

FIELD EVALUATION OF A LOW ENERGY SWINE NURSERY FACILITY

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ABSTRACT. An energy efficient swine nursery house was designed and evaluated. The design included heated pig brooder boxes, natural ventilation, and passive solar heating. Early weaned pig performance was satisfactory and energy consumption was less than a conventional nursery house. This nursery house has been enthusiastically accepted by South Carolina swine producers. **Keywords.** Swine housing, Nursery design, Energy, Environment.

The swine industry in South Carolina is a multimillion dollar industry with annual production reaching nearly one million head. Housing designs continue to change as producers strive to improve the efficiency and performance of their enterprise. The current trend is away from total environmental control to a more energy efficient modified environment.

The temperate climate in the southeast has advantages and disadvantages. High temperatures in South Carolina place heat stress on most livestock for the duration of summer (Linville, 1987). The winters can be relatively cool with temperatures approaching -6.1°C (21°F). Producers are looking for facility designs that can take economic advantage of the relative mild climate, and avoid severe stress on the animals during the temperature extremes.

Producers have found that totally environmentally controlled facilities are not necessary for efficient swine production in the southeast. In a report by Christenbury et al., (1987) there was no difference in pig performance for a totally environmentally controlled facility compared to a modified curtain sidewall facility. McConnell and Allen (1989) tested a low energy swine nursery facility that relied on zone heating of pig boxes with limited space heating, natural ventilation and a passive solar design. This facility was constructed on the Clemson University Starkey Swine Farm near Clemson, South Carolina. The results from this experimental facility have shown significant energy savings and acceptable nursery pig performance.

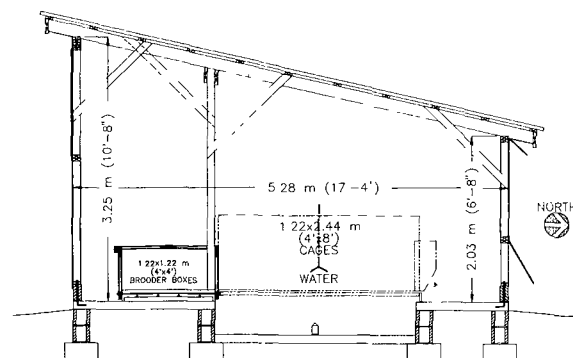
The objective of this project was to develop and evaluate the performance of a commercial low energy nursery and compare it with typical energy consumption

and pig performance of a mechanically ventilated swine farrowing facility.

FACILITY DESIGN

An adaptation of the McConnell and Allen (1989) experimental facility was constructed on a 300-sow feeder pig operation in Clarendon County, South Carolina. Several modifications were made to adapt it to the commercial swine operation. The commercial design of the low energy facility was dubbed CULESS (Clemson University Low Energy Swine System).

The nursery facility (fig. 1) was designed with a 3/12 monoslope roof to promote natural ventilation flow (MWPS, 1989). Both eaves were left open and covered with hardware cloth. The eave on the north side had vent doors that could be used to regulate the winter ventilation rates. Ventilation during other times of year was accomplished using a 48 cm (19 in.) opening near the floor on the north side and a 137 cm (54 in.) opening near the ceiling on the south side. Both openings ran the length of the building and were covered with hardware cloth to exclude birds. The ventilation was regulated by using vent



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Figure 1—Cross-sectional view of the CULESS nursery design.

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doors on the northern openings and a translucent ventilation curtain on the south. Some producers used curtains on the north openings instead of vent doors. Others used storm windows without screens on the south side that lowered from the top to regulate air flow.

The eave height on the south side was approximately 3.35 m (11 ft) and the north side was 2.1 m (7 ft). This roof height produced a solar penetration to the back wall (5.3 m, 17.3 ft) on 21 December at noon and complete shading on 21 June at noon. It was designed using methods described by MWPS (1983) for 34°N Lat (the approximate location of Columbia, S.C.).

The interior configuration of the building consisted of 1.2 × 2.4 m (4 × 8 ft) pens with woven wire flooring over a flush gutter, coupled with a 1.2 × 1.2 m (4 × 4 ft) insulated pig brooder box. The brooder boxes were placed nearest the south wall of the building with the pens extending to the north. Walls were insulated with batts of insulation. The ceiling was insulated using aluminum foil bubble pack radiant barrier insulation with an air space above it. However, insulation should be equivalent to at least 3.8 cm (1.5 in.) of rigid insulation to reduce heat stress.

The pig brooder boxes consisted of insulated boxes resting on a concrete floor. The sides and tops of the boxes were insulated sandwich construction. The panels were constructed on site using 1.2 cm (1/2 in.) plywood with a 1.8 cm (3/4 in.) styrofoam core. A 2.5 × 10 cm (1 × 4 in.) board was used in the perimeter of each panel. The panels were bolted to the sides of the floor and the top hinged to provide access to the pigs and for cleaning.

The floor of the boxes was poured concrete. The pig box floor was heated by hot water circulated through pipe buried in pea-gravel concrete. The floor was insulated from the subbase with 5 cm (2 in.) styrofoam, except for the perimeter. A 2.5 cm (1 in.) strip of concrete rested on the concrete subbase to prevent rodents from getting underneath the box floor. Hot water pipes were spaced 30 cm (1 ft) apart in the slab. Heated water was pumped through the two outside pipes and returned through the two inner pipes.

Three different piping arrangements were tested in this facility. A 3 m (10 ft) section of the slab was fitted with 1.8 cm (3/4 in.) black iron pipe to compare with PVC. Two methods of installing 1.8 cm (3/4 in.) PVC were also evaluated. One section of the PVC was covered with washed sand prior to pouring the concrete. The other PVC pipe had the concrete poured directly onto it. The header pipe to and from the hot water heater was 2.5 cm (1 in.) PVC. The plumbing used for the hot water heating was similar to that used by Aldrich and Bartok (1992) for greenhouse heating. A tempering valve was used to regulate the temperature of the water to the floor heating pipe. The pipe from the water heater to the tempering valve was CPVC.

The heating system for the facility was a 189 L (50 gal) domestic water heater. A pump rated at 22.7 Lpm (6 gpm) was used to circulate the heated water. The pump was regulated by a line thermostat with the sensor embedded in the center of the concrete slab.

The field unit test facility was constructed in the summer of 1989 near Manning, South Carolina. The finished facility contained 12 nursery pens. Total cost of the facility was \$12,432.57, or approximately \$65 per pig

capacity, which included all material, equipment, and labor. Further details are illustrated by CPS (1989).

DATA ACQUISITION

The three sections of pipe were instrumented with type T thermocouples in an effort to compare the different types of pipe installations. Nine thermocouples were evenly spaced across the floor for each of the three piping arrangements. In addition, four thermocouples were placed along the length of the heated floor. The thermocouples were positioned prior to placement of the concrete and held in place with a post embedded in the styrofoam. The thermocouples were placed 1.3 cm (1/2 in.) below the surface. A datalogger (model CR-7, Campbell Scientific, Inc., Logan, Utah) was used to record temperatures. Temperatures were measured every 30 s and recorded as an hourly average.

A black globe thermometer, fashioned out of a painted float ball with a thermocouple installed in the center, was used to measure apparent temperatures inside the pig boxes and the open facility. Other thermocouples were used to measure dry bulb temperatures in the brooder boxes and the open facility. Ambient dry bulb temperature was measured under the north eave.

Time recorders were placed on the circulating pump and each element of the water heater to determine how long each element operated. A kilowatt-hour meter was used to monitor all electrical energy used in the nursery.

OPERATION

The first pigs were placed in the building in June of 1989. The farmer-cooperator made all management decisions. Pigs were weaned at three weeks of age. The building was managed as "all in-all out" with a thorough cleaning between each group of pigs. The pigs were removed when they reached 13.6 to 18.2 kg (30 to 40 lbs).

The building performed well during the summer and early fall. Just prior to the heating season, hurricane Hugo hit the facility directly and interrupted power for several weeks. All farrowing facilities on the farm were totally destroyed which interrupted the normal flow of pigs to the nursery. Normalcy was not returned until new farrowing facilities were constructed the following summer.

The nursery building lost some roofing and several glass panels which were not fully repaired during the duration of the winter. The nursery was used extensively during the first winter, although pen lots were variable in size and the length of stay in the facility was determined more for convenience than for optimum growth of the pigs. Total energy use was recorded during the first winter with the kilowatt-hour meter.

The planned procedure for operating the floor was to heat the slab to 32.2° C (90° F) prior to placing the pigs in the facility. After one week the temperature was to be lowered to 26.7° C (80° F). Water temperature circulated to the floor was to be 35° C (95° F) with a flow rate of 22.7 Lpm (6 gpm). It became apparent that once the floor of the pig boxes was heated for the newly weaned pigs their own body heat was nearly sufficient to keep the floor heated until they were removed from the nursery.

RESULTS AND DISCUSSION

FLOOR TEMPERATURES

The temperature of the slab was relatively uniform across the width as well as along the length. We could not detect any appreciable difference between the method of pipe placement or type of pipe in the floor. There appeared to be some slight-edge effects. This was not unexpected because the perimeter of the heated slab was in direct contact with the unheated concrete subbase. Some peaks in floor temperatures were observed and attributed to pigs laying directly over the sensors.

ENVIRONMENT

The brooder boxes provided a nearly constant microenvironment for the pigs. Figure 2 illustrates temperature responses during 23 January 1991, one of the coldest days encountered while figure 3 illustrates responses during 8 June 1990, one of the hottest days. During 23 January 1991 the average outdoor temperature was 2.7° C (36.8° F) while the room and brooder box dry bulb temperatures averaged 14.2° C (57.5° F) and 28.1° C (82.6° F), respectively. The brooder box temperature remained relatively constant, with a standard deviation of 1.5° C (2.7° F). This created an opportunity for ad lib environmental regulation for the pigs and tended to condition them for movement into the naturally ventilated grower barn. The rapid increase in the room black globe temperature in figure 2 indicates solar heating during the morning.

Figure 3 illustrates data collected on 8 June 1990. Again, the brooder box provided a relatively constant environment. The average ambient and room dry bulb temperatures were 27.4° C (81.3° F) and 28.8° C (83.8° F), respectively. From figure 3 it may be noted that the ambient temperature at 3 P.M. was 38.3° C (100.9° F) while the room temperature was 35.4° C (95.8° F). It is rather unusual for peak temperatures within a livestock facility to be this much less than the ambient conditions during the summertime. This result has two possible explanations. First, the large amount of concrete in the facility, in combination with evaporation from the flushing system, reduced the peak temperature. Second, the ambient dry bulb temperature could be slightly elevated due to radiation from the underside of the uninsulated eave. Although, the ambient thermocouple was shielded, it was naturally

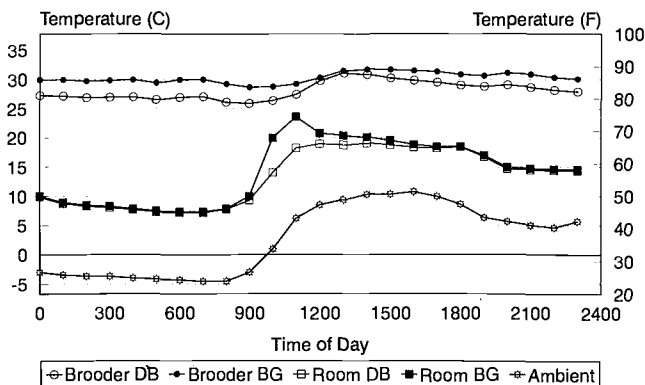


Figure 2—Temperature response of the CULESS nursery in Manning, S.C., on 23 January 1991. Temperatures indicated are dry bulb (DB) and black globe (BG).

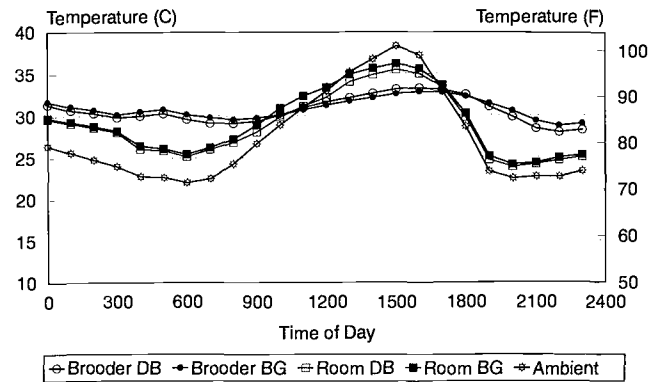


Figure 3—Temperature response of the CULESS nursery in Manning, S.C., on 8 June 1990. Temperatures indicated are dry bulb (DB) and black globe (BG).

aspirated. Presumably, both explanations contributed to this result.

ENERGY USAGE

The cumulative electrical energy use and water circulation elapsed time for the CULESS nursery is shown in table 1. A major portion of the energy use was due to standby losses from the water heater, which was adjusted to maintain a water temperature of 48.9° C (120° F) to prevent any accidental overheating of the PVC pipe, and still provide some reserve capacity. During the first 46 days of operation the nursery consumed 161 kWh, while the pump circulated water for heating the pig boxes only 10 h. If one of the 4500 watt elements was operating during this time then only 45 kWh would have been used for floor heating, which represented 27% of the total energy use. The remainder was a combination of standby losses and lighting. For the first two years of operation the pump ran 424 h and total energy use was 4568 kWh. Assuming that one element in the water heater was sufficient to maintain the system, then floor heating represented 42% of the total energy usage for the two years of operation. Analysis of 1992 data validated this conclusion since the estimate for three years of operation is 43%.

To reinforce the assumption of energy use by the floor, the flow rate to the slab was measured to be 14.0 Lpm (3.7 gpm), with a temperature drop of 3.3° C (6° F). During these conditions the heat loss to the slab was 3.2 kW which is reasonably close to the water heater element rating (4.5 kW).

Table 1. Cumulative energy usage and water circulation elapsed time for the CULESS field nursery

Date	Electric Meter (kWh)	Pump Meter (h)
6/27/89	64	440.1
8/11/89	225	450.1
12/19/89	1819	577.0
3/20/90	2479	645.7
11/28/90	2591	658.5
12/14/90	3001	717.8
2/11/91	4041	805.0
3/18/91	4416	842.6
6/18/91	4632	864.1
8/18/92	6275	1035.3

In order to compare this facility to a mechanically ventilated structure, fuel cost was estimated. The air within a conventional house, the same size as the CULESS nursery, containing 192 pigs, was assumed to be heated to 26.7° C (80° F) with an ambient design temperature of -4° C (25° F). The building was assumed to have a typical UA insulation value of 137 W/K (259 Btu/h-°F) with cold weather ventilation of 0.0566 m³/min-h days (2 cfm/h days). During the period of 1 October 1989 to 1 May 1991, heating degree days averaged 1260° C (2268° F) per year.

To estimate the cost of heating the building, the modified degree-day method (ASHRAE, 1993) was used. This method is less conservative, but generally more accurate than the traditional degree-day method (ASHRAE, 1993). The availability of daily high and low temperatures made the modified degree-day (MDD) method feasible. To utilize the MDD method the balance temperature was calculated using the following equation (ASHRAE, 1993):

$$t_b = t_i - \frac{q_g}{BLC} \quad (1)$$

For the conventional nursery house with the assumed characteristics, the balance temperature (t_b) was 11.7° C (53.0° F). The number of heating degree days (HDD) was then calculated based on the balance temperature using data from Bramblett (1991). This resulted in a new figure of 411° C (740° F) HDD which was then used in the following equation to estimate electrical heating usage for a heating season:

$$E = C BLC DD_{t_b} \quad (2)$$

Conversion to electrical usage yields an estimate of 3541 kWh for an entire season. At 7¢ per kWh, the yearly heating cost is estimated at \$248.

The energy to operate the fans can be estimated using fan duty calculations. Utilizing a three-stage ventilation system (table 2), the operational cost was estimated using a computer program from Albright (1990). This program, called DUTYFACT, predicts yearly costs based on ambient temperature distribution, ventilation rates, and fan ventilating efficiency ratios (VER). No data was available for South Carolina, so computations using Orlando, Florida, and Ft. Knox, Kentucky, were performed and averaged to allow an estimation. Results appear in table 3. Summing the results from the DUTYFACT program and the estimated electrical use from equation 2 yields an estimated cost of \$387.

Using estimation guidelines found in USDA (1977), a nursery this size would use 7185 kWh per year for ventilation fans. Heating would use 1003 L of LP gas

Table 2. Descriptions of the ventilation stages used for energy usage estimations

Step (No.)	Flow Rate		VER	
	m ³ /s	(cfm)	m ³ /s-kW	(cfm/W)
1	0.24	510	2.7	5.8
2	1.33	2810	3.68	7.8
3	3.31	7010	4.67	9.9

Table 3. Results of estimating fan electrical usage using DUTYFACT (Albright, 1990)

Location	Average Ventilation Rate		Duty Factor (%)	Yearly Cost (\$)	Average VER	
	(cfm)	(m ³ /s)			(cfm/W)	(m ³ /s-kW)
Orlando, FL	2330	1.10	33.4	170	8.4	3.98
Ft Knox, KY	1360	0.64	19.4	108.	7.7	3.63

(265 gal) and 365 kWh per year. Assuming electricity costs \$0.07/kWh and LP gas costs \$0.238/L (\$0.90/gal), the total estimated cost would be \$ 767/year.

The measured average electrical usage over three years in the CULESS nursery was 2017 kWh, or \$141, assuming a cost of \$0.07/kWh. The estimated savings attributed to the CULESS design for a one-year period would then be \$626, based on the USDA (1977) procedure, and \$246 based on the MDD and DUTYFACT procedures. Hence, a savings is attributed to the CULESS nursery house.

PIG PERFORMANCE

Pigs were weaned at 21 days old and moved to the CULESS nursery on 12 February 1991. They remained in the nursery until they reached the age of 56 days. The results of this growth trial are shown in table 4.

Groups 9 and 10 each lost one pig, but both groups contained small pigs at the beginning of the study averaging 4.2 and 3.3 kg (9.2 and 7.2 lb), respectively. It is interesting that the farmer believed that he would have lost many more of this size of weaned pig without such a facility. The loss of the larger pig from pen three was attributed to fighting. After 34 days in the nursery, the pigs averaged 15.1 kg (33.3 lb) at 56 days old. This is consistent with typical growth data given by Esmay and Dixon (1986). Average daily gain (ADG) was 238 g/day (0.635 lb/day), but ranged from 247 to 322 g/d (0.54 to 0.71 lb/d) for individual pens. Stevermer (1994) sited unpublished results of a segregated early weaning trial that resulted in an ADG of 350 to 372 g/d (0.77 to 0.82 lb/d) and had a mortality rate of 2%. Mortality in the CULESS nursery was similar to the sited trial, but ADG was less. This may be due in part to the fact that the sited trial used pigs weaned at 16 days with an exceptional health status. McConnell and Allen (1989) found that pigs tended to leave the nursery approximately 0.5 kg (1 lb) lighter than those in a conventional hot nursery. However, the CULESS nursery presumably conditioned animals for the naturally ventilated grower barn and the difference was rapidly eliminated.

Table 4. Growth trial results after 34 days

Pen (No.)	Pigs (No.)	Average Weight, kg (lb)			Mortality (%)
		Initial	Final	Gain	
1	16	6.3 (13.9)	17.0 (37.4)	10.7 (23.5)	0
2	16	6.2 (13.7)	15.3 (33.7)	9.1 (20.1)	0
3	16	5.9 (13.0)	16.9 (37.1)	11.0 (24.1)	6.25
4	16	5.6 (12.3)	16.1 (35.4)	10.5 (23.1)	0
5	16	5.5 (12.2)	14.9 (32.8)	9.4 (20.6)	0
6	16	5.0 (10.9)	14.9 (32.7)	9.9 (21.8)	0
7	16	4.7 (10.4)	13.9 (30.6)	9.2 (20.2)	0
8	10	4.2 (9.2)	13.7 (30.2)	9.5 (21.0)	10
9	10	3.3 (7.2)	11.7 (25.7)	8.4 (18.5)	10
Total	132	5.3 (11.7)	15.1 (33.3)	9.8 (21.6)	2.27

CONCLUSIONS

The results of this study of an energy efficient swine nursery building in South Carolina support the following conclusions:

- The use of naturally ventilated nursery facilities are compatible with commercial swine production in the southeast when combined with heated pig boxes.
- Pipe embedded in concrete provides a satisfactory and durable heating method for insulated pig boxes. No appreciable differences in pipe installation methods were detected.
- Insulated and heated pig boxes provide a satisfactory environment for early weaned nursery pigs.
- Energy use for a naturally ventilated and zone heated pig nursery was less than estimates for a totally environmentally controlled facility.
- Floor heating represents less than 50% of total energy use for the CULESS facility.
- Average daily gain was less for pigs raised in the CULESS nursery house, but mortality rate was comparable to conventional nursery facilities.

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NOMENCLATURE

- ADG = average daily gain [g/day (lb/day)]
- BLC = building loss coefficient [kW/K (Btu/h-°F)]
- C = equation constant [86,400 s/day (24 h/day)]
- CULESS = Clemson University Low Energy Swine System
- DD_{tb} = degree days based on t_b [° C day/year (° F day/year)]
- E = heating season energy usage, kJ/year (Btu/year)
- HDD = heating degree days [° C-day (°F-day)]
- MDD = modified degree day method
- q_g = heat generated excluding supplemental heat, kW (Btu/h)
- t_b = balance temperature [° C (° F)]
- t_i = desired inside temperature [° C (° F)]
- VER = ventilating efficiency ratio [m³/s-kW (cfm/W)]