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Performance of Solar-Assisted Modified-Open-Front Swine Nurseries

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ABSTRACT

Performance data of two modified-open-front non-mechanically ventilated swine nurseries have shown that solar energy can be effectively utilized to maintain a productive environment within the animal space during cold weather (temperatures as low as −26°C (−15 °F). The nurseries feature a monoslope roof design and passive collector panels that also function as warm weather ventilation panels. An active solar-heating system uses a ground-level collector operated in conjunction with an in-floor solar heat distribution and storage system. The nurseries were designed to handle pigs weighing from 7 to 23 kg (15 to 50 lb). An average of 19% of the solar energy incident on the collector was transferred to the floor surface during the heating seasons from October 1980 to January 1982. Season "heating" costs were approximately 1.0% of the estimated cost to heat the nursery by conventional means.

INTRODUCTION

Weaning of pigs at 3 to 5 weeks of age (3.5 to 9.1 kg (8 to 20 lb)) has created a need for nursery facilities capable of providing a suitable environment for young pigs. These small pigs require air temperatures ranging from 27 to 35 °C (80 to 95 °F) depending upon pen design and air velocities through the sleeping/feeding area. The most common technique for achieving these temperatures has been to heat the entire volume inside the building (whole-building heating) and maintain air temperatures within the range necessary for young pigs. With few exceptions these buildings have also been mechanically ventilated, relying upon electrically-powered fans to achieve air movement through the facility. Whole-building heating and mechanical ventilation make operation of these nurseries energy intensive.

Facilities not as energy intensive can be used. Hovers, infrared heating, and floor heating can be used to provide the proper thermal environment in the pigs' sleeping area. The remainder of the pen space does not need to meet the same thermal requirements since pigs do not need a prolonged stay in this secondary environment (feeding and dunging areas). The air temperature in this secondary environment can be allowed to drop below normal nursery air temperatures (Curtis, 1981; Shelton and Brumm, 1986). Similarly, temperatures outside the pen can be much lower. The result is a reduction in heat energy required by the nursery.

Providing several micro-environments within the pig zone decreases the need for exacting ventilation control, since effective temperatures in the secondary environment may vary outside those required for optimum comfort by the nursery pigs. Non-mechanical ventilation systems, i.e., achieving airflow without fans, can meet the environmental needs for nurseries with several micro-environments. Non-mechanical ventilation further reduces energy usage since electricity to power ventilation fans is not required.

This paper describes the performance and economies of solar assisted modified-open-front (MOF) swine nurseries that use different micro-environments and non-mechanical ventilation. The original unit based on this design has been operating continuously since October 1979.

DESCRIPTION OF FACILITIES

Building

Based on previous studies at the University of Nebraska involving the use of solar energy in swine confinement buildings (DeShazer et al., 1976, 1980; Bodman et al., 1978, 1980, 1981) the nursery discussed in this paper may be considered a "third generation" design. The original Nebraska Solar MOF Nursery (Fig. 1) is on a working farm owned and managed by Alvin Paus and Sons (Art and Doug). The Paus farm is located near Fairfield in south central Nebraska (40° 24′N, 98° 11′W). The building measures 35.4 x 7.0 m (116 x 23 ft) and encloses 22 pens plus an equipment area. Design capacity for the building is 550 pigs weighing between 7 and 23 kg (15 and 50 lb). Operation of the building began in October 1979.

A second Nebraska Solar MOF Nursery was built on the farm of Ross Larson near Ceresco in east central Nebraska (41° 8′N, 96° 40′W) (Fig. 2). The nursery measures 18.3 x 7.0 m (60 x 23 ft) and is subdivided into 12 pens. Design capacity of the unit was 300 pigs ranging from 4 to 23 kg (9 to 50 lb). Operation of the facility began in September 1981. Results from this unit are used to supplement findings from the Paus nursery. All results

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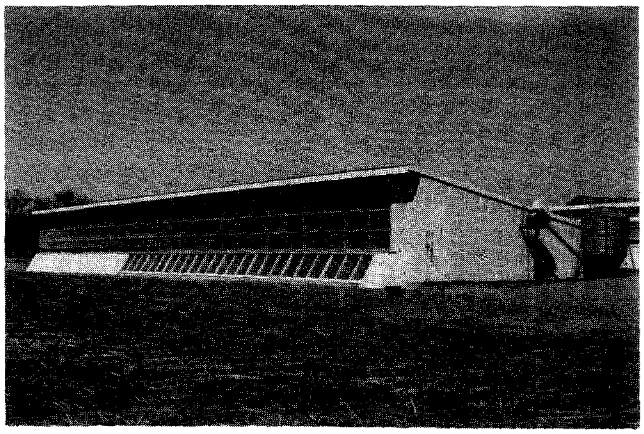

Fig. 1—The first Nebraska solar MOF nursery (Paus 550-head capacity).

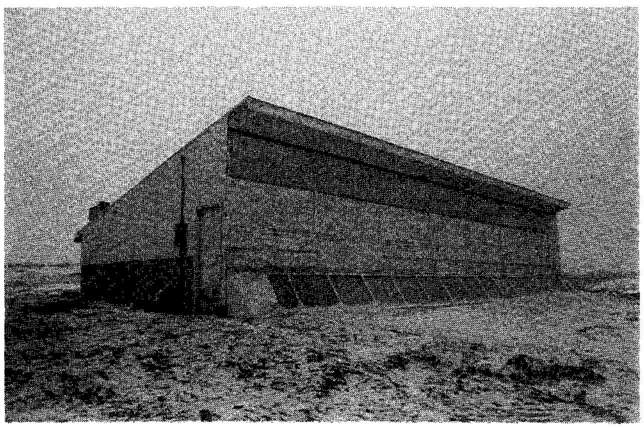

Fig. 2—The Larson 300-pig Nebraska MOF solar nursery.

discussed in the following paragraphs are from the Paus nursery unless otherwise noted.

The nurseries were constructed with insulated sidewalls (RSI 2.3 to 2.6 (R13 to 15) and ceilings (RSI 3.3 to 3.8 (R19 to 22)). A polyethylene vapor barrier was placed between the insulation and inside finish materials to assist in controlling movement of water vapor into the walls and ceiling. A 3:12 single-slope roof and inside ceiling enhance air movement (and ventilation) by natural convection.

A shallow (10 cm (4 in.)) open gutter provides a dunging area for the pigs. Tanks equipped with dosing siphons periodically provide water to remove manure from the gutters. Effluent is discharged to a lagoon.

Individual pens are 1.5 x 6.1 m (5 x 20 ft) and extend from the service alley along the south side to the north wall. Pen width is center-to-center of precast 10 cm (4 in.) concrete partitions. Pen length includes the 0.9 m (3 ft) open flush gutter. The pen arrangement, proceeding from north to south, is, sleeping area, feeding area, and dunging area. Feeders are positioned 0.6 to 0.9 m (2 to 3 ft) north of the edge of the gutter (Fig. 3). A plywood hover (1.3 cm x 1.2 x 2.4 m (1/2 in. x 4 ft x 8 ft)) was installed over the sleeping area (north end of pens). Hover height varies from pen to pen and is adjusted to be 15.2 to 30.5 cm (6 to 12 in.) above the pigs.

The south walls are stud-frame to a height of

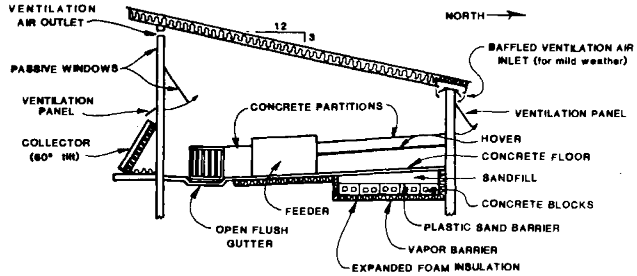

Fig. 3—Schematic of the solar MOF nursery cross-section.

approximately 1 m (3 ft, 4 in.) above grade. In the Paus facility, openable acrylic windows (1.8 x 2.4 m (6 x 8 ft)) above the stud-frame section of the south wall serve as a passive solar collector and ventilation panels. Larson substitued insulated openable panels for the lower half and fixed fiberglass reinforced plastic passive panels for the upper half of the south wall. A 5 cm (2 in.) wide ventilation air outlet runs the full length of the building above the passive windows.

The north wall is insulated concrete sandwich panels (RSI 2.1 (R 12)) to a height of 0.8 m (2.5 ft) above grade (Fig. 3). The remainder of the north wall consists of 0.6 m (2 ft) high insulated panels in a stud framework. These panels run the full length of the building and can be opened during warm weather for increased ventilation.

In-Floor Heat

The sleeping area micro-environment along the rear third of the building consists of in-floor heat and hovers. The in-floor heat is provided by an active solar collector using air as a heat transfer fluid. Air in the closed loop heating system passes from the collector through an In-Floor Heat Distribution and Storage (IFHDS) system before returning to the collector (Fig. 4). The 1 m (3 ft., 4 in.) high flat plate active collector is tilted 60 deg above horizontal and positioned at ground level across the front of the building. Air flow is achieved via a centrifugal fan which "pushes" air through the IFHDS system at the designed rate of 37 $m^3h^{-1}m^{-2}$ (2 cfm/ft^2) of collector surface.

The collectors have two Tedlar® * glazings and a dark brown pre-painted ribbed steel roofing sheet absorber plate. A 5 cm (2 in.) layer of high temperature fiberglass insulation is positioned behind the absorber plate to limit heat losses. Painted wood was used to construct the

*Mention of trade names is for informational purposes only. No endorsement of listed products or discrimination against other products by the University of Nebraska is intended.

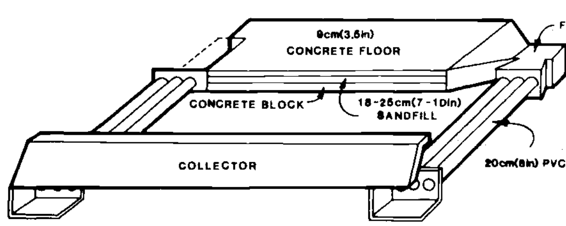

Fig. 4—Schematic of the horizontal closed-loop in-floor heat distribution-storage system.

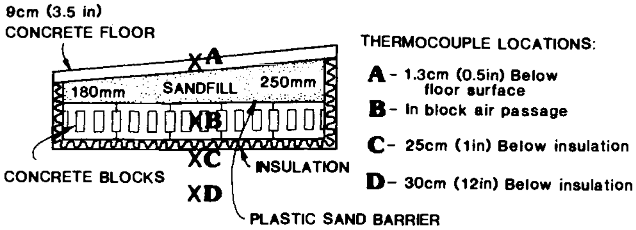

Fig. 5—Schematic cross-section of the in-floor heat distribution-storage system showing thermocouple location.

collector framework. Clear silicone caulking/sealant was used throughout to seal the joints of the collector system.

Components of the IFHDS system are 20 x 20 x 41 cm (8 x 8 x 16 in.) (nominal) concrete blocks, sand, the concrete floor on top of the sand and blocks, and the enveloping insulation (Fig. 5). The concrete block layer is five blocks wide. (Note: Subsequent work has shown a need to vary the number, size and spacing of blocks in buildings of different sizes.) Blocks are laid with the cores horizontal and aligned to provide air passageways through the length of the block layer. An 18 to 25 cm (7 to 10 in.) sand layer above the blocks provides additional thermal storage mass and allows establishment of desired floor slopes during construction. A 4 mil layer of polyethylene is placed over the blocks to keep sand from filtering into the air passageways. The 9 cm (3.5 in.) thick concrete floor is cast directly on the sand. The resultant storage mass is approximately 0.6 to 0.7 m^3m^{-2} (2 to 2.3 ft^3/ft^2) of active collector surface — providing a thermal storage capacity of approximately 1700 $kJC^{\circ -1}m^{-2}$ (84 $Btu/F^\circ/ft^2$).

The IFHDS system is insulated to RSI 0.7 to 0.9 (R4 to 5) by extruded polyisocyanurate foam insulation on the sides and bottom. Equivalent insulation is directly beneath the concrete floor within the feeding area. A 4 mil polyethylene vapor barrier is placed at the insulation-soil interface to limit moisture migration.

SYSTEM PERFORMANCE

Building

The solar-assist features of both Nebraska Solar MOF Nurseries have provided most of the required heating energy (Table 1). Manual adjustment of ventilation panels has not been a drawback since it gave the producers cause to visit the facility at least twice daily, a desirable management regimen. Manual adjustment was found to be necessary in the Paus nursery because condensation on the aluminum sash and frames of the translucent ventilation/passive collector panels freezes during cold weather. Lack of sensitivity on the part of mechanical drive mechanisms for automatic operation would have resulted in damage to the panels.

Air quality was deemed excellent. The maximum gas concentrations measured during the winter were: $H_2S=O$ ppm and $NH_3=5$ ppm. A recording hygrothermograph with monthly calibration with a sling

TABLE 1. Thermal Performance Results for the Solar MOF Nursery (PAUS)

	1980			1981						1982
	OCT	NOV	DEC	JAN	FEB	MAR	OCT	NOV	DEC	JAN
Total active solar heat transferred to IFHDS system, GJ (10^6 Btu)	4.32 (4.09)	3.76 (3.56)	2.48 (2.35)	3.18 (3.01)	2.02 (1.91)	4.16 (3.94)	3.84 (3.64)	3.11 (2.95)	2.33 (2.21)	1.79 (1.70)
Avg. daily radiation incident on active collector, MJ/m^2.day (Btu/ft^2.day)	20.4 (1797)	18.4 (1621)	12.3 (1084)	18.4 (1621)	17.8 (1568)	16.3 (1436)	15.5 (1365)	14.1 (1242)	12.7 (1119)	13.1 (1154)
Avg. daily active solar heat input to IFHDS system, MJ/m^2 (Btu/ft^2) collector area.day	4.27 (376)	3.84 (338)	2.44 (215)	3.14 (277)	2.20 (194)	4.11 (362)	3.80 (338)	3.19 (281)	2.31 (204)	1.77 (156)
Avg. temperature under hover, °C (°F)	28 (82)	25 (77)	24 (75)	26 (78)	NA NA	NA NA	NA NA	23 (73)	28 (83)	29 (84)
Avg. inside temperature, °C (°F)	24 (75)	21 (70)	21 (70)	21 (70)	19 (67)	17 (62)	21 (70)	19 (67)	15 (59)	14 (57)
Avg. outside temperature, °C (°F)	8 (47)	3 (38)	1 (33)	−1 (30)	−6 (21)	2 (36)	6 (42)	3 (38)	−8 (17)	−13 (8)
Active solar energy transferred 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

psychrometer revealed a maximum relative humidity of 80%. The maximum dust accumulation on pen partitions was 6 mm (1/4 in.).

Except for initial start-up difficulties with the dosing siphon in the Larson facility, no physical or pig problems (pigs as small as 3.6 kg (8 lb)) have been encountered with the open flush gutters. All flushing has been accomplished with fresh water. No manual labor for floor scraping has been required.

Passive Solar Collector

Sunlight entering through the passive collectors on the Paus nursery is intercepted by the floor and partitions in the front two-thirds of the building, providing an almost immediate temperature response to sunny days. In contrast, smaller passive panels (0.9 m (3 ft) high) in the Larson nursery result in passive energy striking only the middle third (feeding area) of the pens. The implications of the different passive collector sizes relative to system performance have not been fully evaluated. However, observed lower light levels under the hovers in the Larson nursery are believed to have contributed to pigs dunging under the hovers, rather than in the flush gutter. Placing incandescent lights in the hovers corrected this problem. This need for light is consistent with field observations related to the use of creep boxes in farrowing facilities and as reported by Plessing (1984). We believe the larger passive collector size (1.8 m (6 ft) high) used in the Paus nursery allowed entry of more daylight and averted the need for auxiliary lights to ensure proper dunging patterns.

Active Solar Collector

The thermostat used to control the collector fan senses collector outlet temperatures and is set at 35 °C (95 °F). This normally results in collector fan operation from about 10:00 a.m. to about 4:00 p.m. The temperature of the air leaving the collector during the heating season normally peaked at 55 to 60 °C (130 to 140 °F). Typical daily cycles of the collector outlet temperatures during sunny days are shown in Fig. 6.

The effect of cold, cloudy weather upon collector operation at the Paus nursery can be seen in Fig. 7. From January 20 through 23, 1982, the low solar insolation levels coupled with cold outdoor temperatures (less than 0 °C (32 °F)) reduced the temperature of the air in the collector such that the collector fan activation temperature of 35 °C (95 °F) was reached only once (January 23). This was typical of the local weather conditions from late October 1981 through mid-February 1982 which resulted in the collector fan operating only 20% of the days.

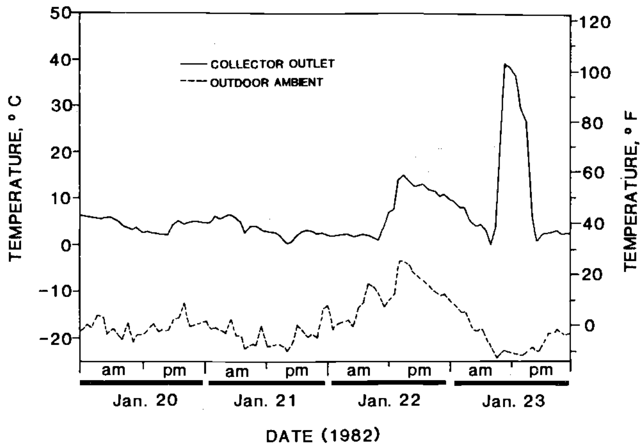

Fig. 7—Air temperatures at the outlet end of the active solar collector on cold, cloudy days (Paus).

In-Floor Heat Distribution and Storage (IFHDS) System

The transfer of heat from the solar heated air to the IFHDS system can be inferred from Fig. 8. The temperature drop of the air in the air passageways between the beginning and middle of the IFHDS system is approximately 70% of the air temperature drop between the beginning and end of the IFHDS system. Thus, heat transfer at the location where the solar heated air first enters the IFHDS system is greatest and decreases as the air travels the length of the IFHDS system. This is a desirable phenomenon for a "continuous flow" nursery since the smallest pigs can be housed above the inlet to the IFHDS system to benefit from the extra heat, and larger pigs can be protected from over-heating by housing them above the exit end of the IFHDS system. The smallest pigs were kept in the first pen since the air from the collector, having just entered the IFHDS system, kept the floor surface

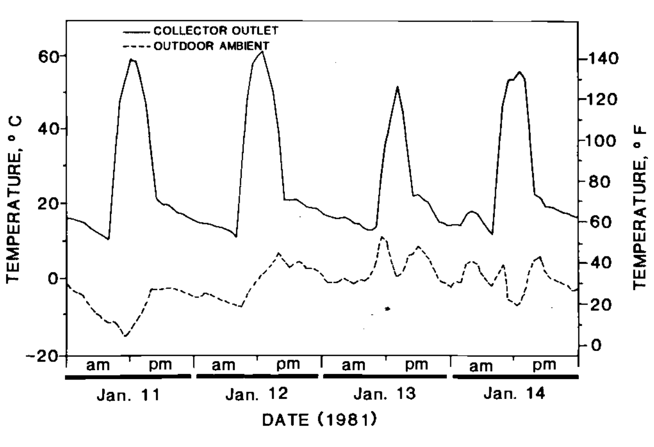

Fig. 6—Air temperatures at the outlet end of the active solar collector on sunny days (Paus).

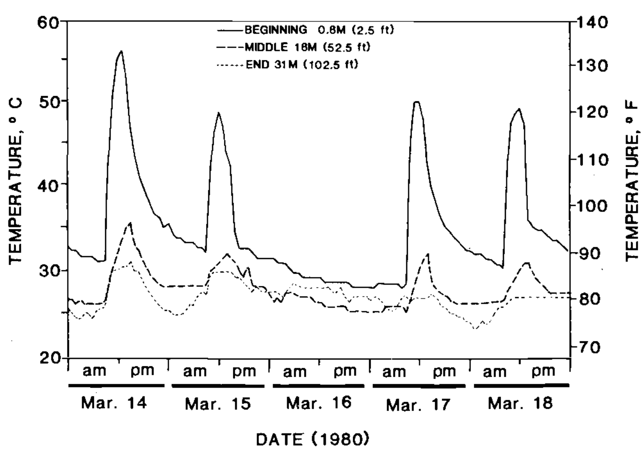

Fig. 8—Temperatures in the air passageway of the IFHDS system at selected locations along the length of the air channels (Paus).

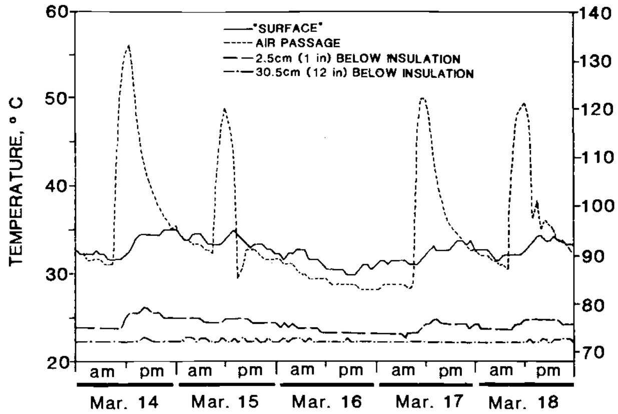

Fig. 9—Temperatures in a vertical profile of the in-floor heat distribution-storage system (Paus).

temperature between 32 and 35 °C (90 and 95 °F) most of the time.

The heat transfer between the solar heated air and the floor surface at the inlet to the IFHDS system produces relatively stable floor surface temperatures (Fig. 9). Floor temperatures did increase when air passageway temperatures increased. A gradual increase in floor surface temperature (4 C° (7 F°) over 12 h) occurred with successive days of sunshine. A gradual decrease (4.5 C° (8 F°) over 28 h) was observed during a "cloudy" day. It is hypothesized that these gradual floor temperature changes permit the pigs to become acclimated to varying temperatures and subject them to less thermal stress than sudden changes in floor temperatures.

System Performance

Some indicators of the thermal performance of the solar heated nursery are presented in Table 1. 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 1.79 GJ to 4.32 GJ (1.70 to 4.09 x 10^6 Btu) with an average of 3.10 GJ (2.94 x 10^6 Btu) per month.

The thermocouple used to measure the air temperature in the local micro-environment beneath the hover was under the middle of the hover of the first pen in the building (east end). Monthly average air temperatures under the hover ranged from 23 to 29 °C (73 to 84 °F) with an average of 26 °C (79 °F). This is the result of the solar heat plus heat from the pigs.

The indoor ambient temperature was measured with a thermocouple in the middle of a pen near the midpoint of the building at 1.5 m (5 ft) above the floor. The temperature at this point was cooler than the temperature in the pig zone under the hover. The increased air temperature under the hover, along with the elevated floor temperature, provided a productive environment for the pig in contrast to cool indoor ambient nighttime temperatures. Thus, this nursery system reduces energy use by providing a heated micro-environment which makes it unnecessary to heat the entire building interior to the high temperature required by the young pigs. These results are consistent with work by Shelton and Brumm (1986). 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. Observation of the pigs and their activity in the three areas served as a primary management tool in adjusting ventilation openings.

The total solar heat usable in the IFHDS system as presented in Table 1 was calculated on an hourly basis. The quantity of the heat available from the active collector was calculated by multiplying the mass flowrate through the collector (from AMCA fan performance data and measured static pressure drop across the fan) and the temperature increase through the collector while the active collector fan was operating. Heat delivered to the IFHDS system was calculated by multiplying the mass flowrate through the IFHDS system (same as through the collector) and the temperature drop of the air as it passed through the IFHDS system while the collector fan was operating.

Temperature differences between the air in the concrete block cores (air passageways) and the soil beneath the IFHDS system coupled with R values of the materials between those points yielded values for the heat loss from the IFHDS system on a 24-h basis. The quantity of solar heat usable in the IFHDS system was calculated by subtracting the 24-h IFHDS system heat loss from the quantity of solar heat delivered to the IFHDS system. The daily quantities of solar heat usable in the IFHDS system were accumulated to determine the monthly totals of usable solar heat. Dividing monthly totals by the number of days in the month and the collector area yielded the average daily heat input to the IFHDS system per unit area of collector. This value divided by the average daily solar insolation incident on the collector yielded the percent of usable solar energy which varied from 12.4 to 25.3%.

During the first 8 years of operation, solar heat provided 100% of the supplemental heating needs of the Paus building except for 4 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 (Tables 2 and 3). January 1982 was the fourth coldest January on record based on over 100 years of weather records. Several days with wind chills of −51°C (−60°F) were recorded. Solar insolation levels averaged about 30% below normal. This January weather—after a cold, cloudy December—did not allow the solar heating systems to provide enough supplement heat. Heat lamps (125 W) added to the first five pens of the nursery (pens with the smallest pigs) provided enough auxiliary heat to maintain proper environmental temperatures in the buildings. A summary of selected weather data during this period is presented in Tables 2 and 3. No auxiliary heat was required during other record cold but sunny periods (December 1983 and November 1984).

It is not known whether all of the heat supplied by the solar system in the "100% 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.

The monthly totals of solar energy available and solar energy transmitted to the floor include effects of varying

TABLE 2. Weather Data Near the PAUS Solar MOF Nursery Winter 1981 to 82

	1981 OCT.	NOV.	DEC.	1982 JAN.	FEB.	MAR.
Average monthly temperature, °C (°F)	9.7 (47.5)	5.0 (41.0)	-3.6 (25.5)	-9.5 (14.9)	-5.5 (22.1)	1.6 (34.9)
Departure from normal average monthly temperature, C° (F°)	-2.4 (-4.3)	1.2 (2.2)	-1.4 (-2.5)	-4.8 (-8.6)	-2.1 (-3.8)	0.2 (0.4)
Heating degree days, C° days (F° days)	256.5 (461.7)	395.5 (711.9)	677 (1218.6)	860.5 (1548.9)	667 (1200.6)	515.5 (927.9)
Normal heating degree days, C° days (F° days)	181 (326)	434 (780)	637 (1147)	706 (1271)	552 (994)	465 (837)

Source *Data from NOAA Climatological Data for Nebraska for the weather station at Clay Center, NE, 12 miles northeast of the unit.

TABLE 3. Weather Data Near the Larson Solar MOF Nursery Winter 1982 to 82

	1981 OCT.	NOV.	DEC.	1982 JAN.	FEB.	MAR.
Average monthly temperature, °C (°F)	10.7 (51.3)	5.5 (41.9)	-3.0 (26.6)	-8.7 (16.3)	-2.8 (27.0)	3.3 (37.9)
Departure from normal average monthly temperature, C° (F°)	-1.6 (-2.9)	1.7 (2.6)	-1.3 (-2.3)	-5.7 (-10.3)	-2.4 (-4.3)	-0.1 (-0.2)
Heating degree days, C° days (F°days)	233.5 (420)	380 (684)	658.5 (1185)	835.5 (1504)	591 (1064)	462 (832)
Normal heating degree days*, C° days (F° days)	181 (326)	433.5 (780)	646 (1163)	723.5 (1302)	599 (1078)	465 (9.37)
Percent possible sunshine†	50	57	39	40	61	50
Normal percent possible sunshine*	67	57	52	57	59	59

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

*Taken from Climatic Atlas of the United States, 1968.

†NOAA data for the weather station at the airport in Lincoln, NE, 15 miles southeast of the unit.

outdoor temperatures and daily radiation. A closer look at data from four days in January 1981 showed the percentage of solar energy available for use in raising the IFHDS system temperature on cold but sunny days is higher than the monthly percentage. Analysis of the Paus nursery active collector and IFHDS system temperature data for January 11 through 14, 1981 showed that on a 24-h average, 44% rather than 13 to 20% of the collected solar heat was usable in the IFHDS system. Outdoor ambient temperatures during this 4-day period averaged −1 °C (30 °F) with a −16 to 12 °C (4 to 54 °F) range. Solar radiation levels in the plane of the collector averaged 16.9 MJm^{-2} day^{-1} (1490 $Btu/ft^2/day$) for those days. Under these conditions, 27% of the solar energy incident on the solar collector was actually usable in the IFHDS system for increasing the temperature of the in-floor storage, or available in the pig zone as heat energy.

A problem noticed from the 4-day data analysis is that a major portion (43%) of the solar heat from the collector was lost between the solar collector and the insulated PVC pipe air ducts leading to the collector fan and IFHDS system. Temperature losses of air passing through this transition regularly reached 17 C° (30 F°) at solar noon. Insulation of the transition area between the end of the collector and the under-floor PVC pipe air ducts was inadequate at RSI 0.77 (R4.4). The recommendation for insulation of this transition area has been increased to RSI 2.6 (R15), which will increase the utilization of the heat from the active solar collector. With the increased insulation, the temperature drop of solar heated air passing through the transition should be reduced from 17 C° (30 F°) to 6 C° (11 F°). The percent of collected solar energy usable in the IFHDS system should increase from 44% to 60%. This should raise the percentage of incident solar energy that is usable in the IFHDS system from 27 to 37.

Active Solar — Management

The active solar collector system should be operational two weeks before heat is actually required at the floor surface. This will provide enough time to raise the base temperature of the IFHDS system to meet the needs of small pigs. The active solar system can then operate automatically for the winter heating season with its thermostat controlling operation of the collector fan.

On occasion, very cold and cloudy weather may persist during the heating season. In these instances, auxiliary heat such as heat lamps or infrared heat may be required in the hovered area for pigs weighing less than 9 kg (20 lb). The electrical wiring system should be planned to meet this potential need.

During warm weather, management of the active collector system must take into account the temperature requirements of the pigs. With pigs weighing approximately 11 kg (25 lb) or more, covering of the active collector might be necessary to prevent overheating of the pig sleeping area. If the unit is used only for pigs weighing approximately 11 kg (25 lb) or less, the need for some heat on a year-round basis might require operation of the collector during the summer. In those instances, the collector can be partially covered to allow collection of the proper quantity of heat.

A thermostat with a remote sensing bulb is the only automatic control for the active solar heating system. A malfunction of the thermostat in the Larson Nebraska Solar MOF Nursery showed the importance of this thermostat. The operator of this nursery had to manually start and stop the collector fan when he thought the fan should operate. Temperature data from this manual control of the collector fan operation is presented in Fig. 10.

Note that IFHDS system air temperatures dropped sharply in mid-morning, indicating a start-up of the collector fan before the air temperature in the collector was above 35 °C (95 °F). Starting the collector fan too early, and letting it run too late, was very detrimental to storage of heat in the IFHDS system. Appreciable quantities of heat were removed from the IFHDS system because of this improper fan operation. Improper

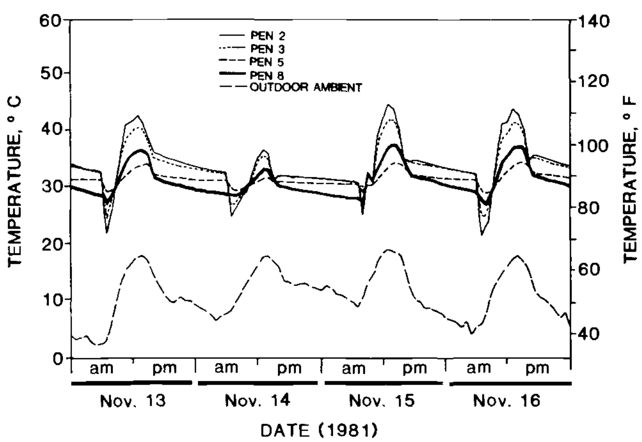

Fig. 10—Air passageway temperatures along the in-floor heat distribution-storage system with manual operation of collector fan.

operation of the collector fan on November 14, 1981 removed more heat from the IFHDS system than was added. This can be concluded from the fact that air passageway temperatures in the IFHDS system on the evening of November 14 were lower than on the evening of November 13 even though the outdoor ambient air temperature was higher on the evening of November 14. A second detrimental effect of improper collector fan operation was that a high proportion of the heat removed from the IFHDS system occurred under the smallest pigs, where heat was most needed. Automatic control (thermostat with remote sensing bulb in the collector) of the collector fan must be utilized to avoid this problem.

CONSTRUCTION AND HEATING COSTS

Construction costs for the Paus Solar MOF Nursery were $55 per pig (1979 cost). Higher labor costs and an auxiliary in-floor warm water heating system, which has not been used, resulted in the Larson Solar MOF Nursery costing approximately $87 per pig (1982 costs). The solar heating systems comprised approximately 18 percent of the total building construction cost in both cases.

Heating costs during the winters of 1979 to 80 and 1980 to 81 for the Paus nursery were $10 and $18, respectively, representing the cost of operating the fan to move air through the active collector and the IFHDS system. These costs are less than 2% of the $1,540 annual heating cost estimate for the 550-head nursery. The $1,540 estimate was based upon calculations for a nursery of the same physical dimensions using propane at $0.15/L ($0.56/gal) as fuel for the heater and comparisons with other nurseries. The $1,540 estimate also assumed use of mechanical ventilation. The entire volume inside the building was heated to the required temperature, and an average winter heating load of 3318°C heating-degree-days (base temperature 18°C) (5973°F heating-degree-days (base temperature 65°F)).

During late December 1981 and early January 1982, low solar insolation levels made it necessary to add heat lamps for the newly weaned pigs in the Paus facility. The operating costs for heat lamps in five pens over a 30-day period resulted in an increase in building heating costs for the winter of 1981 to 82 to approximately $55. Nearly two-thirds of this heating cost was because of the addition of the heat lamps. During the first 8 years of operation (October 1979 to September 1987), a total of 3182 kWh of electricity was used in this facility to operate the solar system and provide auxiliary heat. That is an energy use rate of approximately 142 W-h/pig or 1 cent per pig reared in the unit with electricity at 7 cents/kWh.

Pig performance in the Nebraska Solar MOF Nursery buildings compares favorably with industry standards for pig performance (Mayrose et al., 1985). Feeding trial results in the Larson Nebraska Solar MOF Nursery (January to February 1982) were: a low performance of 2.3 kg of feed per kg of gain (2.3 lb feed per lb gain) with 0.31 kg (0.69 lb) weight gain per day and a high performance of 1.85 kg of feed per kg of gain (1.85 lb feed per lb gain) with 0.35 kg (0.77 lb) weight gain per day. Another study with a high nutrient density diet resulted in feed conversion of 1.17 kg feed per kg gain

(1.17 lb feed per lb gain) and an average daily gain of 0.43 kg (0.95 lb). These feed trials were conducted on pigs with average weights of 8.5 to 18.5 kg (18.75 to 40.75 lb) at the beginning and end of the two trials, respectively. A total of 93 pigs were involved in these trials.

SUMMARY

A total of 13 years operation in two facilities has demonstrated that solar heated non-mechanically ventilated MOF nursery units with IFHDS systems can be effectively used for nursery pigs in Nebraska. Facility construction costs averaged about two-thirds the cost of comparable conventional nursery designs. Heating costs were 1 to 2% of the cost to operate conventional units during normal winters. The use of in-floor solar energy heating reduces heating energy requirements compared to levels necessary for whole-building heating with no loss in pig performance. Whether the savings were due to floor heating—with reduced heat loss from the pigs—or solar energy was not determined.

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