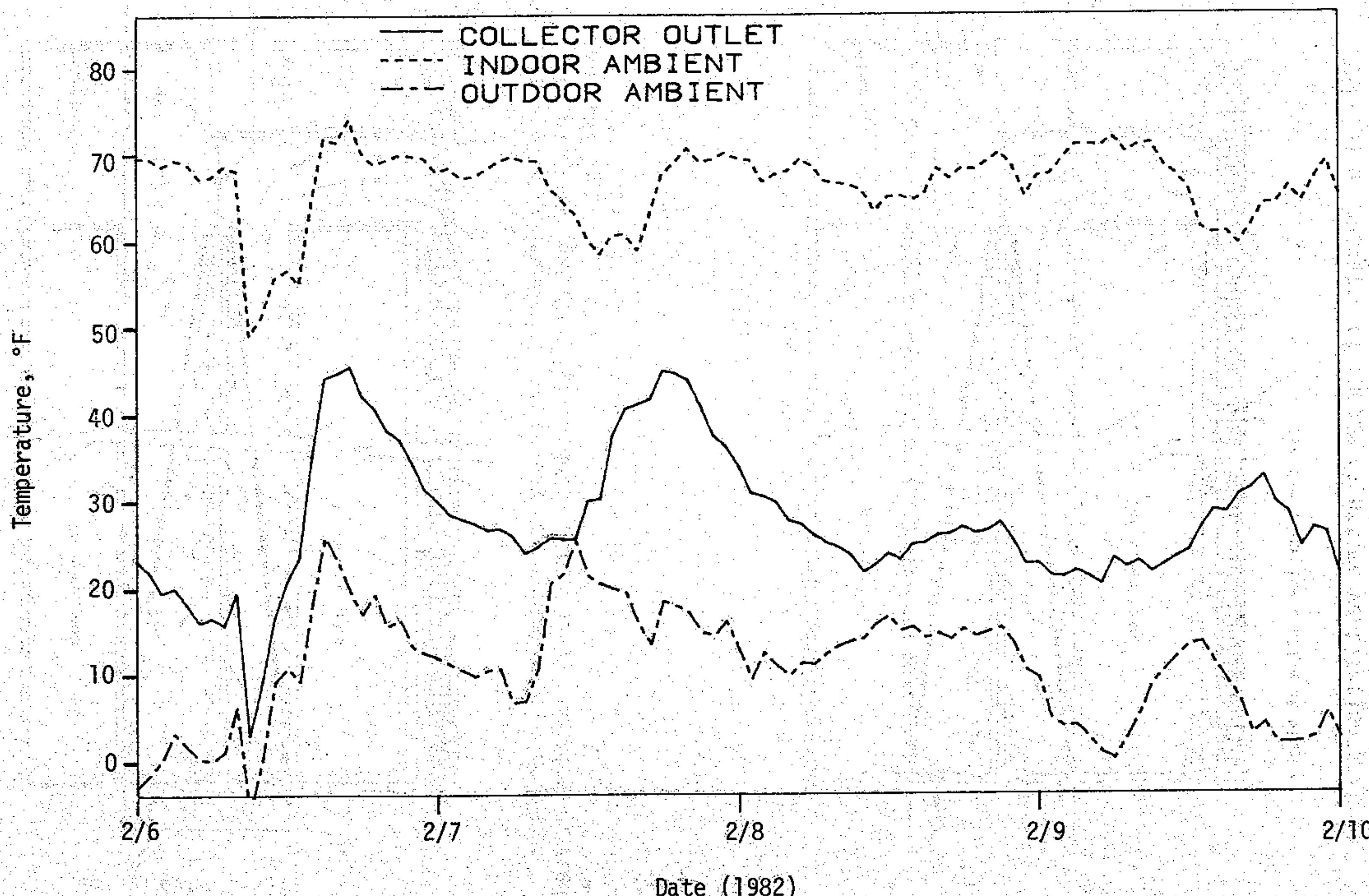

Figure 7. Farrowing room winter ventilation air preheating with a vertical solar wall (Buescher).

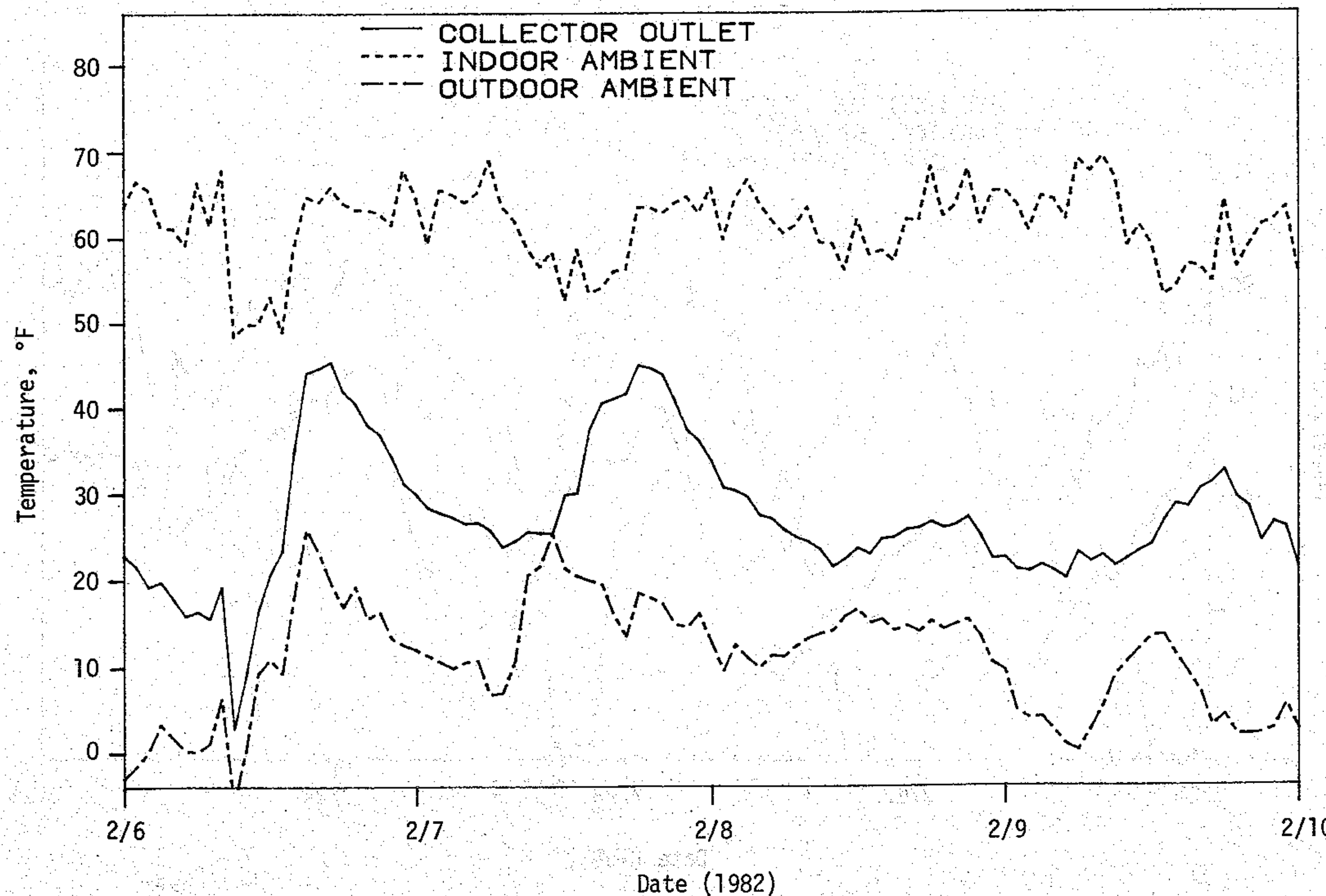

Figure 8. Nursery room winter ventilation air preheating with a vertical solar wall (Buescher).

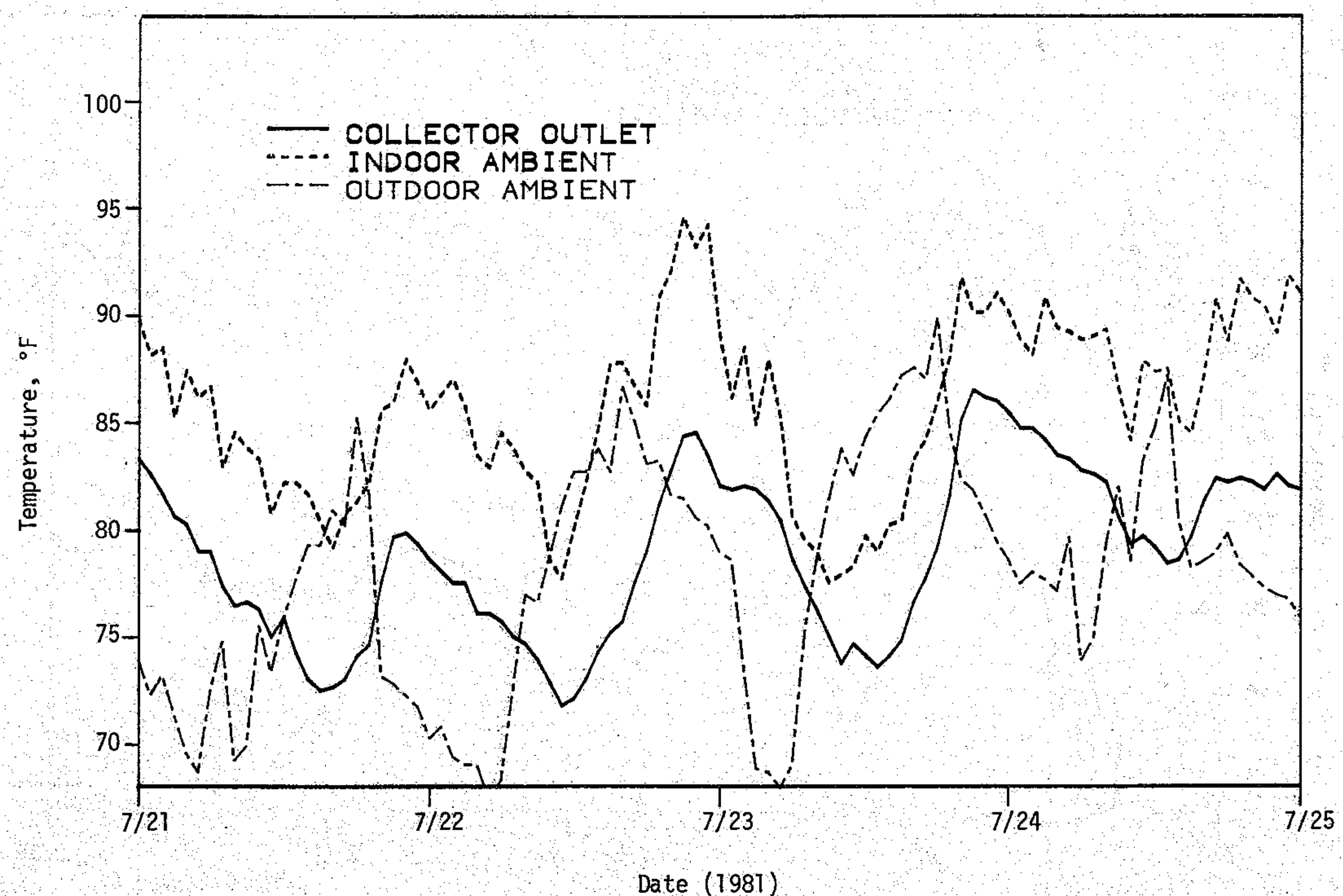

Figure 9. Farrowing room ventilation air cooling in the summer with the vertical solar wall (Buescher).

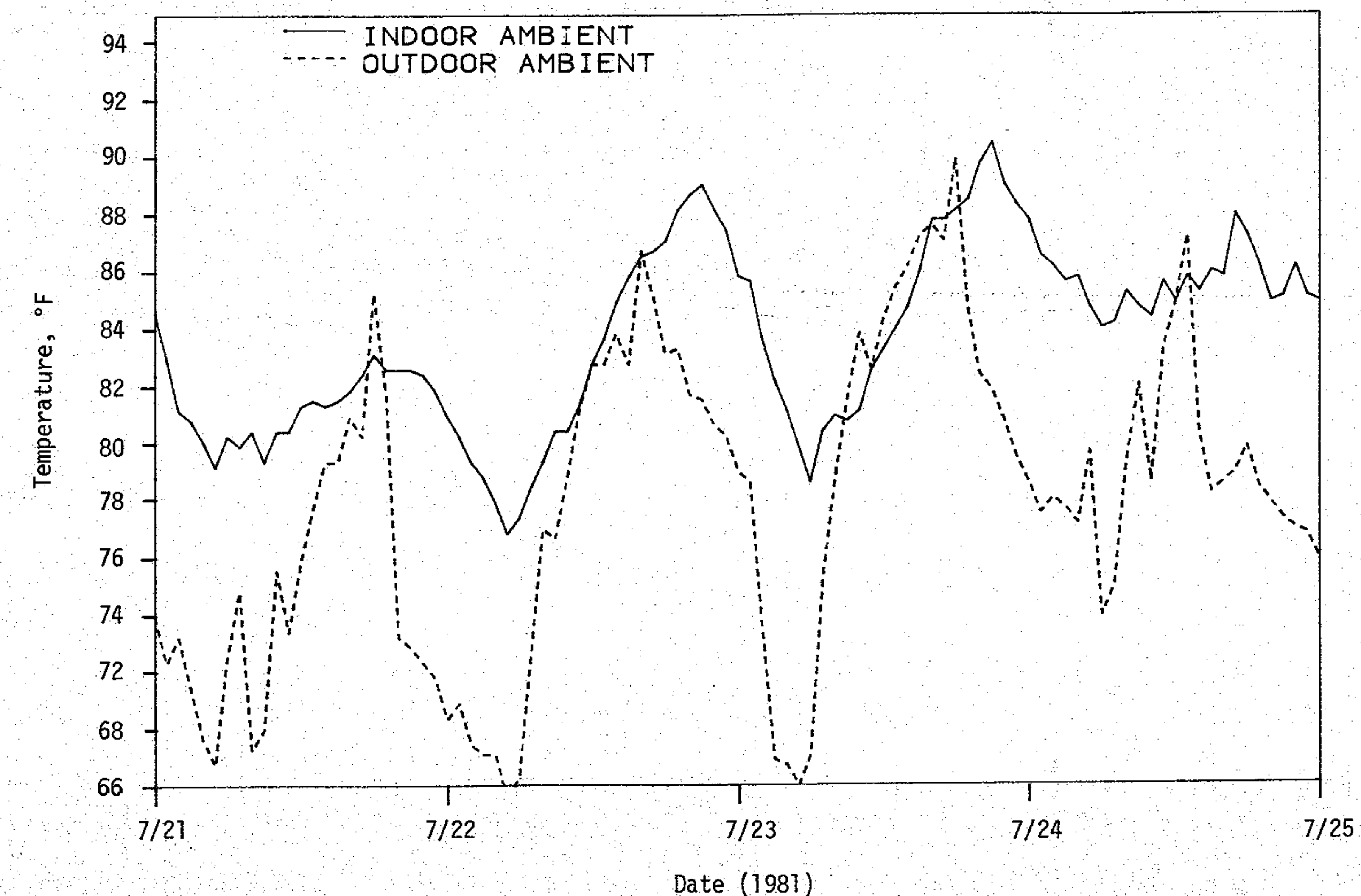

Figure 10. Outdoor air used to ventilate the nursery room during the summer (Buescher).

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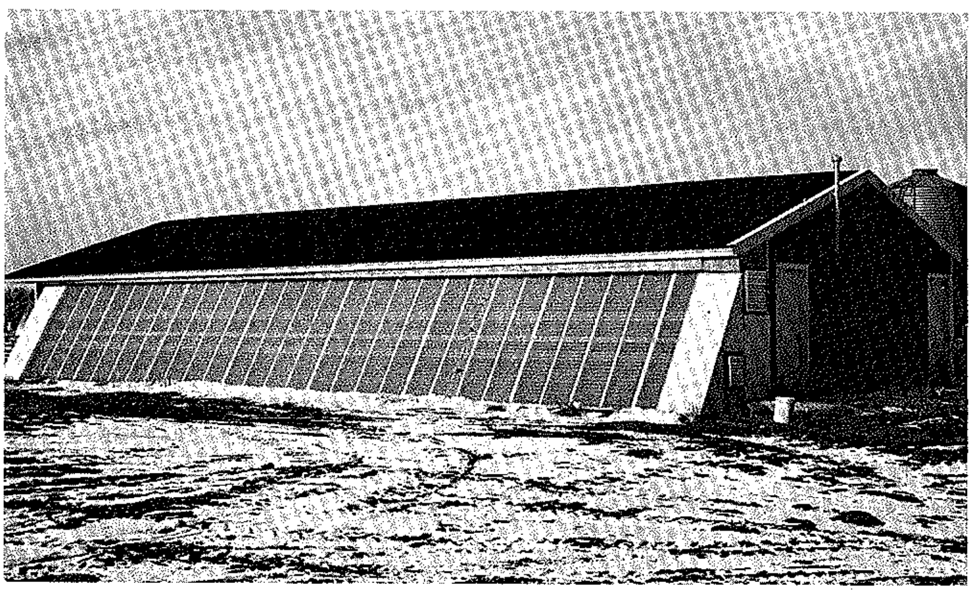
SWINE FARROWING BUILDING WITH SLANT SOLAR WALL

Elwyn Fitzke
Glenvil, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-5



20-sow farrowing building with a slant wall for winter ventilation air preheating and summer water preheating.

SWINE FARROWING BUILDING WITH SLANT SOLAR WALL

Elwyn Fitzke
Glenvil, NE

THE FARM

Elwyn Fitzke and his father, Ward, own and operate the farm on which the demonstration facility is located. The farm (40°26'N, 98°10'W) is located in south central Nebraska's Clay County. The farming operation consists of raising corn and soybeans on 400 and 100 acres of irrigated land, respectively. Sorghum and soybeans are grown on 150 and 50 acres of dryland, respectively. The livestock operation includes a 50-cow herd cow-calf operation and a 60-sow farrow-to-finish operation producing between 900 and 1,000 market hogs per year.

The Fitzke's have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing and instrumenting this system. The Fitzke's constructed the solar heating system which was added on to the existing building. Information in this report includes a description of the farrowing house and the solar collector in both the ventilation air preheating and water heating modes. Guidelines on performance and operation of this system and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing Building

The 24 x 66 ft building contains a 24 x 60 ft farrowing room plus an office and sow wash in the east end of the building (See Figure 1). The building has a gable roof, is mechanically ventilated and utilizes in-floor water lines to provide a warm floor creep area for the young pigs. The farrowing room has two rows of 10 farrowing crates with the rear 30 in. of each crate over slats and an under-slat flushing gutter (See Figure 2). The ventilation system includes over-the-wall slot inlets with three exhaust fans located in a "bank" centered along the north wall of the building. Backup heat is provided by a propane-fired hot water heater which circulates warm water through the in-floor water lines when the building requires more heat than the solar collector can provide.

B. The Solar Collector System

The 450 ft^2 collector used on this building consists of concrete slats stacked in a triangular pile along the south wall of the building with a 60 degree sloped front absorber surface. The slat stack starts 6 in. away from the south building wall to provide a plenum for airflow (Figure 2). Horizontal gaps between each layer of slats in the stack are formed by using strips of flat metal bars to separate the slat layers. The thickness of the metal spacer bars is varied with the thinnest bars at the top and the thickest bars at the bottom of the collector. This feature of the design is to help maintain even airflow through the collector. The sloped south surface of the slats is painted flat black. Copper water lines are laid on top of the ledges formed by each layer of slats in the stack (See Figure 2). Two Filoplate® #556 glazing layers (outside layer corrugated, inner layer flat) cover the sloped slat stack and water lines.

There are several ventilation system operation modes on the collector which serve the needs of the building during different seasons. During the winter, ventilation air (1.5 cfm per ft^2 of collector) is preheated as it passes between the glazing layers, travels through the horizontal gaps between the slats into the plenum and then into the building through the over-the-wall slot inlet (See Figures 3 and 4). Backup heat is provided by the in-floor heat system.

In the spring and in the fall, warmer outside temperatures require higher ventilation airflow rates to remove heat from the building. Heated air is a detriment in this case so air is pulled through motorized shutters in the ends of the plenum allowing ventilation air to bypass the collector (See Figures 5 and 6). This air travels through the plenum behind the collector, through the over-the-wall slot inlet and into the building. This allows the collector to "stagnate" and store heat for use during cold nights (winter type operation).

For high airflow rate ventilation during the summer a baffle above the collector is opened to allow air to bypass the collector (over the top) and go directly into the building. The over-the-wall slot inlets on the north side of the building are opened to provide enough inlet area for summertime ventilation (Figures 7 and 8).

The collector has no ventilation airflow through it during the summer, but is used to heat water for the in-floor heat system. Water is circulated through the collector water lines and is heated by the hot slats and air in the collector as well as by direct heat gain from solar radiation. This water is pumped to an insulated storage tank (See Figure 9). The in-floor heat system uses the heated water from the storage tank as heat is required. Plans are to use the solar water heating system only during the summer (water lines drained in the fall and refilled in the spring) and to use the collector only as a ventilation air preheater during the winter. When necessary, a fan in the end of the collector exhausts hot air from the collector to the outside to keep the collector from overheating.

COST

The collector system, including all the materials and labor, cost \$9961.97 for 450 ft^2 of collector. This is \$22.14 per ft^2 of collector area or \$498.10 per sow. Note that this design includes a full 2 ft^3 of thermal storage mass per ft^2 of collector area and costs more than a vertical solar wall with 8 x 8 x 16 in. blocks having only 1.3 ft^3 of thermal storage mass per ft^2 of collector area. This cost includes all the extra equipment required to integrate the solar water heating system with the in-floor heating system. The water heating option represents \$1943.69 or 19.5 percent of the solar collector system cost. The 20-sow farrowing building, without the solar collector system, cost \$23,256, or \$1163 per sow. The solar collector system added 42.8 percent to this cost.

PERFORMANCE

A. Thermal

The solar collector was installed to preheat winter ventilation air and to heat water for the in-floor heating system during the summer. The collector has been used to preheat winter ventilation air during two heating seasons.

The solar collector system added sufficient heat to the ventilation air to provide all of the 2.69×10^6 Btu of supplemental heat required during 19 days in November 1981. Indoor and outdoor temperatures during this time averaged 67 and 42°F, respectively. The range of outdoor temperatures was from 18 to 66°F. During a fourteen day period in late November and early December 1981, the collector provided 77 percent (2.76×10^6 Btu) of the 3.58×10^6 Btu required. For this time period indoor and outdoor ambient temperatures averaged 65 and 36°F, respectively, with a range of 22 to 58°F in outdoor ambient temperatures. A plot of the variations in the indoor, collector outlet and outdoor ambient temperatures during this time period are presented in Figure 10. The effect of stored solar heat being released at night is evidenced by the continuation of a positive temperature difference between outdoor ambient and the ventilation air at the collector outlet.

Low hog prices and associated limits on cash flow, construction delays, and delays in obtaining some system components combined with functional problems to severely limit the use of the summertime solar water heating system. The result has been collection of insufficient useful data to permit a realistic evaluation of system performance. The cooperator has advised of his intentions to continue development, testing and operation of this component of the solar system despite termination of the overall project. To the extent possible, University of Nebraska Agricultural Engineers will participate in this continued effort.

B. Economic

With no data from the solar water heating operation of the collector, it is impossible to determine economic returns for this part of the system. The winter ventilation air preheating data are limited.

The normal winter heating season consists of 5973 heating degree days with a base temperature of 65°F. The indoor ambient air temperature of this building is normally kept at 72°F. With the exposure coefficient of 1053 Btu/hr·F° and an estimated heat production from the 20 sows and litters of 20,000 Btu/hr, the animals in the building can maintain a 72°F indoor ambient temperature if the outdoor ambient temperature is 53°F or above.

The normal winter heating season for this building consists of 3277 heating degree days with a base temperature of 53°F. With the given exposure coefficient and heating load, the annual heating requirement comes to 82.8×10^6 Btu. Assuming that the solar collector system provides 70 percent of this heat, normally provided by propane costing $0.56 per gal, the solar collector system should save 840 gal of propane or $471 annually. The $9917 collector system saving $471 annually has a simple payback period of 21.0 years. Additional savings from the summer water heating portion of the collector, as well as tax credits, interest, inflation and the time-value of money approach to determining the life cycle cost of the system would reduce this payback period.

C. Problems

The water heating part of the solar collector system was installed in accordance with initial design concepts but several problems kept it from operating long enough to allow collection of useful data. A discussion of these problems will hopefully prevent others from repeating these mistakes.

Zone control valves used to interconnect the solar heated water storage tank into the system that supplied hot water to the in-floor heat system failed to perform satisfactorily. An attempt was made to operate both valves off one thermostat to prevent conflicting valve settings.

However, the electrical circuit to initiate a change in valve position caused the valves to continually rotate. This situation developed due to slight differences in valve rotational speeds--and a resultant continuous electrical current through their controlling motors. The problem was solved by replacing the rotating zone control valves with solenoid valves.

A commercial water tank with sufficient capacity to store the required quantity of water was judged to be prohibitively expensive. This led to a decision by the cooperator to make his own tank out of 1/4 in. steel plate. The tank was constructed and installed. Pressurization of this tank, required for proper system operation, turned the tank from a rectangular box into a quasi-spherical shape. This was deemed unsafe and the system was shut down. Re-design of the solar water heating system resulted in this problem being circumvented. The revised system currently being installed allows operation of the storage tank as a nonpressurized container but requires two additional circulator pumps and associated controls.

COMMENTARY

A. Construction Suggestions

1) Glazing materials for the collector should be chosen to withstand ultraviolet light degradation and have good solar energy transmittance characteristics. The glazings must be able to withstand the impact of icicles and snow that drop off the roof during winter.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places cause serious adverse effects on collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long lasting caulking materials. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlet.

5) Install the collector on a one percent slope so the water lines lying on top of the slats will drain properly for winter collector operation.

6) Be sure to provide air bleed valves at the high point of all collector water lines to aid in collector drain-down for winter.

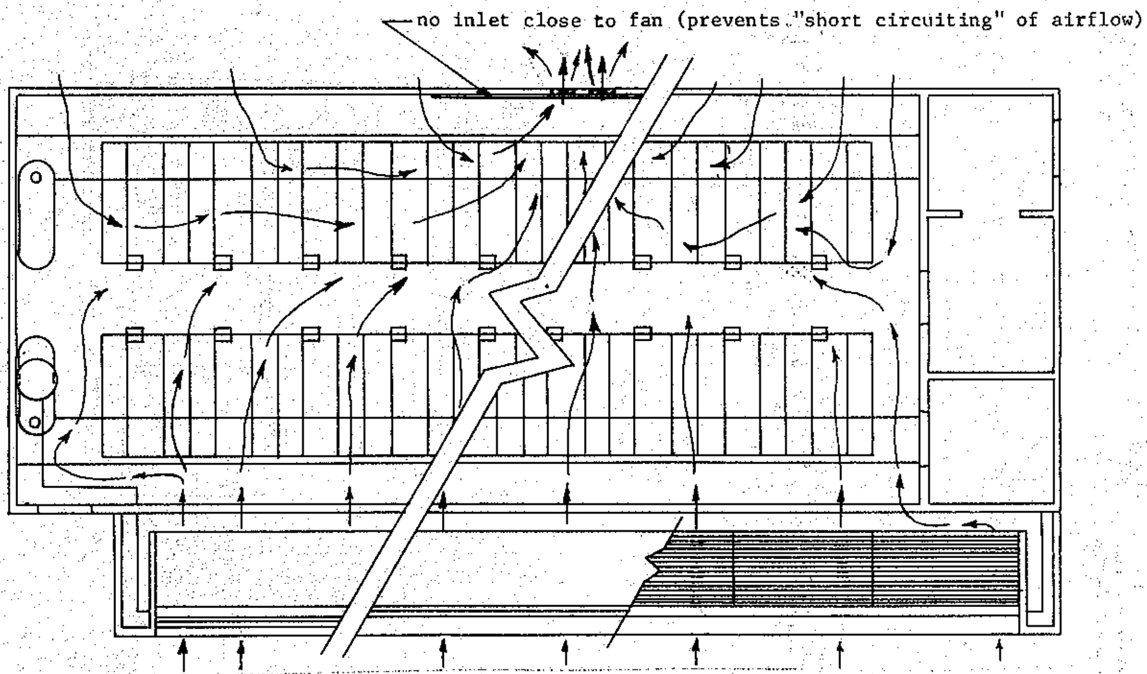


Figure 7. Floor plan schematic of summer ventilation airflow pattern (Fitzke). Details omitted for clarity.

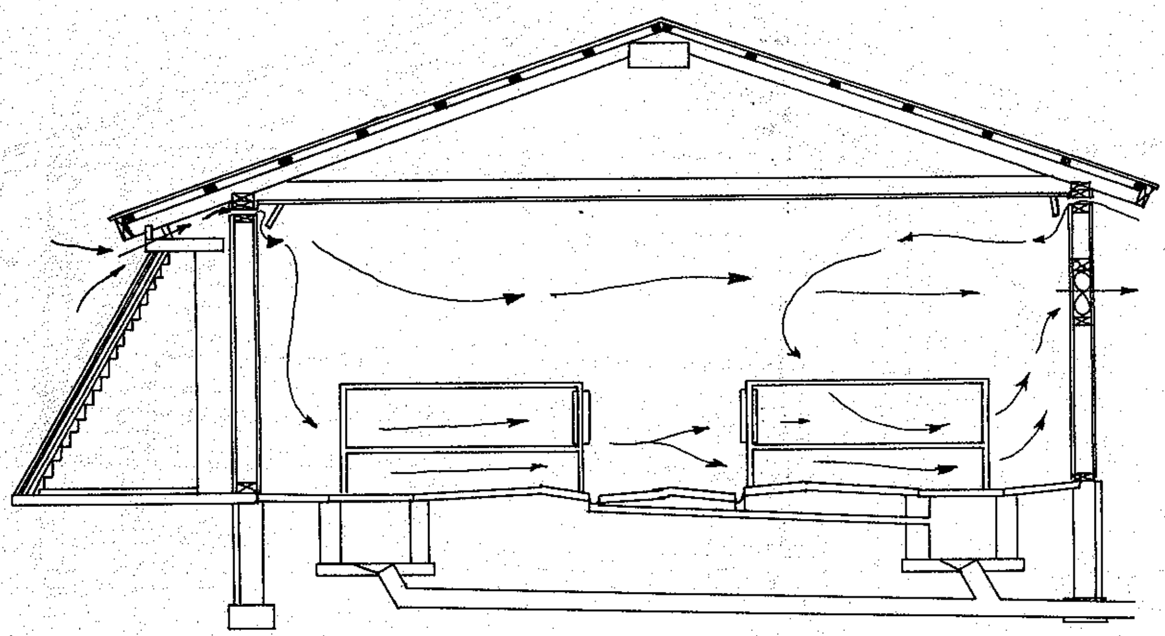


Figure 8. Cross section schematic of summer ventilation airflow pattern (Fitzke). Details omitted for clarity.

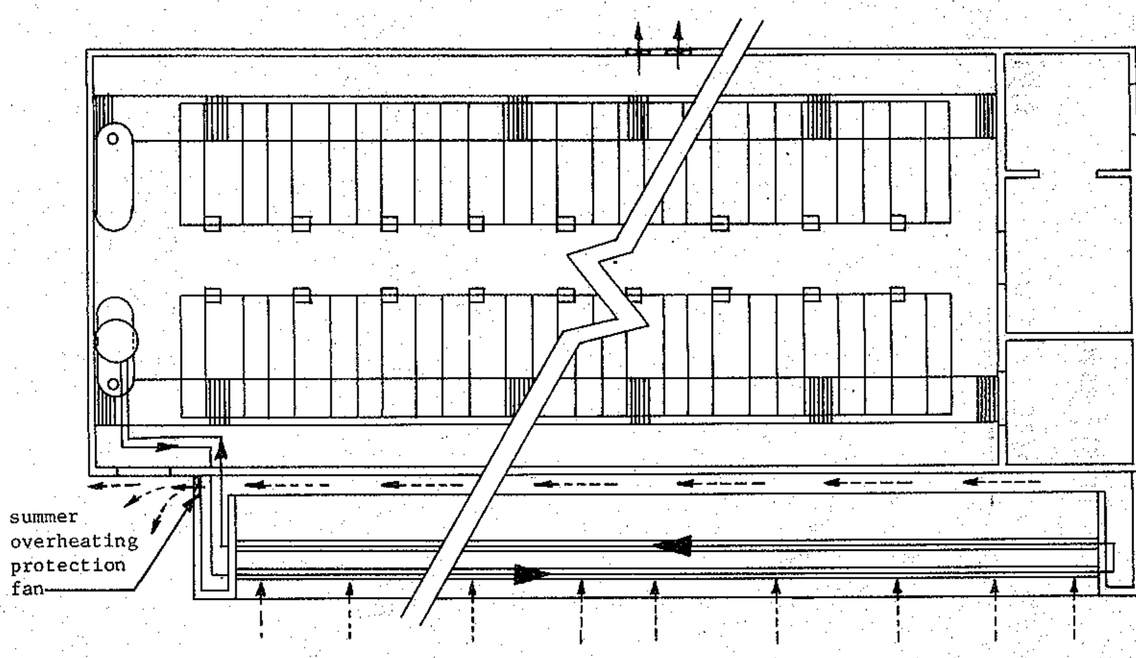


Figure 9. Floor plan schematic of summer water flow through the collector (Fitzke). Dotted arrows indicate airflow pattern on overheating protection. Details omitted for clarity.

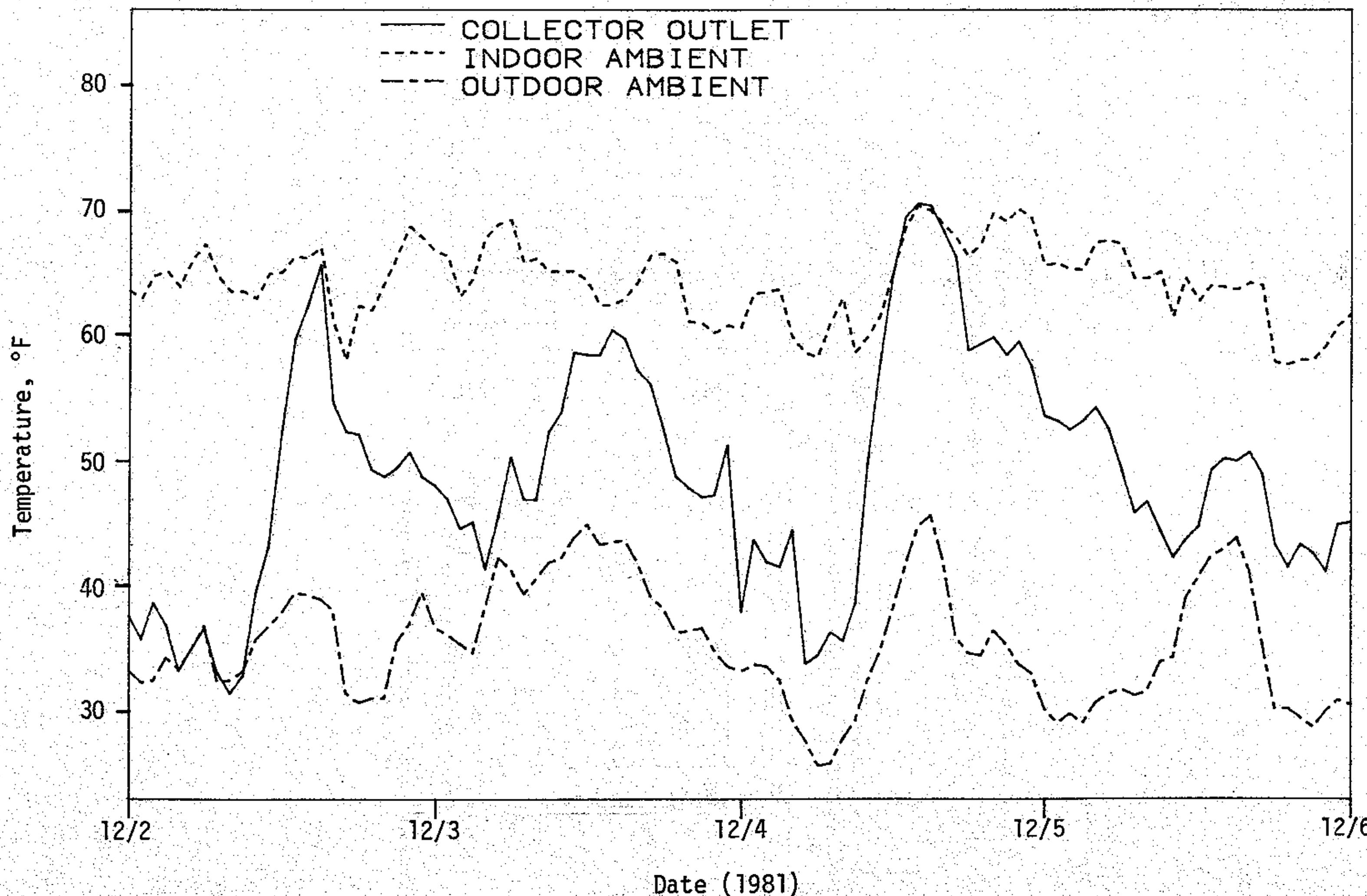


Figure 10. Farrowing house winter ventilation air preheating with the slant solar wall (Fitzke).

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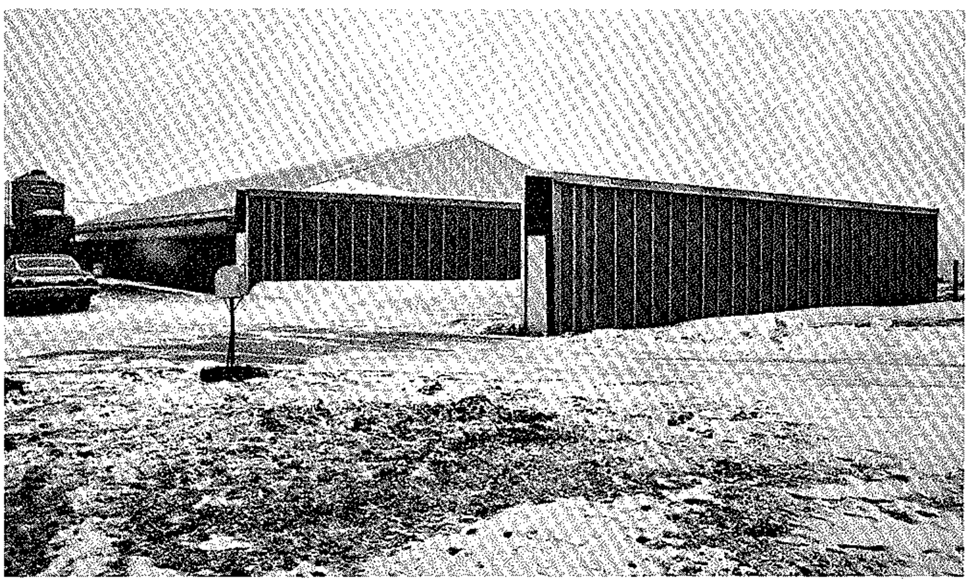
SWINE FARROWING COMPLEX WITH TWO VERTICAL SOLAR WALLS

Logan Valley Swine
Lyons, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-6



Vertical solar collectors (2) for preheating winter ventilation air for the 80-sow farrowing building (8-10 sow rooms).

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[illegible] SOLAR WALLS

Logan Valley Swine
Lyons, NE

[illegible]

[illegible]

SWINE FARROWING COMPLEX WITH TWO VERTICAL SOLAR WALLS

Logan Valley Swine
Lyons, NE

THE FARM

Logan Valley Swine Breeders, Inc. is a pig coop which is located in northeastern Nebraska's Burt County. The solar site is located at 42°2'N, 96°29'W. The operation consists of a 500-sow farrow-to-finish operation marketing 8500 hogs per year. Jim Blasey is the manager of the facilities to which the solar system was added.

Logan Valley Swine, Inc. has cooperated with the University of Nebraska, the U.S. Department of Agriculture, and the U.S. Department of Energy in designing, constructing, instrumenting and monitoring this system. Information in this report includes a description of the farrowing facility, a description of the solar system and the cost of the system. Some system performance results and suggestions for the operation and modification of this system are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Solar Farrowing Building

The farrowing building contains 8 rooms with 10 farrowing crates per room (See Figure 1). The farrowing crates have full wire mesh floors above deep pits (See Figure 2). Ventilation is accomplished by bringing fresh air into a connecting hallway across the west end of the farrowing rooms. The air then moves through inlets over the west wall of each room and is exhausted from above the manure in the pit by a fan at the east end of each room. Heat lamps are used as necessary for the newborn pigs. A vented radiant heater provides heat to the farrowing rooms when the solar collector cannot meet the farrowing building demand for heat.

B. The Solar Collectors

Two solar collectors are used to preheat winter ventilation air and cool summer ventilation air for the farrowing building. The 55 x 10 ft northernmost collector is attached to the south wall of the farrowing building and uses concrete slats (2.0 ft^3 of thermal storage mass per ft^2 of collector) stacked with thin metal spacer bars between the slat layers to provide horizontal gaps for airflow through the slats (See Figure 3). The metal spacer thicknesses were varied, with the thickest spacer bars in the east third of the collector, the medium thickness in the middle third, and the thinnest spacer bars in the west third of the collector. This was done to help maintain even airflow through the collector. The south face of the slats is painted black and covered with two layers of Filoplate® #556 glazing (inner layer flat, outer layer corrugated) to form the collector. A 3 in. space between the back of the collector and the south building wall serves as an air plenum and duct for the system.

The south collector, also 55 x 10 ft, uses 6 x 8 x 21 in. (nominal) solid concrete blocks for the heat storage (approximately 1.4 ft^3 of thermal storage mass per ft^2 of collector) and absorber (See Figure 3). The spacing between the blocks is varied in the same manner as in the north collector to help maintain even airflow through the collector. The south side of the blocks is painted black and covered with the double glazing layers to form the collector. The southern collector is free-standing and is located approximately 35 ft south of the north collector. A 24 in. diameter insulated underground culvert serves as a connecting air duct between the south collector and the farrowing building (See Figure 4).

Air enters the collectors at the slot inlets near the eave overhang and travels between the glazings to the bottom of the collectors. A slot at the bottom of the inner glazing allows the air to travel between the inner glazing and the black surface of the blocks or slats, gradually filtering through the vertical gaps between blocks or horizontal spaces between slats. Once the air reaches the plenums behind the slats or blocks, it travels westward to the ends of the collectors. Air from the south collector then goes down into the underground culvert and travels through the culvert to the west end of the north collector. At this point, air from the two collectors mixes and enters the farrowing building hallway to provide preheated (or cooled, during the summer) ventilation air to the farrowing rooms (See Figure 5). A collector flowrate of 2.5 cfm per ft^2 of collector area occurs during a normal winter ventilation airflow of 35 cfm per sow.

COST

The total cost for the materials and labor to install both collectors was $16,704.63 for 1100 ft^2 of collector area or $15.19 per ft^2. Calculating this on a per sow basis translates to $208.81 per sow. No farrowing building construction cost data were obtainable.

PERFORMANCE

A. Thermal

Several problems prevented gathering sufficient data for analysis of the thermal and economic performance of this solar collector system. Despite this shortfall, several comments about the collector system can be made from the data available.

The structural support system for the free-standing collector has not shown any signs of failure, despite several occasions of wind speeds in excess of 60 mph. Thermal performance of this collector indicates insulation levels in the collector are adequate.

The temperature of air leaving the north collector normally varies from the temperature of the air leaving the south collector by only 3F° indicating airflow through the two collectors is nearly the same. The temperature drop of the air that passed through the underground air duct between the south collector and the north collector was normally 2F° showing that insulation of this duct was adequate. The temperature rise from the collectors in August and September of 1981 averaged 16F°.

Although this particular system does not have data for analysis, it is based on sound engineering principles. Extrapolation of performance data based on the minimal amount of information available and the performance of similar but smaller collector designs indicates the design concepts incorporated were valid and offer an alternative for retrofitting large existing installations.

B. Problems

A problem with the data logger prevented gathering much data during the first winter. Some malfunction of equipment kept the data cassette tape operating when it should have been off. Thus, one side of a data cassette tape filled up in less than two days rather than the normal time of 3 weeks.

A change in management, and management philosophy regarding the use of solar energy, kept the solar collector from being used during the second winter. No data could be collected under these circumstances.

The hallway serves as the duct from the solar collector to the farrowing rooms during the winter. In the summer, it serves as the duct from the evaporative coolers to the farrowing room. This may be a problem in that it is difficult to seal the alternate openings, preventing air leakage at low static pressure differences and airflow rates.

COMMENTARY

A. Construction Suggestions

1) Select only glazing materials which are resistant to ultraviolet light degradation and have good solar energy transmittance characteristics.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places can greatly affect collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long-life caulking. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlets. Do not use excessive overhang as this results in shading the collector.

5) Any collectors not attached to a building (free-standing) must be designed and built to withstand normal building loads including wind and snow loads.

B. Operation Suggestion

Some cooling of summer ventilation air can be accomplished without covering the collectors. However, it is recommended that the collectors be covered during the summer for increased cooling capacity. Do not cover the air inlets to the collectors!

C. Suggested Modifications

1) The use of the free-standing south collector greatly increased the cost per ft^2 of collector area for the total system. The free-standing collector was used in this instance only because calculations showed that more collector area was required than could be obtained with a collector attached to the building (on-site space limitations). It is recommended that collectors be attached to the south side of the building wherever possible and free-standing collectors be added only when extra collector area is required. This procedure reduces construction costs as well as exposed surfaces through which heat loss can occur.

2) Different footings were used underneath the north and south collectors due to the different storage materials. The 10 ft long slats were supported at the ends only and required footings 10 ft on-center perpendicular to the building. The solid blocks were supported on rigid insulation which covered the floor of the south collector and required a trenched footing underneath the full length of the south collector. Be sure to use a footing design compatible with the storage material.

3) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

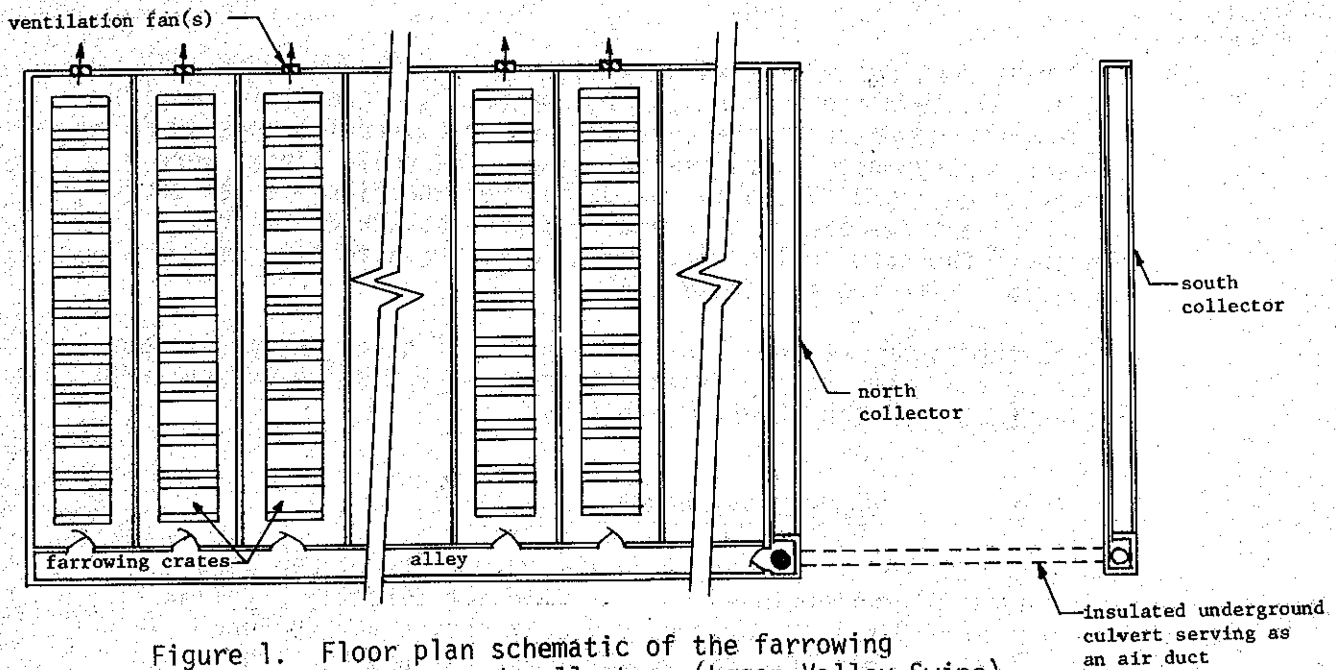

Figure 1. Floor plan schematic of the farrowing building and collectors (Logan Valley Swine). Details omitted for clarity.

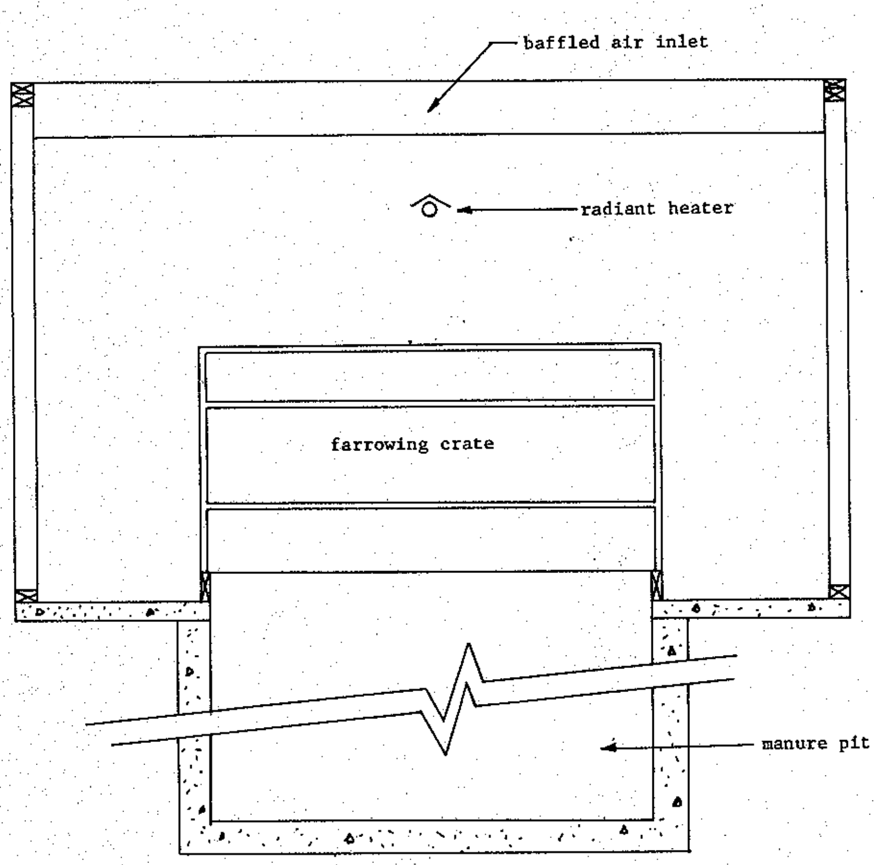

Figure 2. Cross section schematic of a farrowing room. (Logan Valley Swine). Details omitted for clarity.

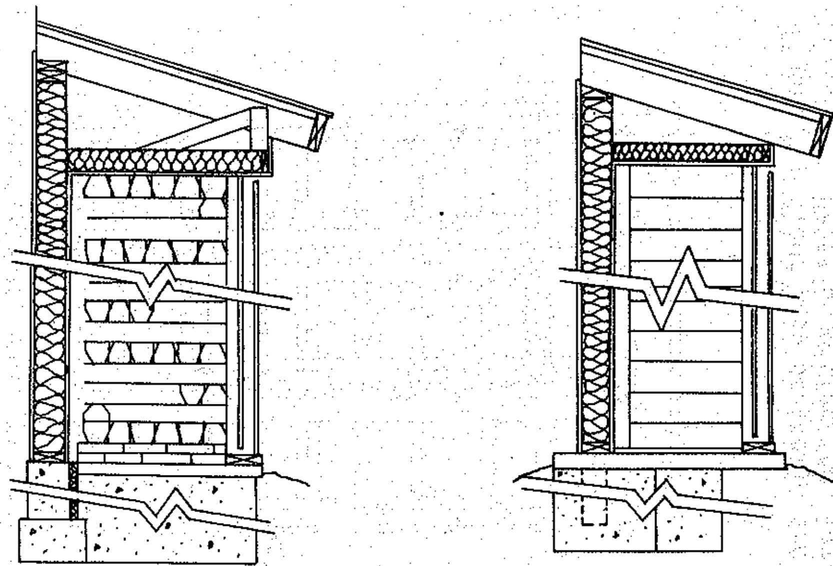

Figure 3. Partial cross sections of the north (left) and south (right) collectors (Logan Valley Swine). Details omitted for clarity.

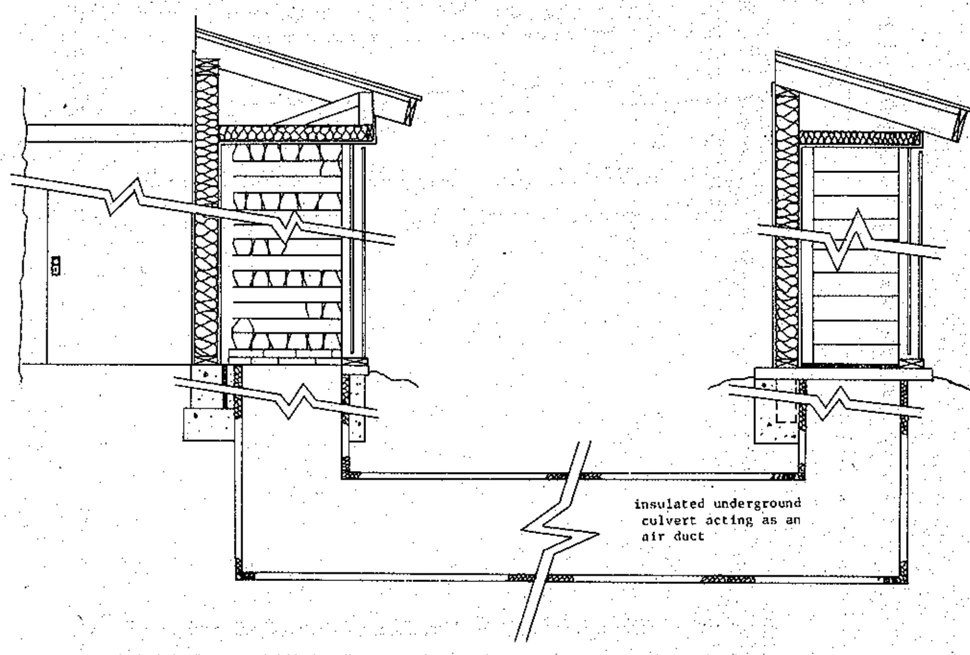

Figure 4. Partial cross section of the collectors and the connecting underground duct (Logan Valley Swine). Details omitted for clarity.

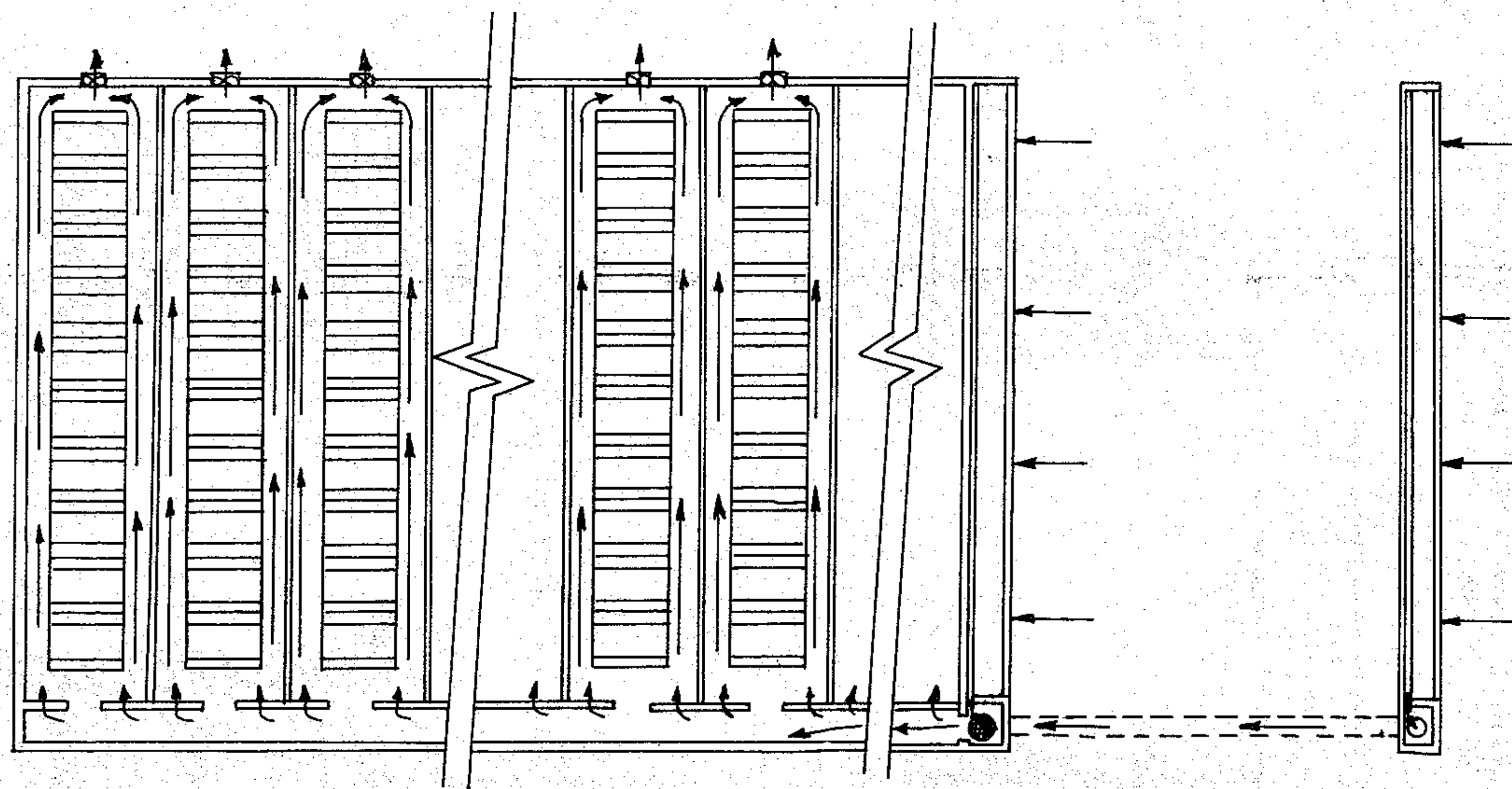

Figure 5. Floor plan schematic showing winter ventilation air movement (Logan Valley Swine). Details omitted for clarity.

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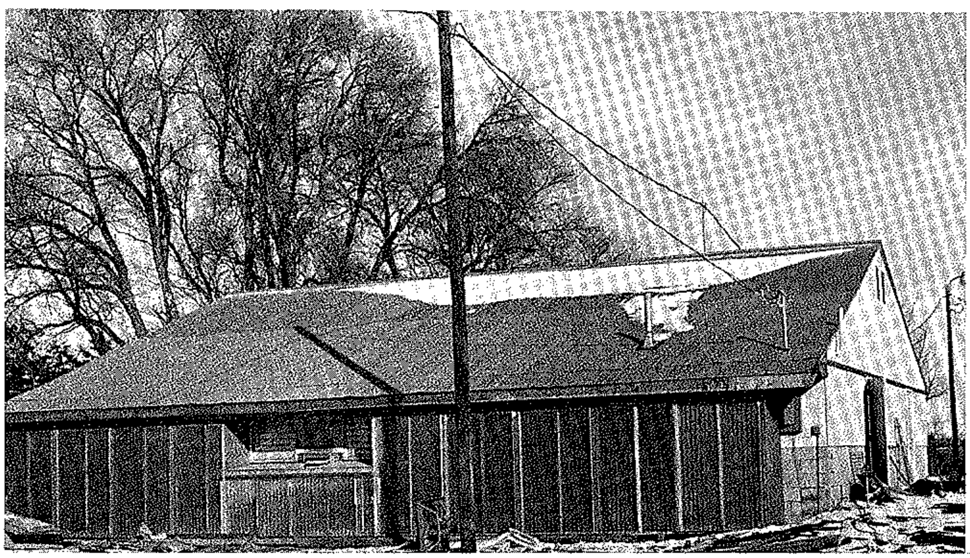
COMBINATION SWINE FARROWING-NURSERY WITH VERTICAL SOLAR WALL

Phil Menke
Cozad, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-7



16-sow farrowing-240 pig nursery building with solar collector for preheating or cooling ventilation air.

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COMBINATION SWINE FARROWING-NURSERY WITH VERTICAL SOLAR WALL

Phil Menke
Cozad, NE

THE FARM

Phil Menke owns and operates the farm on which this demonstration facility is located. The farm (40°53'N, 99°53'W) is located in central Nebraska's Dawson County. Dryland farming operations include approximately 30 acres of soybeans, 15 to 30 acres of wheat and 80 acres of alfalfa. Irrigated farming operations consist of raising corn on 130 acres. The livestock portion of the farming operation consists of a 60-sow farrow-to-finish operation with annual production of approximately 900 market-weight hogs.

The Menkes have cooperated with the University of Nebraska, the U.S. Department of Agriculture, and the U.S. Department of Energy in designing, constructing, instrumenting and monitoring this system. This report includes descriptions of the farrowing-nursery building and the solar collector system as well as the cost of the system. Guidelines on constructing this system and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing-Nursery Building

Two 22 x 46 ft rooms are connected side-by-side to make up the 44 x 46 ft farrowing-nursery building. The facility is a gable roof, mechanically ventilated building utilizing in-floor warm water lines to provide a warm floor creep area for the young pigs. The farrowing room contains two rows of 8 farrowing crates with the front of the crates facing the walls. An 8 ft wide slatted area with an under-slat flush gutter runs down the center of the farrowing room. The nursery side of the building has the same configuration except that pens are utilized instead of farrowing crates and the alleys at the sidewalls do not exist in the nursery room (See Figure 1). The nursery room is smaller than the farrowing room because an office and a sow wash occupy the east 10 ft of the nursery side of the building.

A ventilation duct runs the length of the building above the divider wall between the two rooms. This ventilation duct is not divided but has continuous slot inlets the full length of the duct opening into each room. The nursery room is on the south side of the building and ventilation fans for this room are centered in a bank along the south wall and vented through the collector to the outside. The farrowing room is on the north side of the building and has ventilation fans in a bank centered along the north wall exhausting ventilation air directly to the outside (See Figure 2).

B. The Solar System

The 300 ft^2 vertical solar wall uses concrete slats (approximately 2.0 ft^3 of thermal storage mass per ft^2 of collector) stacked vertically with thin metal spacer bars between the slat layers to provide horizontal gaps for airflow through the slats (See Figure 3). The metal spacer thicknesses were varied, with the thinner spacer bars at the top and thicker spacer bars at the bottom of the collector. This was done to help ensure even airflow through the collector. The south face of the slats is painted black and covered with two layers of Filoplate® #556 glazing (inner layer flat, outer layer corrugated) with slots for ventilation air inlets. A 3 in. space between the back of the collector and the south building wall serves as an air plenum and duct for the system.

During the winter, ventilation air (5.7 cfm per ft^2 of collector) is pulled through the slots in the glazings and is warmed by traveling through the gaps in the collector slats on its way into the plenum chamber behind the slats. From there the air can travel directly into the farrowing room through two ducts, one each at the east and west ends of the building that supply air to the central ventilation duct, and into the nursery room. The central ventilation duct supplies air to the north side of the farrowing room and the south side of the nursery. During the winter the north wall slot ventilation inlets to the nursery room are completely closed to prevent cold outside air from entering the nursery room. Small openings may be required in the north wall slot ventilation inlets to prevent "dead air" spots in the nursery room. Continuous operation ventilation fans in both the farrowing and nursery rooms cause a continuous airflow through the collector and through the ventilation ducts into the animal spaces from which the air is discharged to the outside. Air moving through the animal spaces picks up odors, gases and moisture for subsequent discharge from the building (See Figures 3 and 4). The in-floor heat water lines provide the back-up heat for the building when the solar collector cannot meet the building heating demands. Water for this system is heated by a conventional water heater.

Motorized shutters in the ends of the central ventilation duct are wired in parallel with the spring/fall fans. When the thermostats sense higher temperatures and a need for additional ventilation (i.e., warm spring/fall days) the motorized shutters open, allowing outdoor air to be pulled through the central ventilation duct (See Figures 5 and 6). This allows the collector to "stagnate", conserving the stored solar heat for use during cool evening or nighttime hours.

During the summer the collector is covered to provide cooling for the ventilation air. Cool night air is passed through the collector to cool the slats. During the day, the warm ventilation air is cooled as it passes through the collector before entering the building. Covers on the ends of the central ventilation duct can be removed for increased ventilation airflow during the hottest part of the summer, when the collector cannot adequately cool the ventilation air for the building (See Figures 7 and 8). Under this operational mode, sow cooling is accomplished through a combination of "wind chill" and evaporative cooling associated with evaporation of moisture from floor surfaces.

COST

The cost for the materials and labor for the solar collector system was \$5446.16 for 308 ft^2 of collector or \$17.68 per ft^2. These cost data do not include costs for interest or tax returns, and are only first cost data. No total installation cost data were obtainable from the cooperator.

PERFORMANCE

A. Thermal and Economic

No data that would allow any thermal or economic analyses of the solar collector system performance were gathered. Problems relating to this lack of data are related in part B of this section.

The efficiency of this collector should be slightly higher than efficiencies of other vertical solar wall collectors because the airflow through the collector is higher than in most vertical solar walls. This higher airflow is because of the side-by-side farrowing and nursery rooms, rather than an end-to-end construction with a vertical solar wall along the south side of each room. The increase in efficiency because of the increased airflow may be offset by the increased static pressure and temperature loss of the solar heated air as it passes through the ducts in the attic that allow the solar heated air to enter the north room of the building (farrowing room). Whether the efficiency of the collector experiences a net increase or decrease, the temperature rise of air passing through the collector will not be as great with this increased airflow.

B. Problems

After completion of the solar collector system, a decision by the cooperator to change the ventilation system resulted in non-operation of the system until the middle of the '81-'82 winter. A nearly concurrent disease outbreak at this time forced the cooperator to immediately depopulate the building for six months in order to break the disease cycle. This prevented data gathering during the '81-'82 winter. An early termination date for the project prevented gathering data during the '82-'83 winter.

COMMENTARY

A. Construction Suggestions

1) Use glazings that are resistant to ultraviolet light degradation and have good solar energy transmittance characteristics.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places can greatly affect collector performance. All air duct joints must also be well sealed. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long-life caulking. Use of clear silicone caulk is recommended.

3) All air inlets to the collector and air ducts should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlet.

5) Provide hoods over the motorized shutters and inlets to the ventilation ducts to prevent rain from entering the ducts.

B. Suggested Modifications

1) Side-by-side room construction in this building complicated the ventilation system construction and operation by requiring the central ventilation duct and the two cross ducts. End-to-end room construction is recommended in that virtually all duct work is eliminated and proper ventilation can easily be accomplished with over-the-wall slot inlets.

2) The slats used in this collector are becoming more and more expensive. It is possible to use solid concrete blocks in these collectors, however the footing for the collector must be modified to accommodate the use of blocks rather than slats.

3) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

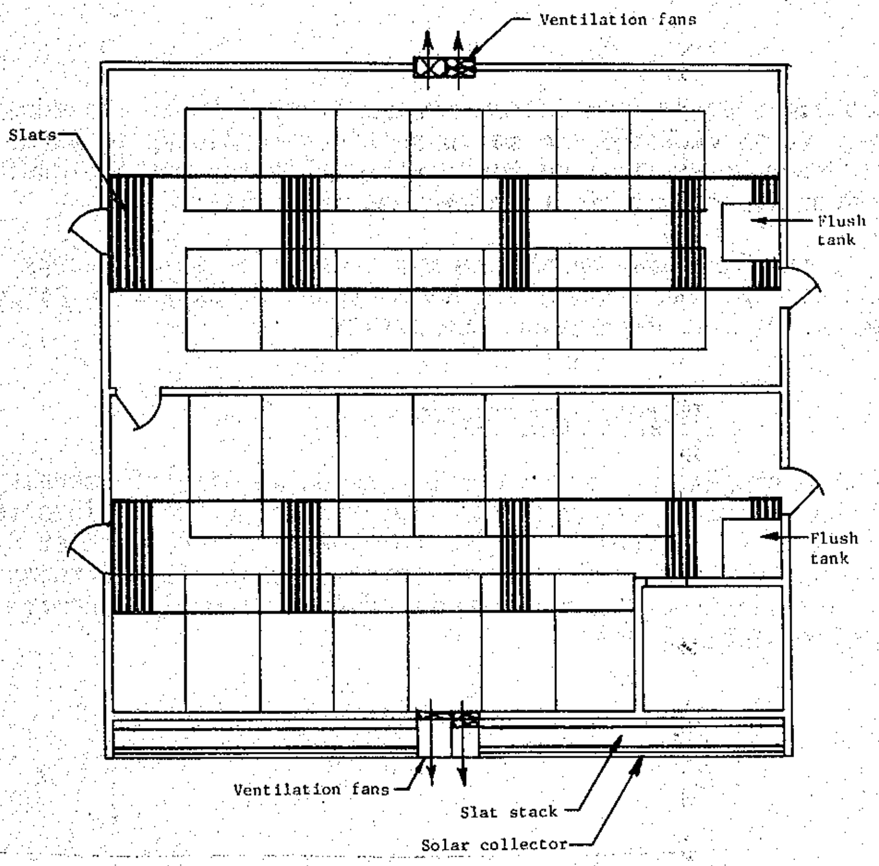

Figure 1. Building floor plan. (Menke). Details omitted for clarity.

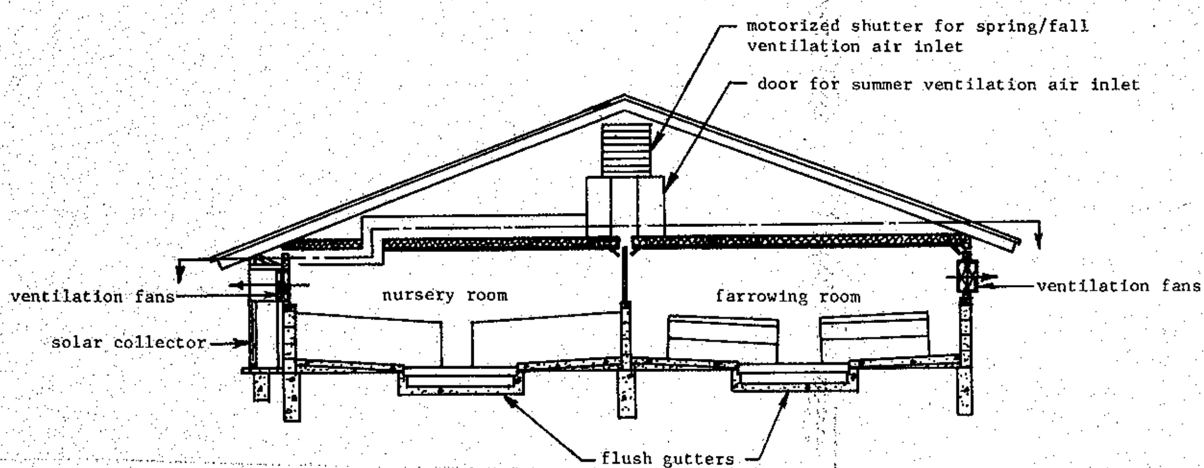

Figure 2. Building cross section (Menke). Details omitted for clarity.

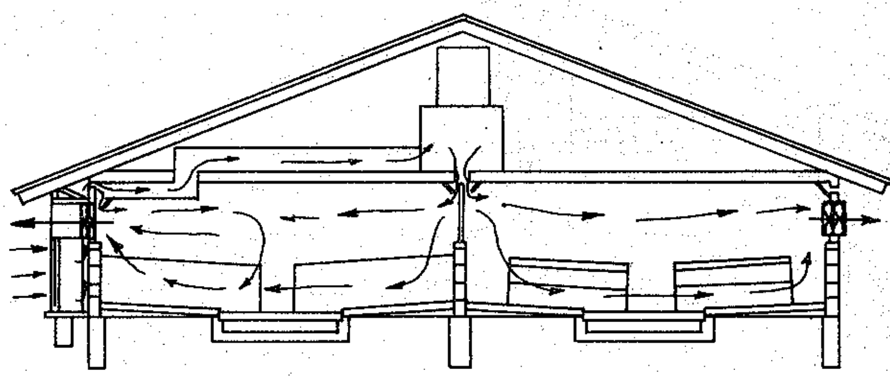

Figure 3. Cross section schematic of winter ventilation airflow paths (Menke). Details omitted for clarity.

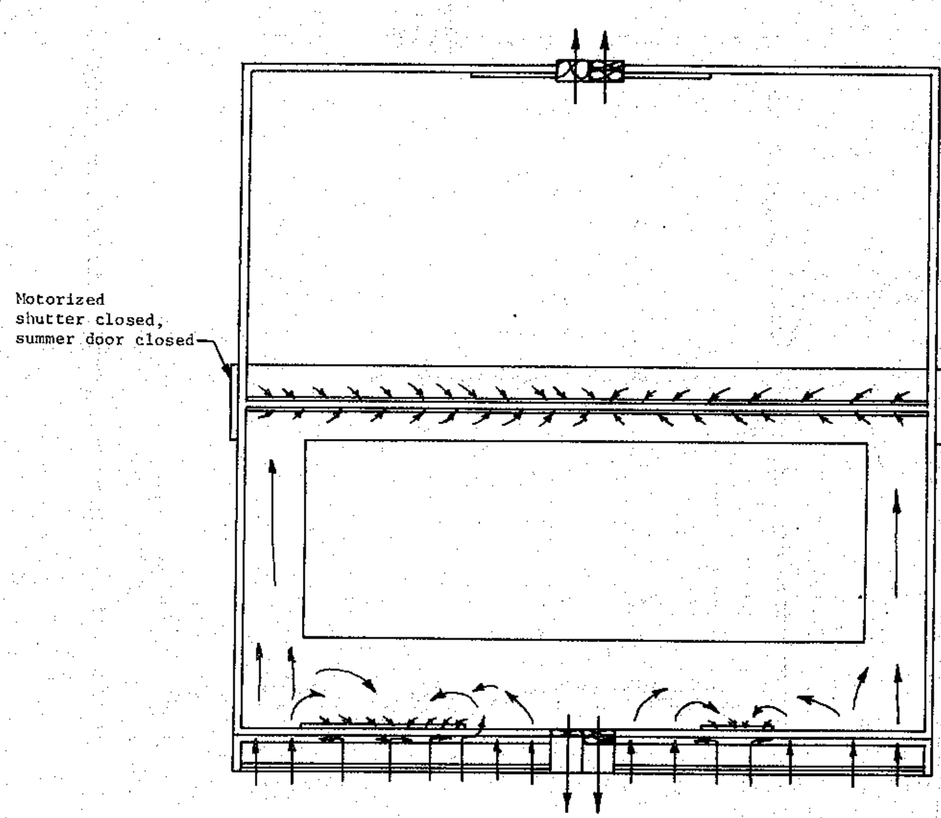

Figure 4. Floor plan schematic of winter ventilation airflow paths (Menke). Details omitted for clarity.

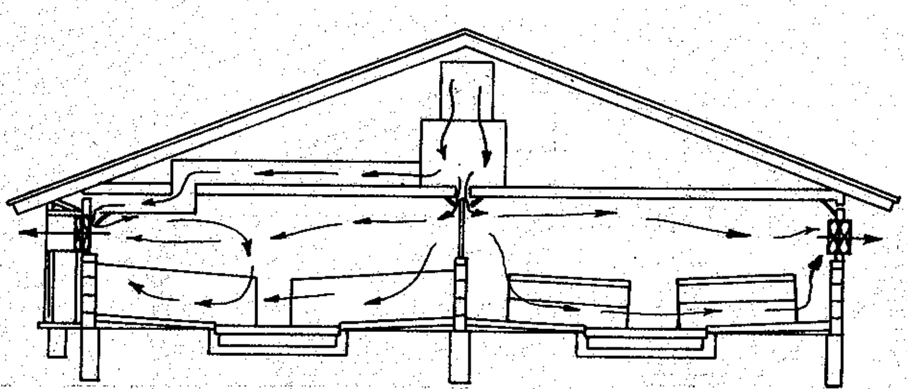

Figure 5. Cross section schematic of spring/fall ventilation airflow paths (Menke). Details omitted for clarity.

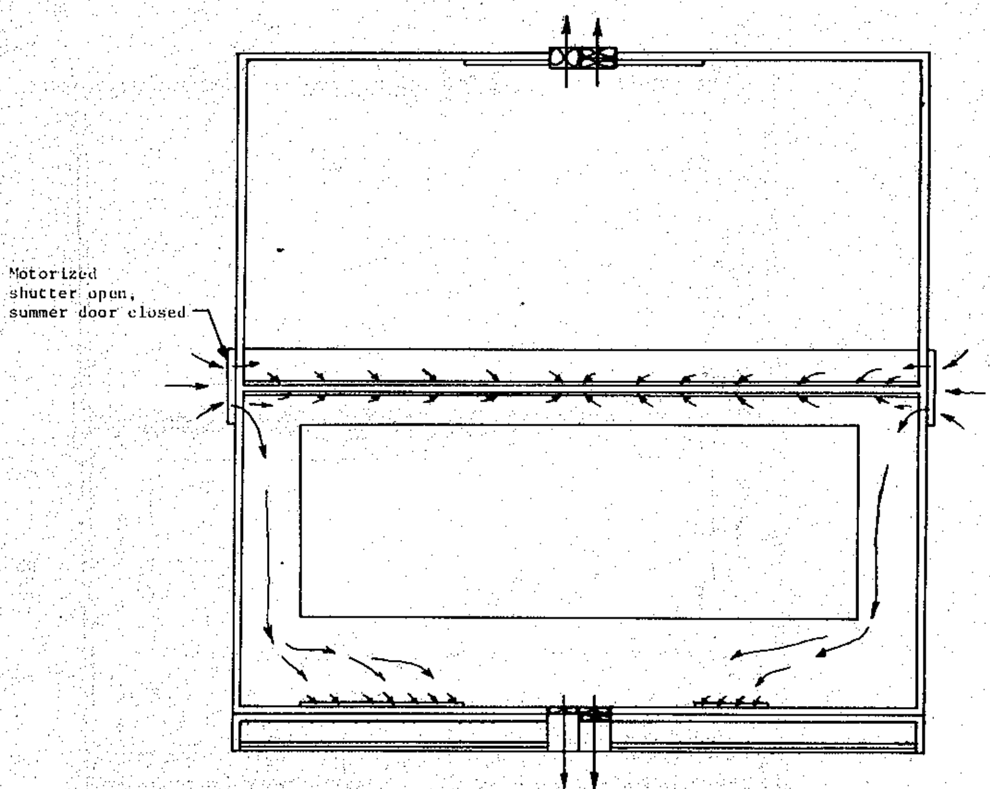

Figure 6. Floor plan schematic of spring/fall ventilation airflow paths (Menke). Details omitted for clarity.

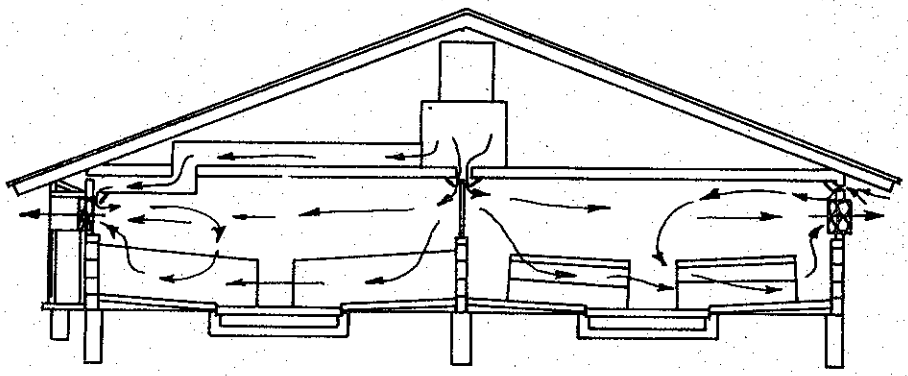

Figure 7. Cross section schematic of summer ventilation airflow paths (Menke). Details omitted for clarity.

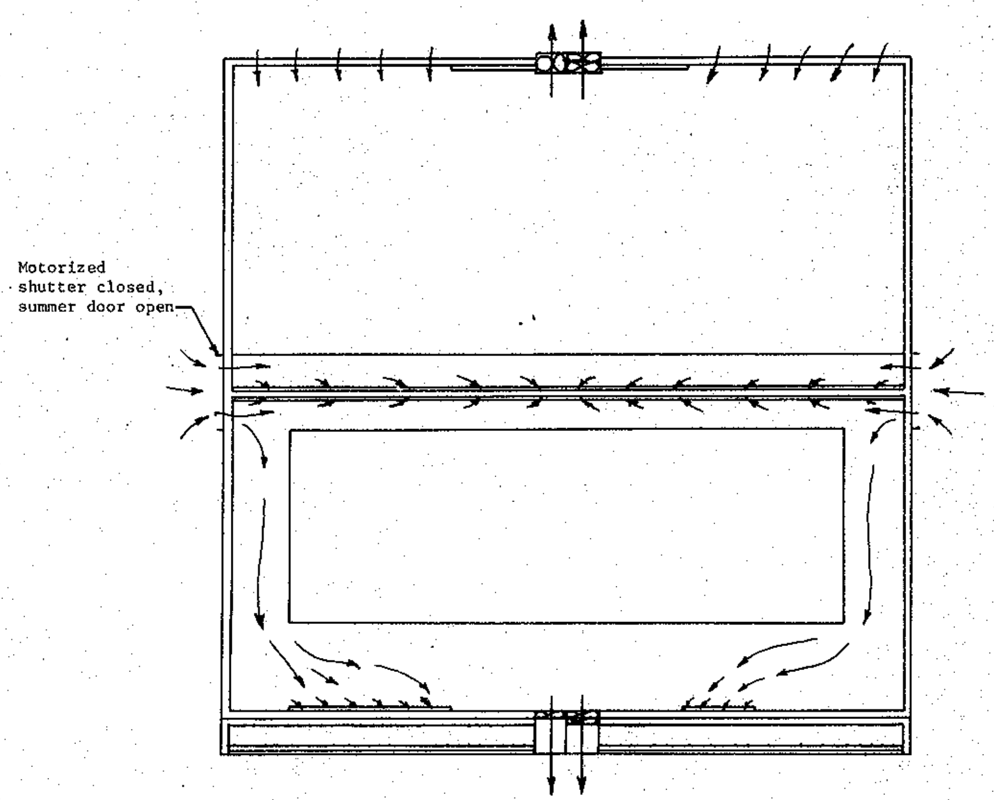

Figure 8. Floor plan schematic of summer ventilation airflow paths (Menke). Details omitted for clarity.

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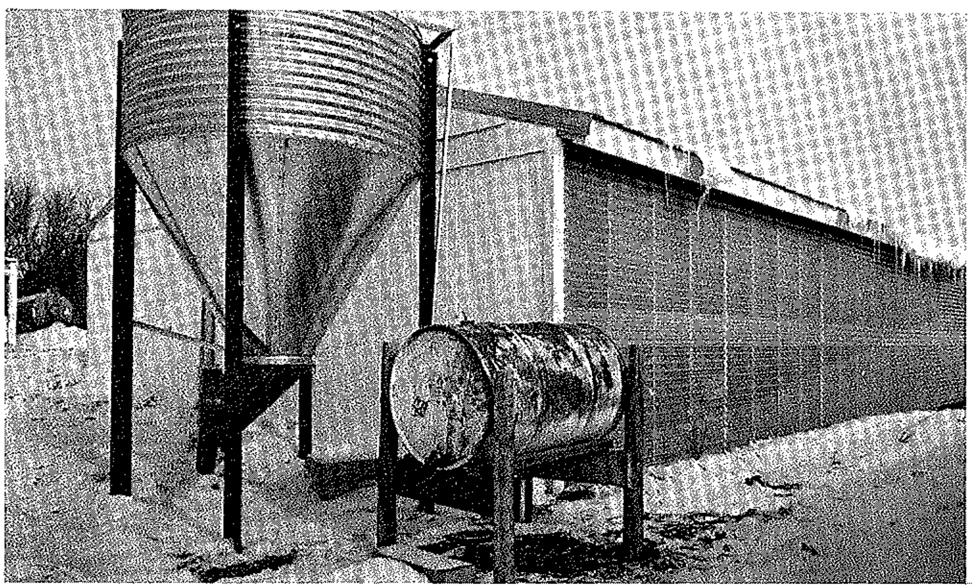
SWINE NURSERY WITH VERTICAL SOLAR WALL

Galen Stevens
Creighton, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-8



200-head nursery building with a vertical solar collector for preheating ventilation air.

SWINE NURSERY WITH VERTICAL SOLAR WALL

Galen Stevens
Creighton, NE

THE FARM

Galen Stevens rents and operates the farm on which this demonstration facility is located. The farm (42°29'N, 97°46'W) is located in northeastern Nebraska's Knox County. Corn and alfalfa are grown on 225 and 30 acres of irrigated cropland, respectively. Corn and oats are grown on 75 and 100 acres of dryland, respectively. The livestock operation consists of a 40-cow herd cow-calf operation with calves fed out to market weight and an 80-sow farrow-to-finish swine operation with an annual production of 1100 market-weight hogs.

The Stevens have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting, and monitoring this system. Information in this report includes a description of the nursery building and the solar collector. Guidelines on constructing and operating the system, some system performance results and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Nursery Building

The 24 x 40 ft building contains two separate areas--a 33 x 24 ft nursery room and a 7 x 24 ft storage area at the east end (See Figure 1). Along the full south wall of the building is the 40 x 7 ft solar collector. The building has a gable roof and is mechanically ventilated using over-the-wall slot inlets for ventilation air. The ventilation fans are grouped together in a bank and centered on the north wall of the building. The floor in the nursery room is 100 percent woven wire above a manure storage pit (See Figure 2). The continuous operation winter ventilation fan and the thermostatically controlled spring/fall fan draw air from above the manure in the pit and exhaust the air from the building (See Figures 3 and 4). The summer ventilation fan draws air directly across the pig environment and exhausts the air from the building (See Figures 5 and 6). This arrangement provides for control of pit odors and gases at all times of the year while providing cooling during the summer.

B. The Solar System

The 280 ft^2 solar collector is a concrete block wall with two Filoplate® #556 (inner layer flat, outer layer corrugated) glazing layers (See Figure 2). The east 8 ft of the collector consists of concrete slats stacked with spacer bars between slat layers to provide horizontal gaps for airflow. The remainder of the collector consists of 6 x 8 x 21 in. (nominal) solid concrete blocks stacked with the long dimension perpendicular to, and 3 in. away from, the south wall of the building. This particular storage configuration was used because the owner had a few concrete slats left over that he wished to use in the collector and purchased the blocks to fill the remainder of the collector.

The south side of the concrete blocks and slats is painted black to increase solar energy absorption. This absorber surface is covered with the double-layer glazings. The blocks are dry stacked (no mortar) with vertical gaps left between adjacent blocks. These gaps allow airflow through the block wall. The slots and gaps in the collector glazings and blocks are designed so winter ventilation air (2.6 cfm per ft^2 of collector), enters the collector between the glazings, travels across the warm black surface of the block wall, filters through the gaps between the blocks and goes into the building through the ventilation air inlet. The ventilation fans exhausting moisture, gases, and odors continually pull ventilation air through the collector into the building (See Figures 3, 4, 5, and 6). In this way the building ventilation fans provide the power to move the air through the collector, thus eliminating the need for a separate fan to perform this function. The concrete blocks and slats act both as absorber plate and heat storage. When the solar heating system cannot provide all the heat required, backup heat for the nursery room is provided by a propane fired heater.

COST

The materials and labor cost for the collector system was \$1,961.04 for 280 ft^2 of collector or \$7.00 per ft^2 of collector area. This can also be calculated as \$9.81 per pig space based on a 200-pig building capacity.

The materials cost for the building (without the solar collector) was \$14,578. Labor costs were not recorded since the cooperator constructed the building. Assuming the cost for materials was 65 percent of the total building costs yields a building cost of \$22,428 or \$112 per pig. Including the solar collector brings the total building cost including labor and materials for the building and collector to \$24,389. The solar collector system costs added 9 percent to the building cost.

PERFORMANCE

A. Thermal

The vertical solar wall provided 2.76 x 10^6 Btu of ventilation air preheating during 15 days in April 1982. For these same 15 days, with an average indoor ambient temperature of 84°F and an average outdoor ambient temperature of 26°F (range was -4 to 55°F), the calculated heat requirement of the building was 6.82 x 10^6 Btu. Thus, the collector provided 40 percent of the heat required by the building during those 15 days.

A plot of the typical ventilation air preheating operation of the collector is presented graphically in Figure 7. The air leaving the collector and entering the building (collector outlet) generally has a higher temperature than the air entering the collector (outdoor ambient). The storage of solar heat is reflected in the temperature increase of ventilation air passing through the collector at night. At this time, solar heat stored during the day is released to the ventilation air, increasing the air temperature and decreasing the need for auxiliary heat.

On March 27, 1981, the outdoor ambient air temperature increased faster and peaked higher than the temperature of the air leaving the collector. At the point where the two lines intersect, all the solar heat is being stored in the thermal mass of the concrete storage. When the temperature of the air at the collector outlet is lower than the temperature of the collector inlet, some heat from the outdoor air passing through the collector, as well as all the solar heat, is being stored in the collector thermal storage mass. As the outdoor air temperature drops the thermal storage mass begins to release heat to the air passing through the collector, and the temperature of the air at the collector outlet returns to a temperature higher than that of the outdoor air.

B. Economic

Lack of sufficient data through an entire heating season does not allow accurate evaluation of the economic returns from this solar collector system. Returns from this collector are assumed to be equivalent to returns from other vertical solar walls when calculated on a per ft^2 of collector area basis. This collector will probably not be able to supply the same annual percentage of required heat as collector systems operating at other locations in Nebraska because of higher indoor ambient temperature requirements for nursery buildings and lower outdoor ambient temperatures at this northerly location.

The normal heating season in this location is 6876 F°·days with a base temperature of 65°F. The overall exposure factor for the building is 1244 Btu/hr·F°, and the indoor ambient temperature for this nursery is generally kept at 80°F. The 200 pigs are assumed to generate 33,600 Btu/hr. The balance point temperature for this building is 53°F, reducing the normal heating season to 4058 F°·days.

With the 1244 Btu/hr·F° exposure factor and 4058 F°·day heating load, the annual building heating requirement can be calculated at 121 x 10^6 Btu. Assuming 40 percent of this load, normally provided by the propane furnace burning propane costing $0.56 per gal, the solar collector annually saves 702 gal of propane or $393. The $1961 collector cost divided by the $393 annual fuel savings yields a simple payback period of 5.0 years.

C. Maintenance

The solar heating system does require some maintenance. Regular monthly maintenance of the ventilation fans and equipment should keep the ventilation equipment operating properly.

Adjustment of the ventilation air inlet baffle positions is necessary to keep airflow through the collector and nursery at proper levels.

Maintenance of the collector exterior (except for glazings) is similar to maintenance of typical building exteriors. All wood must be kept covered with a good coat of paint to minimize weathering. Protect the collector from entry by rodents, birds, animals, termites, etc. Caulk all cracks to prevent cold air from entering the collector at improper locations.

Maintenance of the collector glazings may require washing the outside glazing in the fall. Keep all glazing joints properly caulked with a good quality clear silicone caulk. These glazings may need to be replaced after several (between 5 and 10) years.

D. Problems

Problems with the data logger-cassette tape interfacing mechanism prevented gathering data several times. The distance from Lincoln, NE to this site near Creighton, NE (about 200 miles) added to the difficulty in gathering data.

COMMENTARY

A. Construction Suggestions

1) Glazing materials for the collector should be chosen to withstand ultraviolet light degradation and have good solar energy transmittance characteristics. The glazings must be able to withstand the impact of icicles and snow that drop off the roof during winter.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places cause serious adverse effects on collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long lasting caulking materials. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlet.

B. Suggested Modifications

1) Use of standard quality butyl caulk at collector glazing joints resulted in cracks in the caulk, and resultant cold air leaks, after the first year of operation. Use of good quality clear silicone caulk is recommended for all glazing joints.

2) Use of a standard roofing nail with a thin neoprene washer did not allow proper compression of the glazing to the framing members supporting the glazing. Use of a roofing nail with a thick rubber washer (for example Fabseal® nail by Fabral) is recommended.

3) Other blocks may be substituted for the 6 x 8 x 21 in. (nominal) concrete blocks. When substituting other blocks, be sure to provide proper spacing between the blocks for airflow. Allow between 3 and 5 ft^2 of open area in the block wall per 1000 cfm of ventilation air.

4) The 6 x 8 x 21 in. (nominal) concrete blocks are made of a low density concrete. They do not meet the generally recommended storage mass to collector area ratio. Consideration should be given to alternative designs which provide 2 ft^3 of storage mass per ft^2 of collector area. The slat stack in the east end of the collector does meet the 2 ft^3 of storage mass per ft^2 of collector area. Availability of used slats locally might make the slat storage mass less expensive than concrete blocks.

5) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

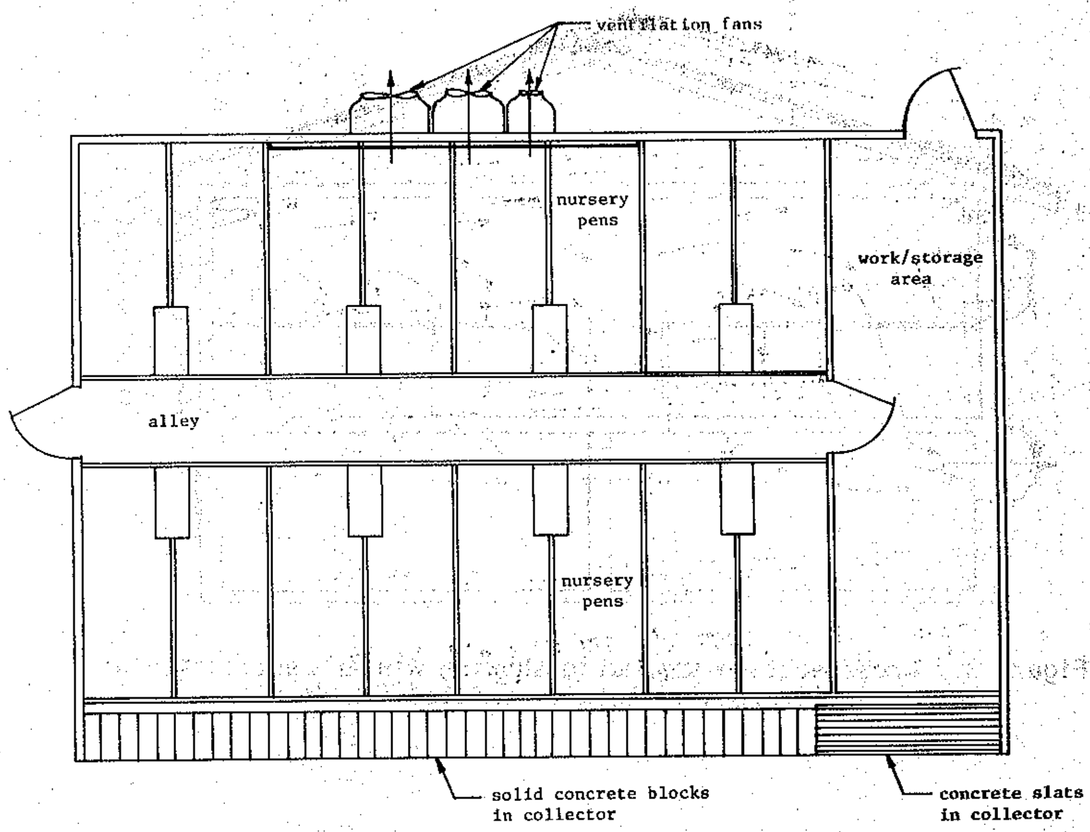


Figure 1. Floor plan of the 200 pig nursery (Stevens). Details omitted for clarity.

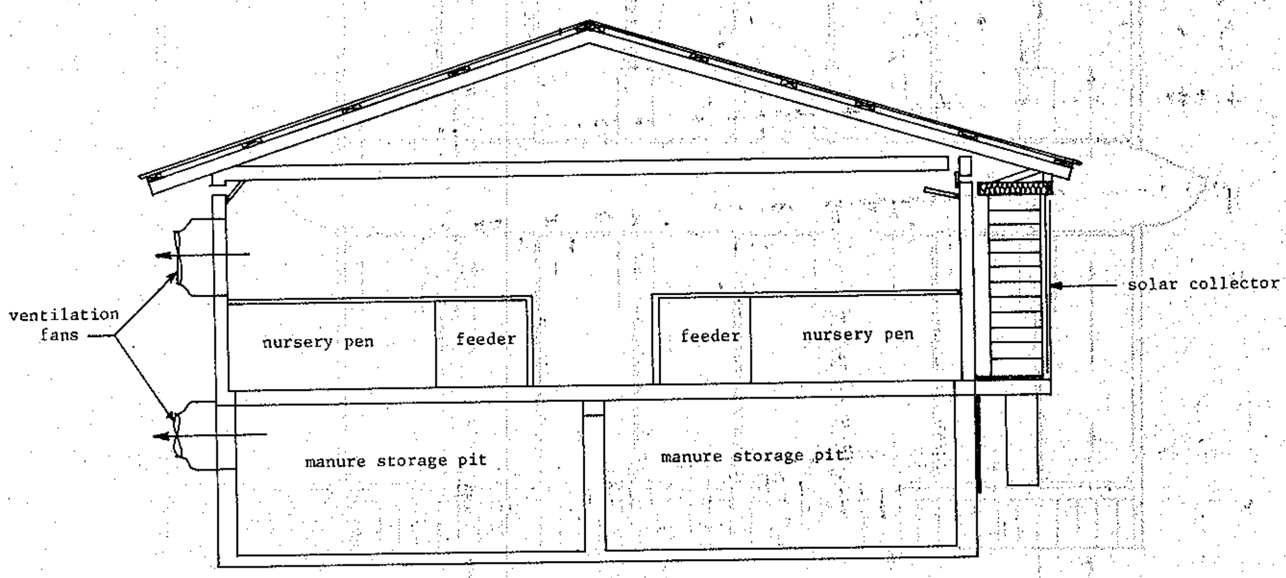


Figure 2. Cross section schematic of building (Stevens). Details omitted for clarity.

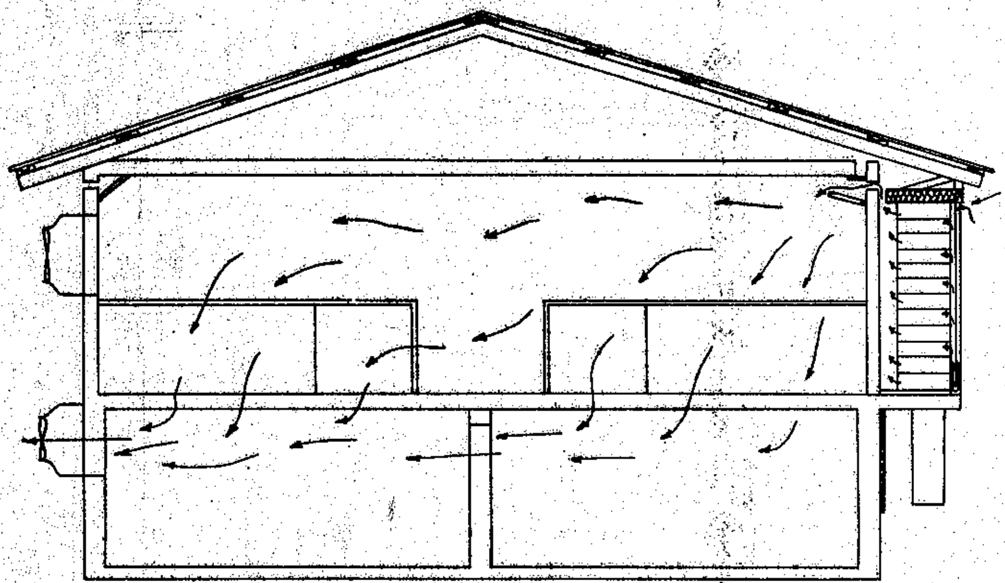


Figure 3. Cross section schematic showing winter ventilation airflow paths (Stevens). Details omitted for clarity.

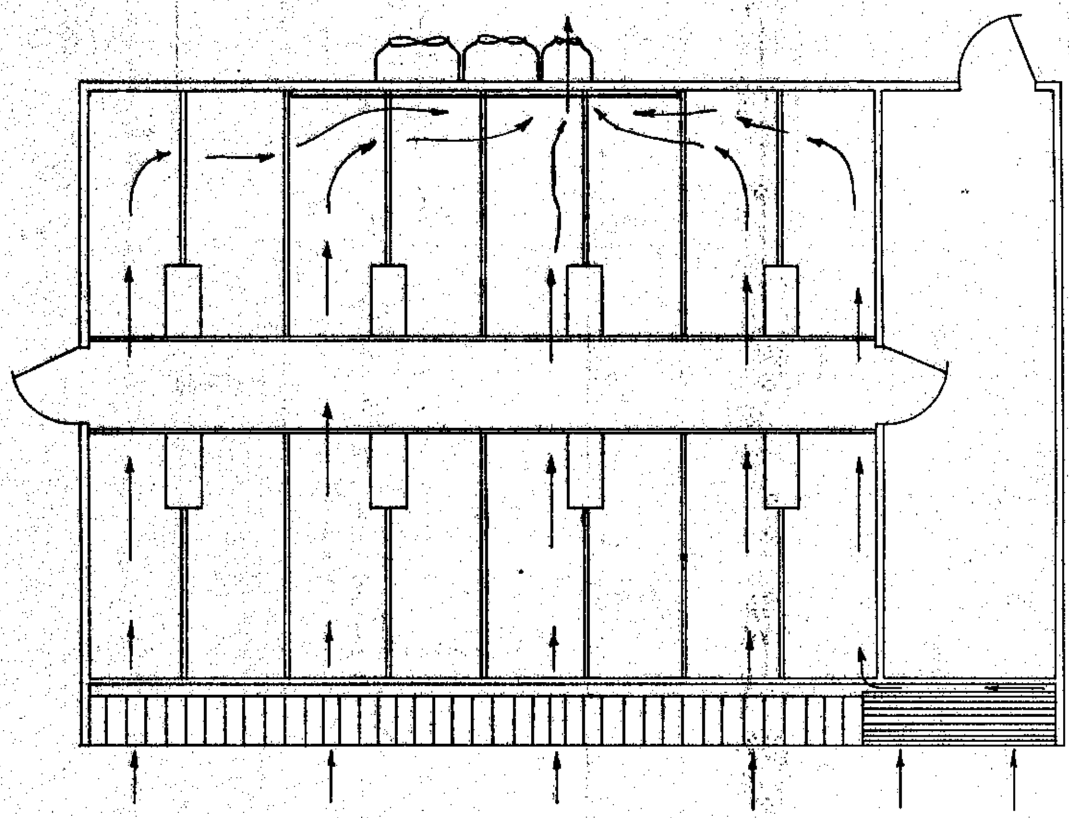


Figure 4. Floor plan schematic of winter ventilation airflow paths (Stevens). Details omitted for clarity.

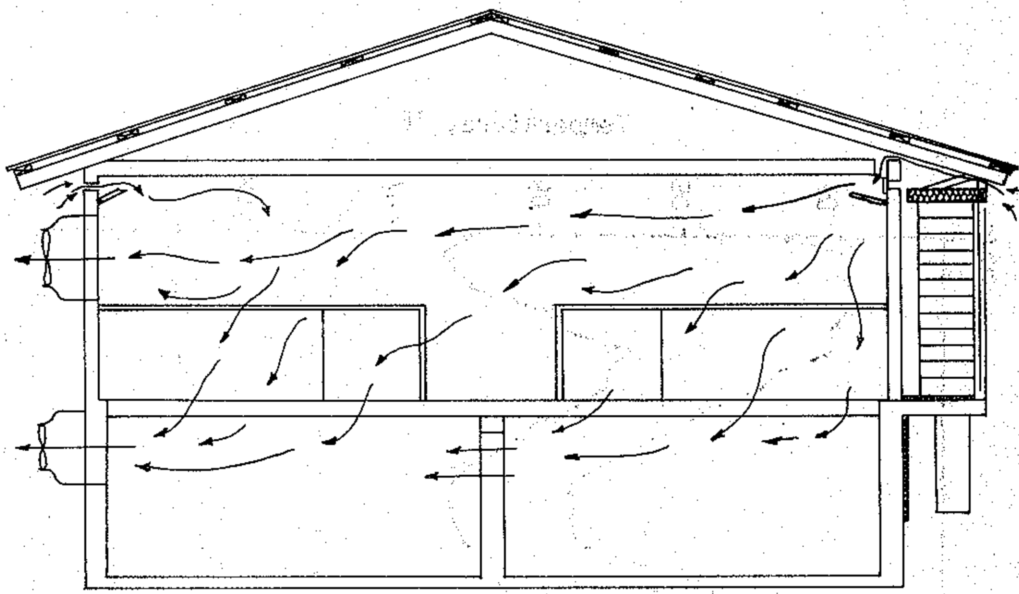


Figure 5. Cross section schematic showing summer ventilation airflow paths (Stevens). Details omitted for clarity.

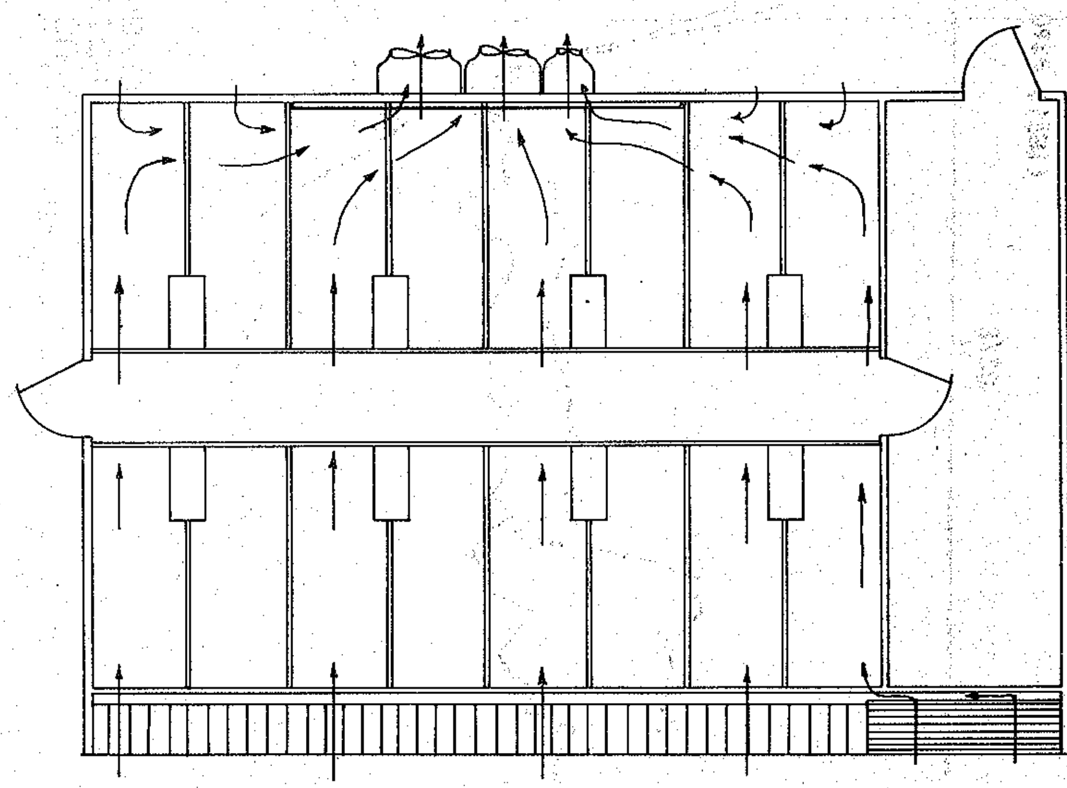


Figure 6. Floor plan schematic of summer airflow paths (Stevens). Details omitted for clarity.

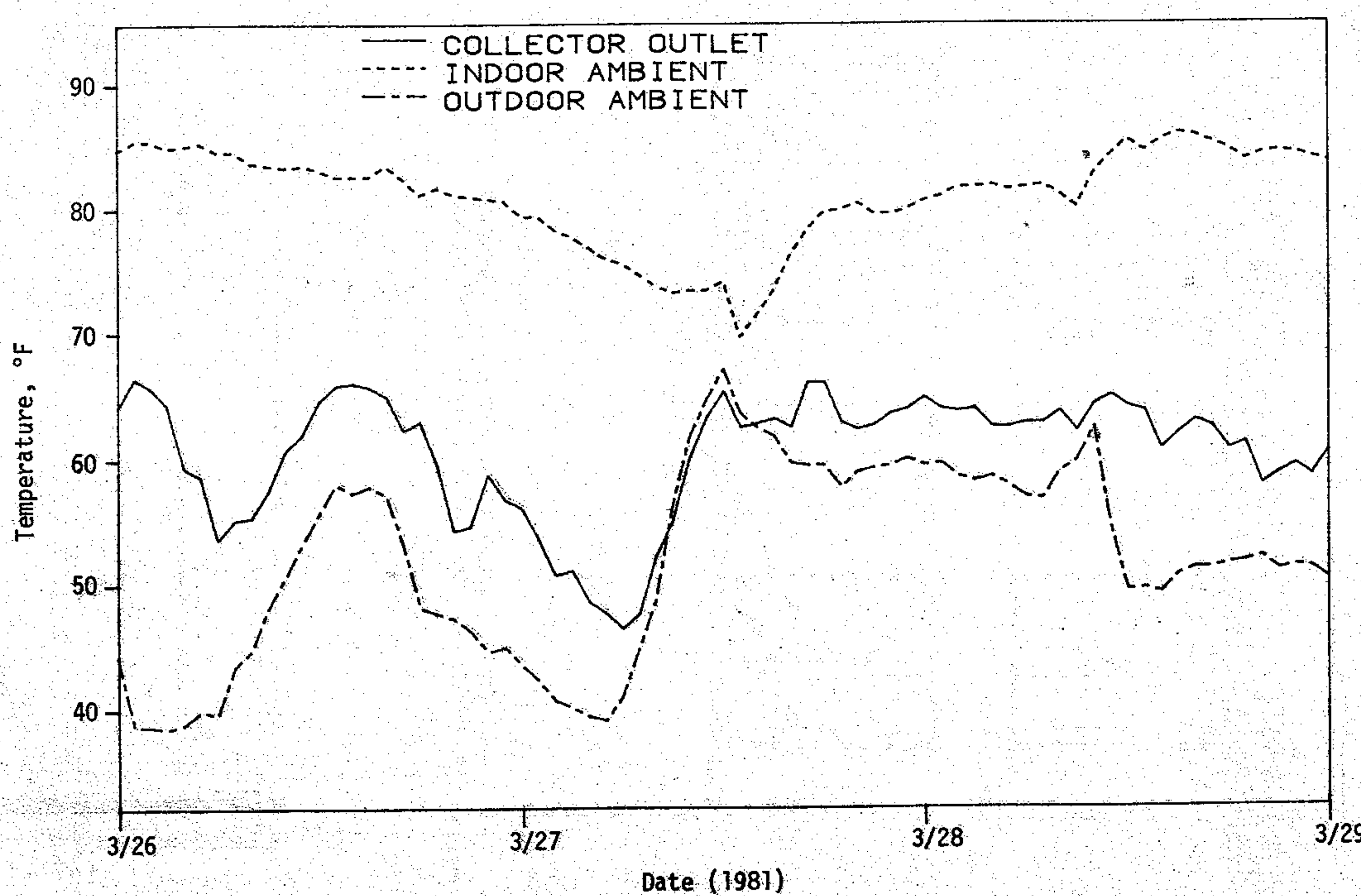


Figure 7. Nursery winter ventilation air preheating with a vertical solar wall. (Stevens)

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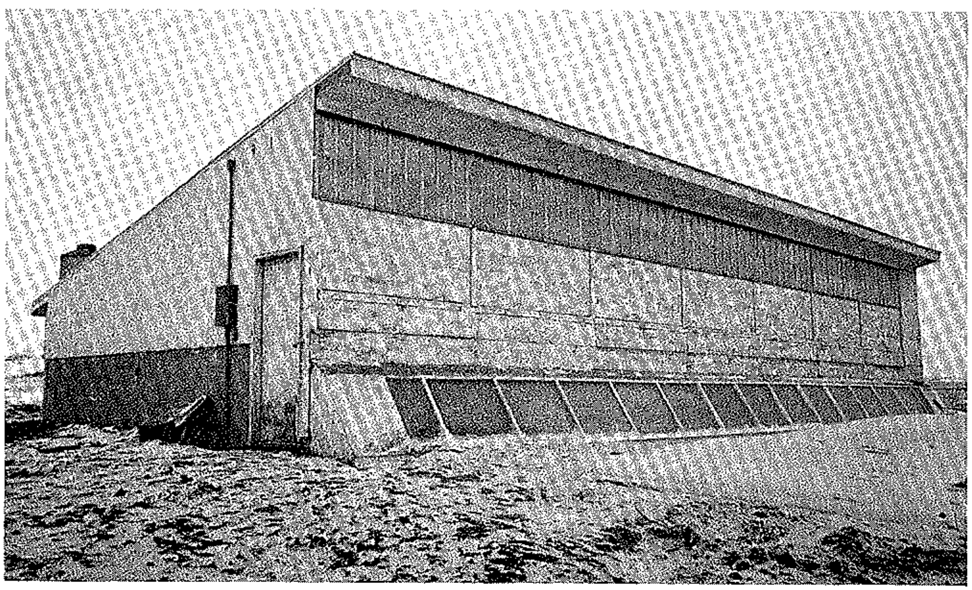
MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Ross Larson
Ceresco, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-10



300-head Solar MOF Nursery building with active/passive solar system and in-floor heat.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln | The University of Nebraska Medical Center | The University of Nebraska at Omaha

MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Ross Larson
Ceresco, NE

THE FARM

Ross Larson rents and operates the farm with the recently added solar nursery. The farm (41°8'N, 96°40'W) is owned by Ross' father and is located in eastern Nebraska's Saunders County. The farming operation consists of growing milo and soybeans on 200 and 120 acres of dryland, respectively. Alfalfa is grown on 40 acres of dryland. The remaining 40 acres of the farm are used for pasture and the production of oats.

Ross has cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting and monitoring this system. This report includes descriptions of the nursery and the solar collector system as well as the cost of the system. Some performance results, suggested modifications of the system and details on where to obtain plans for construction of a building similar to this one are presented.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Solar Nursery

The 12-pen 300-head nursery unit incorporates several energy conserving features besides the solar heating system. The 23 x 60 ft building has a mono-slope roof and is non-mechanically ventilated and well insulated (See Table 1 for recommended R values). The building uses in-floor heat for zone heating--heating the floor and allowing the warm floor to heat the pig's immediate environment. Insulated hovers are used to help keep the majority of this heat down in the pig's environment. The in-floor heat and insulated hovers are located in the rear 40 percent of each pen. Feeders in the pen partition walls are located in the middle portion of each pen. Manure is removed from the building via an open flush gutter system located along the south end of the pens. Flush water control is provided by a dosing siphon flush tank (See Figure 1).

B. The Solar Collectors

Supplemental heat for the nursery building is supplied by a combination of active and passive solar collectors. The double glazed passive collection system consists of 3 ft windows at the top of the south wall. Solar energy passing through these windows is absorbed by the 3 in. thick concrete floor which is insulated from the underlying soil. Two sets of doors, one 3 ft high and the other 18 in. high, beneath the passive windows are openable for ventilation. The sills of the lower of these doors (18 in. high), are approximately 4 ft above exterior grade level, allowing room for the active collector below them. The single-pass, 3 ft-3 in. x 50 ft collector is sloped 60 degrees from the horizontal to allow maximum winter solar energy collection. The active collector heats air which travels through the collector (approximately 2.0 cfm per ft^2 of collector), through the heat distribution-storage part of the floor and returns to the collector in a closed loop arrangement (See Figure 2).

The In-Floor Heat Distribution-Storage (IFHDS) system for the active collector system consists of concrete blocks laid on edge with the cores aligned to provide air channels along the length of the building. The heat storage is five 8 x 8 x 16 in. (nominal) blocks wide, with a 7 to 10 in. sand layer above the blocks, and a 3 in. concrete floor above the sand. This heat storage is insulated to prevent excessive heat loss to the surrounding soil. The resultant storage capacity is approximately 2 ft^3 of storage per ft^2 of collector.

Black polyethylene water lines positioned in the sand layer allow heat to be added to the IFHDS system from water heated by a boiler (See Figure 3). This fossil fueled auxiliary heating system was added to the system design because of plans to place 3-week old, early-weaned pigs weighing approximately 10 to 12 lbs directly into this facility. (Note: Results from the NE-1 demonstration project have shown that during normal winters a fossil fueled backup heating system is not needed for 20 lb pigs. The backup system was installed at Larson's to ensure maintenance of a constant floor surface temperature for the lighter weight pigs.)

C. Non-Mechanical Ventilation

The non-mechanical ventilation system is another energy-saving feature of the nursery. Winter ventilation is achieved through adjustment of the lower set of small openable panels and an air outlet near the top of the south wall. The larger openable south wall panels in combination with openable panels and an eave vent along the north wall facilitate increasing airflow through the animal space during warm weather. Airflow under all weather conditions is augmented by the 3:12 roof slope.

COST

The active collector and the heat storage added a total cost (materials and labor) of $5509.33 to the cost of the building. With a collector area of 182 ft^2, this translates to $30.27 per ft^2 of collector area. Based on a 300-pig building occupancy rate, this cost can be presented as $18.36 per pig for the solar heating system.

This collector cost of $30.27 per ft^2 of collector area is higher than the $11.98 per ft^2 of collector area cost reported for a very similar building in the NE-1 project. This increase in cost can be attributed to several factors. One of these factors is the time difference of two years between construction dates, allowing inflation to affect the collector costs. Great care was taken by the contractors in constructing the IFHDS system to ensure that this part of the system will remain in optimum operating condition. This increased care led to increased cost. The third factor affecting the price increase for the construction of the collector is the presence of system parts that are not greatly affected by changes in the collector length. Examples are the under-floor air ducts(PVC pipes) at each end of the building between the collector and the IFHDS system and the fan and associated controls.

The cost of the complete solar nursery was $25,970, including the solar heating system. This cost represents an investment of $86.57 per pig. If the solar collector system had not been installed in the building, a $420 propane-fueled space heater would have to be purchased and a 500 gal propane storage tank purchased ($725) or rented. Assuming purchase of the propane tank and the space heater, the building could have been constructed with fossil fuel heat for $21,606. The difference between the costs of the solar and conventionally heated units is $4364. This represents a 20 percent increase in costs for the solar heating system.

PERFORMANCE

A. Thermal

Ross has been pleased with the performance of the building. Initial performance for this first winter of operation was satisfactory, although the solar collector system did not provide all the heat required to keep the building warm. This is because the building was not completed until early fall and was not stocked to design capacity until mid-winter. About 200 pigs were moved into the building on October 14, 1981. This compares with the 300 pigs required for full capacity.

The winter of '81-'82 was also a cold winter, with the fourth coldest January in over 100 years of weather records (See Table 2). Below normal insolation levels during this winter also contributed to the heat from the solar collector system not meeting the heat requirements of the building. The percent possible sunshine for October was 75 percent of normal. With lower than normal solar insolation and a reduced quantity of heat available from the pigs, the floor surface temperature in pen 2 was only about 60°F on November 4, 1981 (See Figure 3). On November 5, 6, and 7, the solar collector added heat to the IFHDS system and the floor surface temperature rose to about 71°F.

On these dates the temperature of the air within the IFHDS system air passageway below pen 2 was lower at nighttime than below pen 8. At this time there were no pigs in pen 2, so no heat from the thermal interaction between the pigs and the floor surface was available to help maintain floor surface and IFHDS system temperatures. Pen 8 was stocked with 30 to 40 lb pigs that gave off reasonable amounts of heat as they interacted thermally with the IFHDS system. Heat from these pigs helped keep the air in the IFHDS system below pen 8 about 10F° warmer overnight than air below pen 2, even though pen 8 received less heat from the active solar collector system during hours of collector fan operation.

In November of 1981, the temperature of the air leaving the solar collector regularly peaked at about 178°F on sunny days (See Figure 5). The temperature of the air entering the collector during this same time period normally peaked at about 75°F. Concurrently outdoor temperatures were between 35 and 65°F and indoor ambient temperatures were between 60 and 75°F.

Temperatures under the hovers in the pens averaged approximately 10F° warmer than the temperature 5 ft above the floor in the feeding areas of the pens. This demonstrates the advantage of hovers and in-floor heat in energy savings since the whole building interior need not be heated to the high temperature required by the young pigs. This design reduces conductive heat losses through building surfaces while meeting the thermal needs of the young pigs. The use of hovers over the heated floor, a cooler open feeding area, and a cooler flush gutter area also allowed pigs to choose between three micro-environments to fit their thermal needs.

Although the auxiliary heating system involving the boiler and the water lines in the IFHDS system was never completed, two other auxiliary heating systems provided heat to the building during this first winter of operation. Heat lamps (250W) were placed in the 4 pens that had the smallest pigs. A space heater was also used to keep indoor ambient temperatures above 50°F.

It is not known whether all of the heat supplied by the solar system was needed at the time it was delivered to the floor surface. If excess heat was added to the building by the solar heating system it was removed from the building with increased ventilation. With a non-mechanically ventilated building, accurate comparison of the supplied solar heat and heat actually required is not possible.

B. Animal

Pig performance in the nursery has been very good. The worst performance was a feed conversion ratio of 2.33 lb feed per lb of gain with a 0.69 lb per day weight gain. The best performance was a 1.85 lb feed per lb of gain with a 0.77 lb per day weight gain. These ration tests plus a death loss of less than one percent indicate the high level of pig performance.

C. Economic

An engineering heat balance was performed for this building for normal winter conditions. Estimated annual heating costs were $840 if petroleum-based fuels and conventional whole-building space heating techniques were used. This cost is based on a propane price of $0.56 per gallon.

During the winter of 1981-82, 7545 kWh of electricity at $0.033/kWh were used for the heat lamps. Seventy-eight gal of kerosene at $1.00 per gal were used in the space heater. The total cost of the auxiliary heat came to $327.

Assuming the $840 per year conventional heating costs and using the $4364 extra cost for all of the solar components above the cost of the conventionally heated building and an annual auxiliary heating cost with the solar collector of $327, the simple payback period can be calculated at 8.5 years. This payback period presents an extreme. It is anticipated that during a normal winter the auxiliary heat required for these small pigs could be provided by 6 - 40W light bulbs operated for six months. This represents 1051 kWh or about $35. Therefore, with an annual savings of $805 and an initial investment of $4364, the simple payback period drops from 8.5 years to 5.4 years. With tax credits, consideration of interest, inflation and the time-value-of-money approach to calculating life cycle costs, the payback period of this system should be very reasonable.

D. Ventilation System

All ventilation openings are manually adjusted. Openings are usually adjusted as needed during morning and evening checks of the facility and animals. The manually adjusted openings in combination with the three micro-environments within each pen have served to allow ventilation rates to be varied to meet the needs of various size pigs.

Adjustment of the south wall winter ventilation panels is accomplished by hand adjustment of the panel position. A friction-fit hinge maintains panel position after adjustment. The summer ventilation panels in the south wall can be adjusted by moving individual panels and placing hooks provided at each end of the panel through links in chains hanging from the ceiling.

The air inlet along the top of the south wall stays open except for extreme winter weather. North wall panels are opened and closed as necessary during the summer. The inlet vents at the top of the north wall can be opened and closed as necessary for increased ventilation during mild weather.

E. Maintenance

The solar heating system does require some maintenance. Dust must be washed off the active collector glazings about once per month, especially when peak solar heating is required (i.e., when a group of newly weaned pigs is moved into the building). The solar collector fan bearings must be greased and belt tension checked. Glazings must be checked for damage after bad storms or, just generally, about twice per year. The active collector must be covered at the beginning of the summer to prevent overheating the building and the collector. The collector must be uncovered about 2 weeks before heat is needed in the nursery. This allows the solar collector to "charge" the IFHDS system. The wood on the exterior of the collector should be kept protected with paint to reduce the effects of weathering. Joints in the solar collector system should be inspected at least annually to be sure they are tightly caulked to prevent air leaks. Attempts by rodents to enter the system must be repaired.

F. Problems

A particular problem with this facility was the failure of the thermostat that controlled operation of the fan in the active solar collector system. Lack of the ability to replace this thermostat led to manual control of the collector fan operation. Data have shown that this manual operation is far inferior to automatic operation. Starting the fan before the collector air temperature was high enough to deliver heat to the IFHDS system resulted in a heat loss from the IFHDS system. One hour of fan operation before the collector air temperature was high enough to deliver heat to the IFHDS system required 2 to 4 hours of proper collector operation to offset the heat loss. Therefore, two or three hours of poorly timed fan operation in the morning and afternoon can cancel all the benefits of heat gained from an entire day of proper collector operation. Manual control of the fan operation is <u>not</u> recommended, while automatic control (thermostat with a remote sensing bulb) is felt to be essential.

Hovers placed 3 to 6 in. above the backs of the pigs in the first 6 of 12 pens allowed the pigs to jump up and crawl around on top of the hovers. Hovers were raised to the top of the pen divider walls (approximately 3 ft above the floor) and a flap at the front end of the hover added to keep heat trapped under the hover. This hover construction technique made it dark under the hovers and pigs soon began to dung in this area. Placement of heat lamps in the top of the hover lighted the area under the hover so that the pigs began to dung in the flush gutter. It is recommended that 40W light bulbs be used instead of heat lamps unless the auxiliary heat is required. This problem of darkness and dunging under the hovers did not occur at the Paus nursery (NE-1). We believe the large (3 ft high) panels in the south wall should be glazed as at the Paus' nursery rather than made into an insulated panel as was done at Larson's. This should let enough daylight into the building to keep the area under the hovers lighted well enough to prevent the incorrect dunging pattern.

One problem with the active solar collector system, noticed from the data early in the project, was a large temperature drop (28 to 35F°) in the solar heated air between the outlet from the collector and the inlet to the IFHDS system. A similar temperature drop was noticed at the inlet end of the collector. These problems occurred during collector operation. A door in the outlet end of the collector to allow access to the collector for instrumentation, inspection, etc. was caulked shut to reduce air leaks. This measure reduced the large temperature drop but did not completely solve the problem. We believe increasing the level of insulation from R 4 to R 15 for all surfaces of the transition boxes between the solar collector and the PVC pipes will reduce the temperature drop at these locations to a reasonable level of about 10F°. Be sure to use a high temperature insulation in these locations.

Other problems noticed from the data were gradual overnight temperature decreases at the active collector inlet and outlet, and at the inlet and outlet of the IFHDS system. These temperature drops occurred overnight, whereas the previously mentioned problem occurred while the collector was operating. These overnight temperatures decreased towards the outdoor ambient temperature with the collector outlet temperature between the floor inlet (air passageway, pen 2) and outdoor ambient temperatures (See Figure 6). We believe natural convection currents at each end of the building are set up by the density differences between the warm air at the IFHDS system and the cold air at the collector. The convection currents are causing the temperature decreases in the air at the IFHDS system. To prevent these convection currents and the associated heat loss from the IFHDS system, we recommend placing back-draft dampers at the outlet ends of the PVC pipes. The recommended back-draft dampers are pieces of plastic that can withstand temperatures as high as 200°F (See Figure 7). A layer of high temperature fiberglass insulation should be attached to the plastic sheet to reduce conductive heat transfer from the air in the IFHDS system to the air in the PVC pipes during these overnight periods.

COMMENTARY

A. Construction Suggestions

1) Plan No. NE 10.726-37 Solar MOF Nursery is available from the University of Nebraska Agricultural Engineering Plan Service for $5.00 and provides the information needed to construct one of these buildings. The plan packet includes guidelines regarding construction techniques and materials, solar energy, equipment selection and system management.

2) One specific construction procedure is to completely seal the active collector system against air leaks during construction.

Collector performance is highly dependent on having an airtight system. It is much easier to build properly the first time than to repair air leaks. Use only high quality, long life caulking materials. Clear silicone caulk is recommended.

3) Glazing material for the collector should be chosen to withstand ultraviolet light degradation and to have good solar energy transmittance characteristics.

4) If Tedlar® is used as glazing care should be taken to prevent creasing of the Tedlar® during construction of the active collector. The Tedlar® will crease if a heavy object is laid on a fold. The creases are weaknesses in the Tedlar® sheet and tearing might occur as the Tedlar® shrinks in very cold weather.

5) Installation of the Tedlar® collector glazing with a clear silicone caulk adhesive and nailers are recommended over installation with an adhesive transfer tape. The tape was tricky to use, and is therefore not recommended.

6) Install the fan and back-draft dampers in a manner that allows for servicing and repair. The fan and transition should be placed in an "empty pen" to allow easy access, proper heat delivery to the floor of the first pen with small pigs, and space for equipment storage.

7) Use a high temperature fiberglass insulation board in the active collector behind the absorber place to prevent "failure" of this insulation. Plastic foam insulations in this location will "melt". Normal fiberglass insulation in this location will experience decomposition of the organic binder or "glue" holding the fibers together. This decomposing binder will give off a gas that will "cloud" the inside of the glazing and reduce transmittance of solar energy to the absorber plate.

8) Placement of the fan to provide a suction at the collector outlet is recommended. In this arrangement, any leaks would allow cold air into the collector. Alternately, with the collector under pressure from the fan, a leak near the collector outlet could result in warmed air being pushed outside. Cold air leaking into the collector is more easily detected with temperature sensing equipment in the collector than is warm air leaking out.

9) With the recommended fan placement, the fan must be constructed so that its motor is remote from the airstream. Hot air from the collector will be passing through the fan, but most electric motors are not built to take the high temperatures from these solar collectors. A belt driven fan is almost mandatory in this situation.

10) Automatic control (thermostat with remote sensing bulb) of the solar collector fan is highly recommended. Manual control of

the solar collector fan in this unit has been unsatisfactory since two to three hours of fan operation at the wrong time can cancel benefits of heat gain from an entire day of proper collector fan operation. The remote sensing bulb for the thermostat that controls the collector fan should be located in a shady spot near the collector outlet. The suggested location is in the upper half of the collector height and one to two inches from the edge of the solid cover used to form the transition.

11) When building the transitions from the collector to the PVC pipe (or equivalent) air ducts, and from the air ducts through the fan to the concrete blocks, be sure to insulate the transitions well. Insulation at these locations will reduce heat loss and prevent the fan motor from being overheated. High temperature insulation should be used.

B. Suggested Modifications

1) The ventilation openings along the top of the south wall must be equipped with baffles or other devices to allow partial closure during extreme winter weather. The closure devices are especially needed during periods of low temperatures and strong north and south winds. North winds tend to over-ventilate the nursery by drawing warm air out the openings while south winds force excess amounts of cold air in through the openings.

2) Use back-draft dampers at the <u>outlet</u> ends of the PVC pipe air ducts to prevent convection currents removing heat from the IFHDS system at night. A small flap of plastic (See Figure 7) can act as a gravity shutter to provide this back-draft damper. The plastic used for this flap must be able to withstand the 200°F temperature air from the collector. Attach a piece of high temperature insulation to the plastic sheet to reduce conductive heat losses. Cut the ends of the PVC pipe air ducts at an angle to provide a plane surface on a slope against which the damper can fall. Smooth the end of the pipe after cutting to increase the probability of a tight fit between the damper and the end of the pipe. Place beads of silicone caulk between the 2 x 4 in. (nominal) block and plastic flap, and plastic flap and nailer, to provide a good "hinge" for the damper. Use 3/16 in. diameter stove bolts and fender washers to fasten the insulation to the plastic flap. Place silicone caulk between the fender washers and the plastic flap and between the insulation and the plastic flap around the holes for the stove bolts to reduce stress concentrations and places where the plastic can tear.

3) The optimum collector and IFHDS system length seems to be in the 50 to 75 ft range. Multiples of these lengths are suggested for longer buildings with small pigs in the 15 to 30 lb category.

4) Buildings with lengths of 100 to 150 ft with pigs ranging from 15 to 50 lbs may need only one 50 to 75 ft active collector and solar IFHDS loop. The smaller pigs may be kept above the solar IFHDS system. The smallest pigs should be kept in the pens where the air in the solar IFHDS system is warmest (i.e., pens closest to the place where the hot air from the collector enters the solar IFHDS system). As the pigs grow they should be moved through the building towards the area where the air in the solar IFHDS system is cool (i.e., pens closest to the place where the air leaves the solar IFHDS system and returns to the collector). The rest of the building need not have the active collector system but research results indicate heat storage may be beneficial. This insulated thermal storage can be identical to the solar IFHDS system except the concrete blocks are not needed because no air will pass through this heat storage. The insulated thermal storage mass will help store heat released from the animals at night as they lie on this storage area. Some of this heat is slowly released to the air during the day. The remainder of the heat stored in this area is used to maintain or slightly increase the average floor temperature above this heat storage. The research data referred to herein were reported in a technical paper (No. 80-4514) of the American Society of Agricultural Engineers.

5) Provisions to allow installation of heat lamps above the sleeping area in one-fourth of the pens is recommended. These heat lamps should be provided for the pens in which the smallest pigs will be located (i.e., closest to the place where hot air from the collector enters the solar IFHDS system) on an "as needed" basis.

6) Caution should be taken in constructing a unit of this design in locations outside Nebraska. Certain features may need to be modified to accommodate local climatic conditions. For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

Table 1. Recommended types and levels of insulation for the Nebraska Solar MOF Nursery (Larson).

Insulation Location	Insulation Type	Insulation Level
Ceiling/roof	Fiberglass batt	R-19
Stud wall	Fiberglass batt	R-11
Insulated concrete sandwich panel	Rigid foam board	R-13
Foundation perimeter	Extruded foam board	R-8
Beneath feeding floor	Extruded foam board	R-4
Around IFHDS system	Extruded foam board	R-8
Around solar collector air ducts	Fiberglass batt	R-11
Behind solar collector absorber plate	High temperature fiberglass*	R-8
Transitions between air ducts (PVC pipe) and collector outlet	High temperature fiberglass*	R-15
Transition between air ducts and fan	High temperature fiberglass*	R-12
Transition between fan and IFHDS system	High temperature fiberglass*	R-12
Outlet end of air ducts (backdraft damper)	High temperature fiberglass*	R-4

*High temperature fiberglass is necessary to prevent this insulation from degrading at the temperatures attainable in the collectors.

Table 2. Weather data near the Larson unit.

	1981			1982		
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Average monthly temperature, °F	51.5	42	26.5	16.5	27	38
Departure from normal average monthly temperature F°	-3	3	-2.5	-10.5	-4.5	0
Heating degree days, F°. days	420	684	1185	1504	1064	832
Normal heating degree days,[1] F°. days	326	780	1163	1302	1078	837
Percent possible sunshine[2]	50	57	39	40	61	50
Normal percent possible sunshine[1]	67	57	52	57	59	59

Source: NOAA Climatological Data for Nebraska for the weather station at Wahoo, NE, 8 miles northeast of the unit

[1] Taken from Climatic Atlas of the United States, 1968.

[2] NOAA data for the weather station at the airport in Lincoln, NE, 15 miles southwest of the unit.

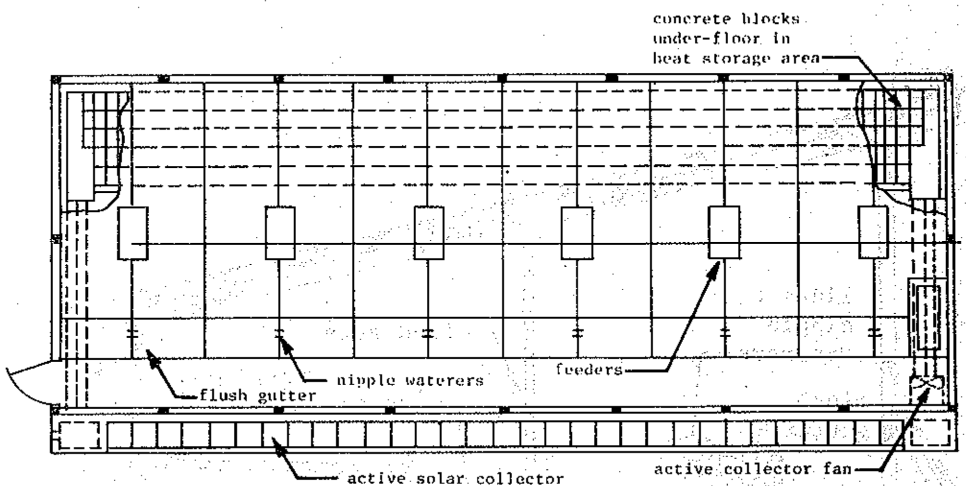


Figure 1. 300 pig Solar MOF Nursery floor plan (Larson). Details omitted for clarity.

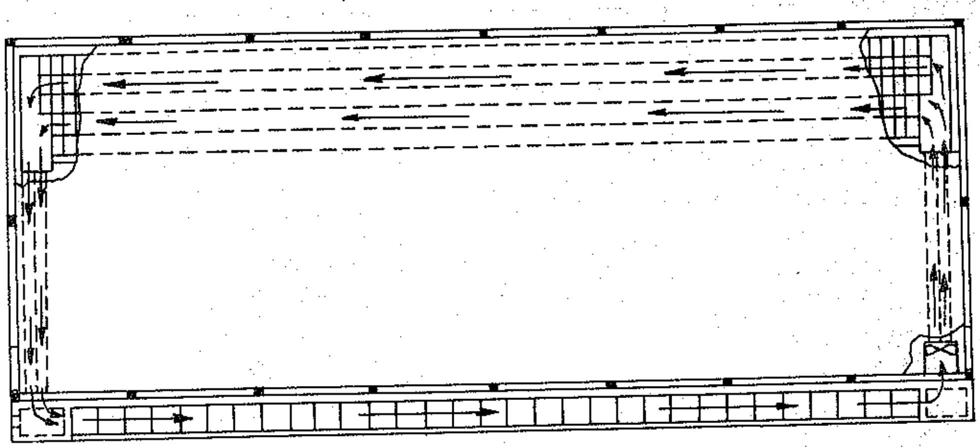


Figure 2. Fluid flow through the active solar collector and storage system (Larson). Details omitted for clarity.

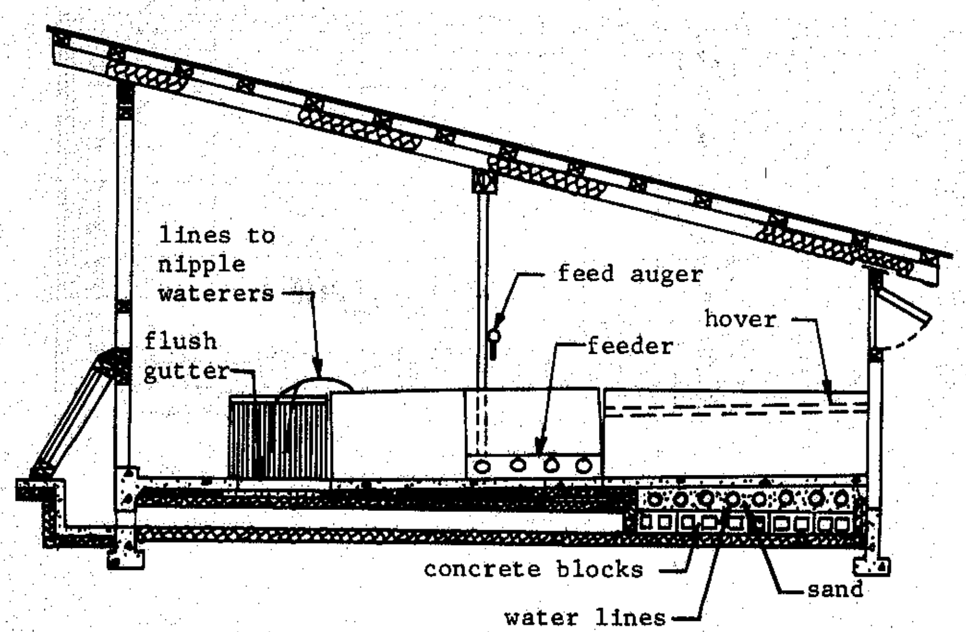


Figure 3. Cross section schematic of the solar modified open front nursery. (Larson). Details omitted for clarity.

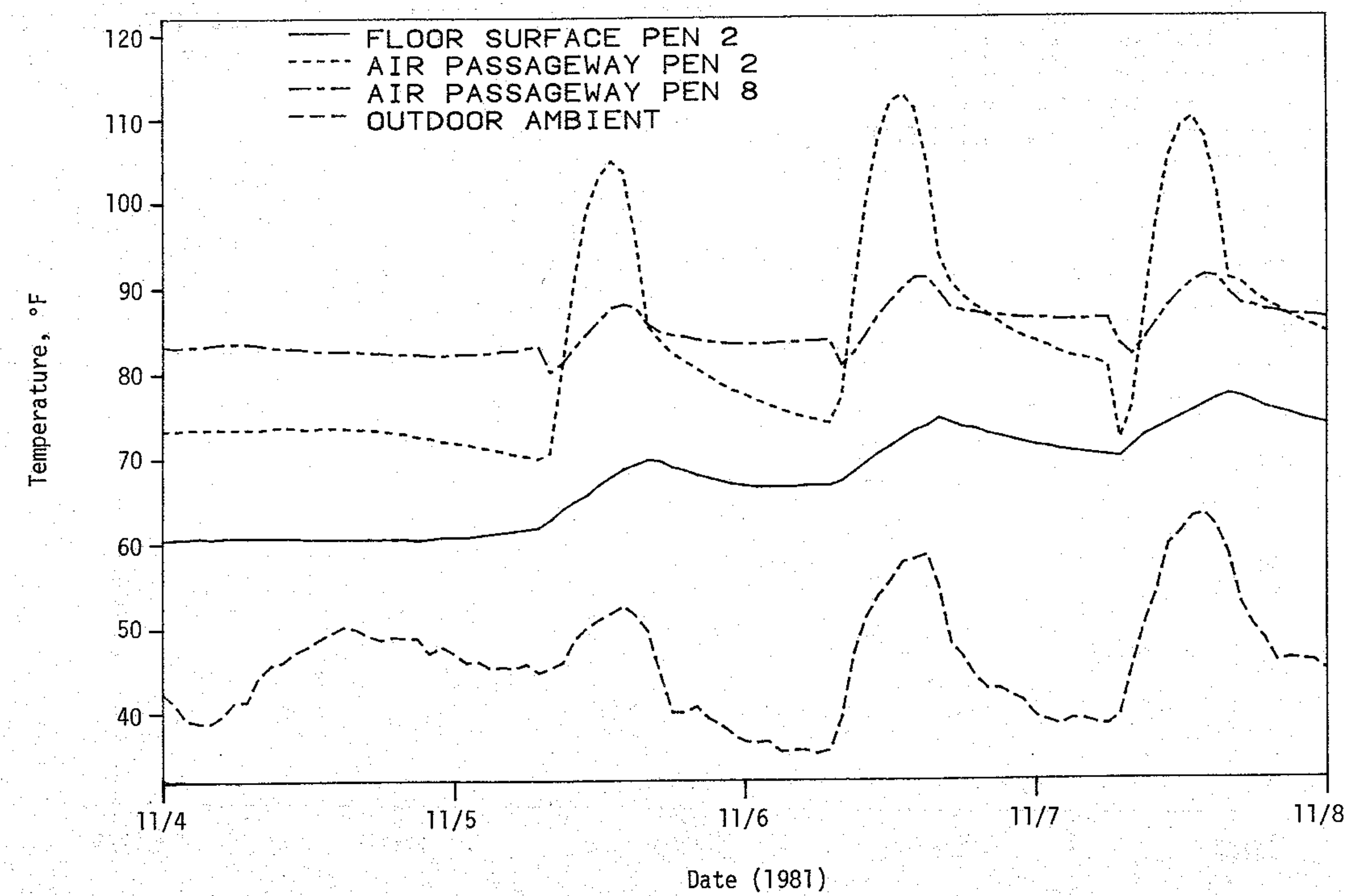


Figure 4. Temperatures relevant to the IFHDS system (Larson).

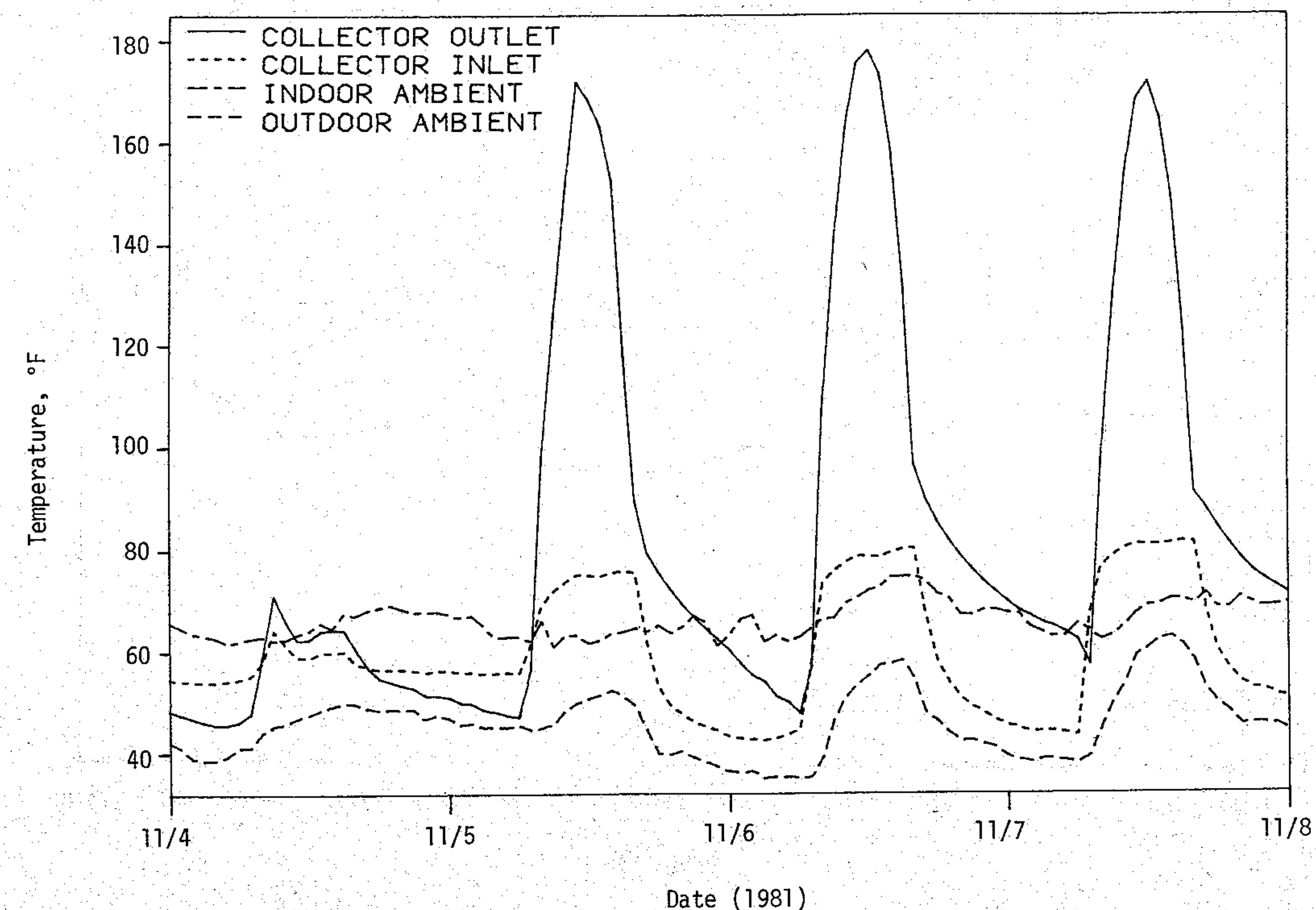


Figure 5. Temperatures relevant to the thermal performance of the Solar MOF Nursery (Larson).

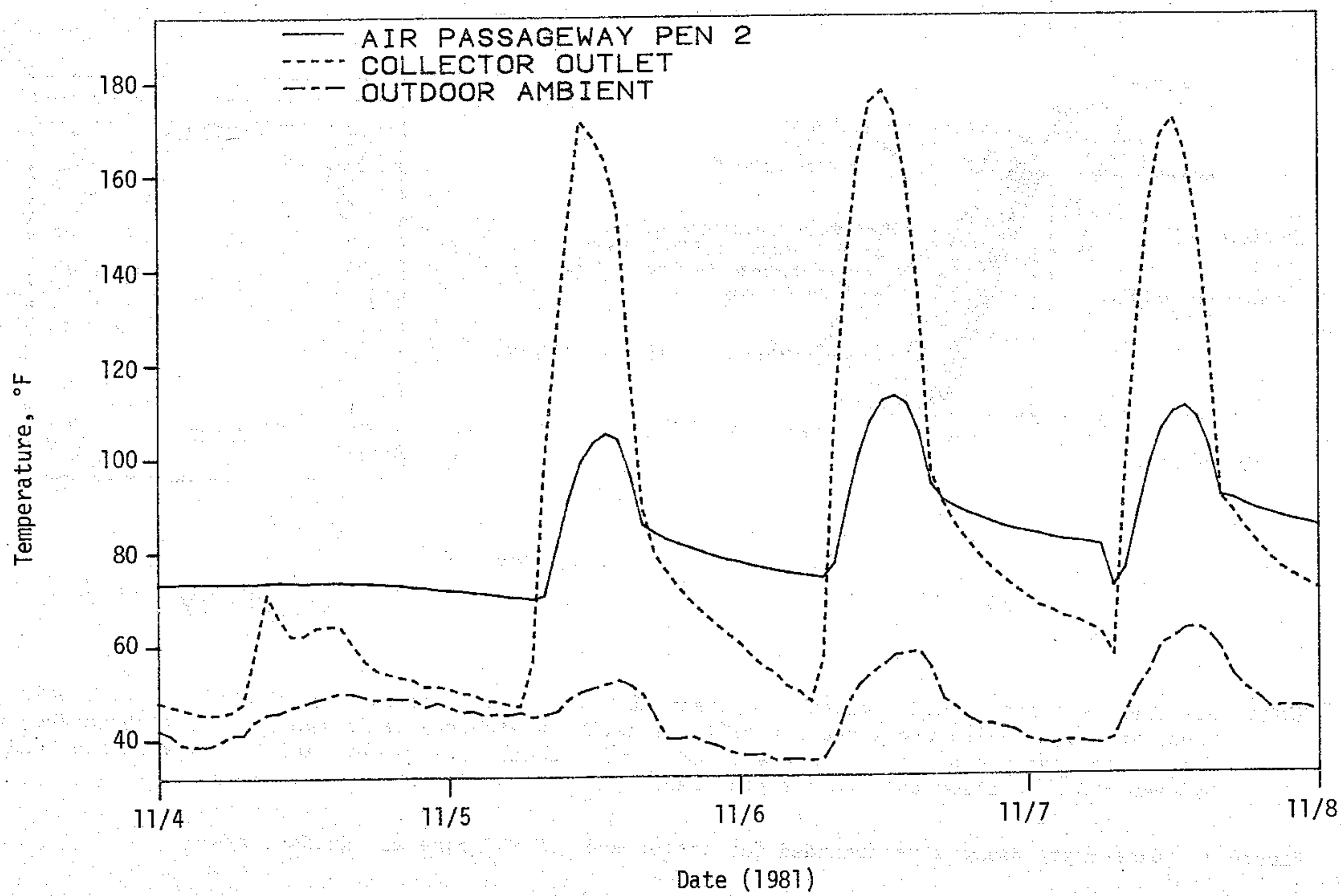
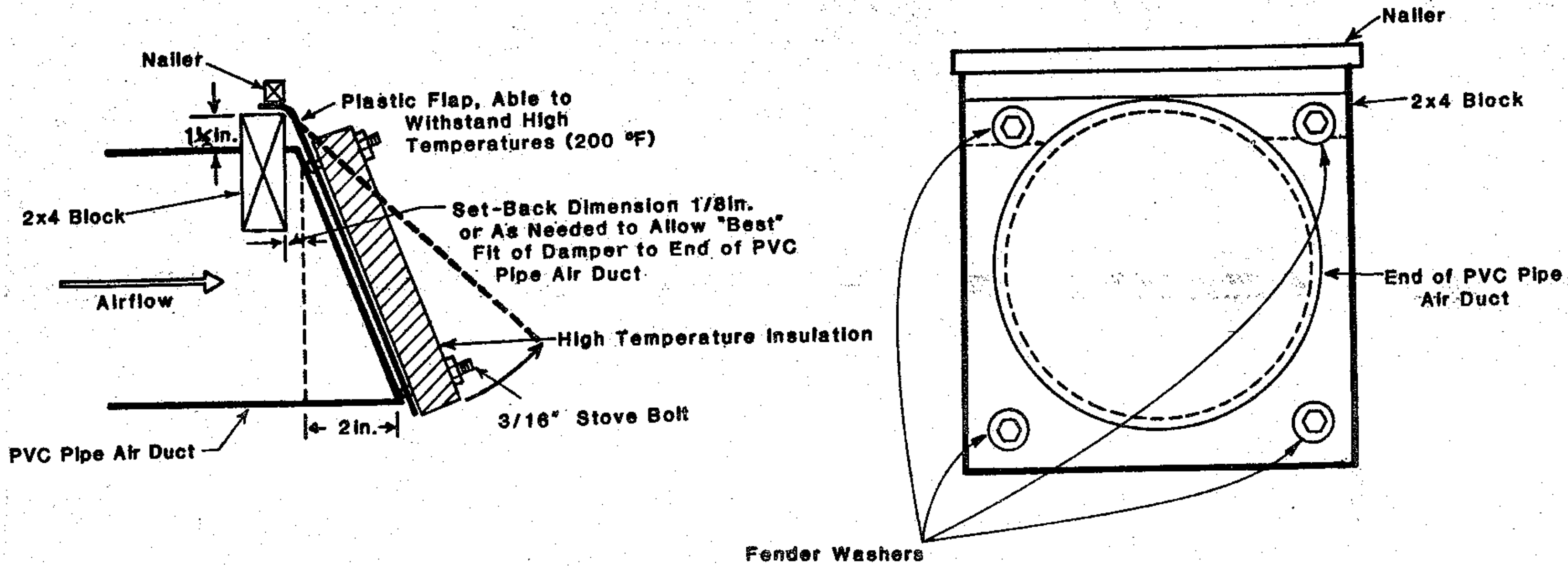


Figure 6. Temperatures at the outlet end of the air ducts (Larson).



a) Side View

b) End View

NOTE: Use clear silicone caulk "adhesive" between the 2 x 4 block and the PVC pipe air duct to hold the block in place. Also use a bead of silicone caulk on either side of the plastic flap between the 2 x 4 block and the nailer. Place silicone caulk between the washers and the plastic flap and between the insulation and the plastic flap.

Figure 7. Back-draft dampers recommended for outlet ends of PVC pipe air ducts (Larson).