

FINAL REPORT

RETROFITTING A PIG NURSERY WITH A TRANSPIRED SOLAR WALL TO SAVE HEAT ENERGY AND IMPROVE
PIG PERFORMANCE (NC 67)

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2 October 2009

Acknowledgements

Many individuals and organizations aided in the completion of this project. The NC Pork Council funded the study. Prestage Farms, particularly, their nursery manager Mr. Alan Parker and Mr. Jeff Barnhill cooperated in the selection of the research site and supported the study. The study was conducted at the N&J Butler Farms, Clinton, NC, and its owners are thanked for their support to the project. Personnel from NC State University, namely, LT Woodlief, Craig Baird, Michael Adcock, Richard Currin, Phil Harris, and Carl Tutor provided critical support. Undergraduate students Casey Garland and Chris Love (now graduated) also provided valuable support. Advice from Isaac Singletary, Aerotech Fans is sincerely appreciated.

Abstract

Raising nursery pigs is an energy intensive enterprise and in eastern North Carolina, a 1,520-pig nursery with curtain sides can consume >5,000 gallons of propane per year. While propane prices dropped in 2009, the energy market remains volatile and reducing energy use reduces the financial risks to producers. While there are a number ways for reducing energy use, use of renewable energy such as solar energy can be an option particularly since there are tax breaks and grant and/or loan support. Further, using renewable energy can also reduce carbon dioxide (CO₂) emissions. While solar panels are still very expensive, the transpired solar wall (TSW), because of its high efficiency and low maintenance could be a viable option for reducing energy use in pig nurseries. The TSW consists of a dark colored, perforated metal wall, which when heated by solar radiation, heats the air passing through it.

A TSW (440 ft²) was installed on the south-side wall of a 1,520-pig nursery near Clinton, NC. Pig performance, energy use, internal conditions, and temperature rise at the inlet in the test nursery were compared to an identical, adjacent control nursery during November 2008 through June 2009. The TSW was equipped with a bypass damper that opened to allow the fresh air to bypass the TSW when heating was not needed. Over the four herds monitored, the test nursery had 14% more pigs than the control nursery. More pigs in the test nursery could have reduced livability (-0.33%), daily weight gain (-0.08 lb/d), total weight gain (-3.89 lb/pig), and feed conversion (-4.4%) in the test nursery. Internal conditions (temperature, RH, and CO₂ concentration) were comparable in the test and control nurseries. Propane use was 20% higher in the test nursery vs. control nursery; however, during winter, air at the test nursery inlet was substantially warmer than the control inlet temperature. For example, on 2 February 2009, the test and control inlet temperatures were 103.5 and 75 F, respectively. During warm weather, the test and control inlet temperatures were comparable. For herd 2, day 17, when the ambient control and test temperatures were comparable, the TSW supplied 0.93 million Btu of energy resulting in saving of 10.15 gallons of propane. This reduction in propane use reduced CO₂ emissions by 127 lb for that day. Additional monitoring will be undertaken during fall 2009 through spring 2010 which will also allow for the determination of the economics of using the TSW.

Background

When 18-day weaned piglets are first placed in a nursery, the temperature is maintained at 84 F and as the pigs grow older, the temperature is reduced. A curtain-sided nursery housing 1,520 piglets in eastern North Carolina can consume >5,000 gallons of propane per year (Alan Parker, personal communication, 23 June 2008). Hence, raising feeder pigs is an energy intensive enterprise even in the relatively warm climate of North Carolina. While the US Dept. of Energy (DOE) forecasted in August 2009 that residential propane prices during the 2009-2010 heating season would be ~14% lower than during the previous heating season in the south, the energy market remains highly volatile because of both financial and political reasons. Further, propane prices are weather dependent and a cold winter could result in higher prices than forecasted by the DOE. Hence, there is need for pork producers to continue to take steps to improve energy efficiency and reduce energy use.

Reducing infiltration of fresh air through unplanned inlets and increasing insulation (where inadequate) can help reduce energy costs. Converting curtain sides to solid sidewalls can also result in substantial energy savings since a solid sidewall (R value of 5) will lose only 20% of the heat compared with a curtain side (R = 1). However, when pork producers do not have dedicated generators, they are hesitant about converting curtain sided nurseries to solid sidewalls because if power fails, mortalities can occur more rapidly in a solid sidewall nursery than in a curtain sided nursery where the curtains drop to bring in fresh air. Use of solar energy may also help reduce heat energy use in pig nurseries. While photovoltaic systems for generating electricity are still quite expensive (about \$10,000 per kW before tax incentives), as summarized below, passive solar collectors may be more cost effective in reducing heat energy use in pig nurseries.

Reeder (1985) evaluated a passive solar collector that heated the water that was circulated through pipes in the floor of the farrowing room in the pig creep areas. The \$12,000 system saved \$900 in LPG and had monthly efficiencies ranging between 10 and 30% (Reeder, 1985). A double solar attic system

consisting of a fiberglass-reinforced plastic roof underlain with polyethylene sheeting attached to a rock bed was used in a chicken house by Timmons and Baughman (1987). The double attic system had a maximum hourly collection efficiency of 45% (Timmons and Baughman, 1987). More recently, a passive solar collector, known as the transpired wall system (TSW) was developed which has solar energy conversion efficiency as high as 80% (vs. 15-20% for solar panels). The TSW consists of a dark colored, perforated metal wall, which when heated by solar radiation, heats the air passing through it. The air can be heated by as much as 63°F, depending on the orientation, cloud cover, and airflow rate through the wall. The TSW can also improve environmental and indoor (unvented heaters) air qualities by reducing CO₂ emission by 41 lb/ft² of surface area (Conserval, 2008). With unvented propane or natural gas heaters, the TSW can also reduce indoor humidity since these fuels produce water vapor upon combustion. Apart from being the most efficient solar collector currently in the market, the TSW needs minimal maintenance (no moving parts). Hence, this R&D 100 Award-winning (NREL, 2006) has the potential to reduce heat energy use in livestock production considerably while improving pig performance through improved indoor air quality. It is estimated that the TSW has a simple payback period of 3 years (NREL, 2006), without any incentives.

Godbout et al. (2004) evaluated the impact of a TSW in a 1,000-head pig nursery in Quebec, Canada during the period Nov. 2002 to Apr. 2003. While they reported that propane energy savings ranged from 23 to 31%, no information was provided on pig performance. Deutsch (2007) reported that solar walls reduced propane use by at least 25% in two pig nurseries in Quebec; even without incentives, the payback was less than 5 years. Transpired solar walls are widely used on Canadian farms; Solagra alone has installed them on more than 400 farms (Solag, 2008). There are no reports of TSWs being used on US animal farms.

Hence, the objective of this study was to evaluate the impact of a TSW on energy use and economics in a pig nursery near Clinton, NC. The economic impact of the system would also include pig performance which was not investigated by Godbout et al. (2004).

Materials and Methods

Description of the research farm

The research site is the N&J Butler pig nursery located near Clinton, NC, that contracts with Prestage Farms. The farm has two nurseries that were built in 1996, and each nursery (44 ft by 100 ft) has a nominal capacity for 1,520 pigs; however, as will be presented later, the numbers of piglets placed were substantially higher. Weaned piglets (~12 lb ea.) are placed at about 18 d and removed 45 d later at ~48 lb ea. Each nursery is populated over a 1-wk period and placement dates in the two nurseries vary by about 15 d. Both nurseries run approximately E-W and have 4 ft high and 80 ft long curtains on each of the sidewalls and insulated drop ceilings. Supplemental heating is provided by two propane-fired forced air furnaces (225,000 Btu/h ea.). Minimum ventilation is provided by two variable speed 24 in. fans (Aerotech ATZ 24), whereas mild and hot weather ventilation are provided by four single speed fans (two 24 in. and two 36 in.). Fresh air is brought in through continuous sidewall inlets running the full length of both sidewalls.

Transpired solar wall construction

While the north nursery served as the control, the south nursery (experimental) was fitted with a 440 ft² black, galvanized TSW (medium airflow rate of 6.9 cfm/ft²) on the south side of the nursery, 5 ½ ft in height and 80 ft in length (fig. 1) in November 2008. As shown in Figure 1, the TSW structure covered most of the south sidewall so that when the minimum ventilation fans came on, air pulled through the TSW was routed through the sidewall inlets. Because both nurseries lacked tightness, the inlets did not open under minimum ventilation, and the south side inlet in the test nursery was kept

~1/2 in. open. Apart from allowing normal operation of the TSW, this opening allowed for the heat escaping through the south side wall to be recycled back into the building.



Figure 1. Solar wall installed on the south side of a pig nursery on the N&J Butler Farm near Clinton, NC

In the study by Godbout et al. (2004), the preheated air was distributed in the nursery through an overhead plenum installed in the attic; hence, it was convenient to bypass the solar wall during warm weather. However, since the fresh air in this study was drawn only through the sidewall inlets, ten 8 ft dampers that could open 12 in. were installed (fig. 1) to bypass the TSW when no heating was required. These dampers are simultaneously raised or lowered by a linear actuator through a system of pulleys and cable (fig. 2) based on the input from the nursery environmental controller. Whereas the dampers closed at desired room temperature (DRT) minus 1 F, the heaters came on at DRT minus 2 F. The dampers are also designed to open in case of a power failure, concurrently with the curtain drop. The dampers can also be operated with a manual winch if necessary. The linear actuator is powered by a 12 V DC car battery that is charged by a trickle charger. While the winch and cable system was installed in early-December 2008, the installation of the linear actuator was completed in January 2009. The wiring

to operate the linear actuator from the controller was completed on 12 February 2009 in preparation with the onset of spring when the dampers would have to be raised on warm days. However, despite sealing with caulk, rainwater leaked into the limit switches during mid-February 2009 and rendered the actuator inoperable in the open position. Beginning February 27, 2009 a data logger was used to monitor the operation of the dampers (this data is not presented here). Further weatherproofing allowed the actuator to run until mid-June 2009. However, the linear actuator's power source failed and the bypass damper was locked open sometime between 16 and 24 of June, 2009. Power was restored to the actuator on 22 July 2009. It was noted that during the warm weather the bypass damper should have been in the open position.

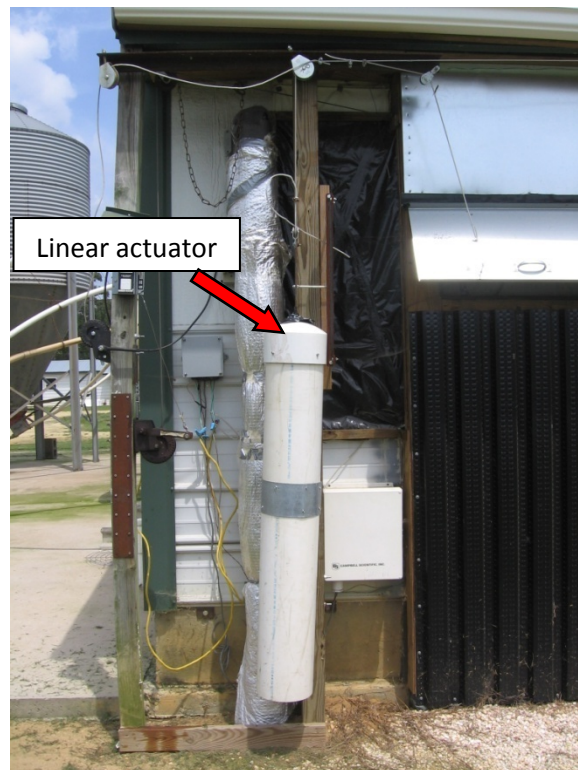


Figure 2. Picture of the linear actuator used to operate the dampers to bypass the TSW

Instrumentation and measurements

Temperature and relative humidity (RH) were measured every 15 min. inside a stilling well at a height of ~4 ft at the same location in both nurseries with a TinyTag Ultra sensor/data logger (Make:

Omni Instruments, UK; ranges: -22 to 122 F and 0 to 95% RH; accuracies: ± 0.76 F and $\pm 3\%$ RH at 77 F). Hourly carbon dioxide (CO₂) concentrations were measured with a GMT220 sensor (Make: Vaisala, Finland; range: 0 to 3,000 ppm; accuracy: $\pm 1.5\%$ of range plus 2% of reading) were measured alongside temperature and RH inside both nurseries and recorded on a Hobo U12-006 data logger (Make: Onset Computers, MA). The CO₂ concentrations provided information on the ventilation states of the two nurseries. Temperature and RH were also measured every second with a Hobo S-THA-M002 combination sensor (Make: Onset Computers, MA; ranges: -40°C to 75°C and 0% to 100% ranges; accuracies: $\pm 0.7^\circ\text{C}$ and $\pm 3\%$) at the air inlets of the two nurseries and averaged every 5 min on a Hobo H21-002 data logger (Make: Onset Computers, MA). When the temperature – RH sensor installed on the inlet of the control nursery malfunctioned, it was replaced with a TinyTag Ultra sensor/data logger that measured and recorded every 5 min.

One of two minimum ventilation (MV) fans in the experimental and control nurseries were equipped with Hobo motor on/off sensors (Make: Onset Computers, MA) to determine motor run times as affected by the solar wall. These motor sensors were installed in early-January 2009 since the original sensors provided by the manufacturer did not work on these fans and had to be modified in the BAE Dept. to increase their sensitivities. Used electric sub-meters with current transformers were installed in both nurseries to measure power consumption in late-November 2008; however, due to some undiagnosed problem, no meter readings could be obtained in the control nursery. New and more accurate electric meters have been purchased with funds from another source and will be installed in fall 2009. Gas consumptions in the two nurseries were monitored based on separate gas bills provided by Parker Gas. A wind vane – anemometer combination sensor S-WCA-M003 (Make: Onset Computers, MA; accuracies: ± 1.1 mph + 3% of full scale reading and $\pm 5^\circ$) and solar radiation sensor S-LIB-M003 (Make: Onset Computers, MA; accuracy: greater of ± 10 W/m² or $\pm 5\%$) were installed ~100 ft from the solar wall in December 2008 to monitor wind effects and solar radiation receipt on the solar wall. These

hourly wind speed, wind direction, and solar radiation measurements were recorded on a Hobo H21-002 data logger.

Pig performance data

In addition to the number of piglets placed in each nursery and herd, livability (%), daily and total weight gain, and feed conversion (lb of weight gained per lb of feed, %) were obtained from Prestage Farms. These parameters were compared between the two treatments to see if the solar wall affected pig performance.

Results and Discussion

Data collected during November 2008 through June 2009 are presented and discussed below. This 8-month monitoring period encompassed four herds of piglets.

Pig performance

Table 1 presents pig placement numbers, livability, weight gain and feed conversion data for four herds in the control and test nurseries. The test nursery consistently housed more piglets than the control nursery, and averaged for the four herds, it had 14% more piglets (Table 1). Hence, difference in pig populations in the two treatments, placements dates, and to a lesser extent, the duration of placement (43 to 47 d) (Table 1), may have confounded the main effect on pig performance.

Averaged over the four herds, livability of the pigs was comparable in the two treatments (Table 1); the slightly higher livability in the third herd in the test nursery was surprising because it had 16% more pigs than the control nursery (Table 1). Averaged over the four herds, daily weight gain, total weight gain, and feed conversion were higher in the control vs. the test nursery (Table 1). It is possible that higher pig populations in the test nursery may have reduced feed access reducing weight gain and feed conversion. Averaged over the four herds and based on total initial numbers placed, livability, and total weight gain, the test nursery produced 53,187 lb of live weight per herd vs. 52,722 lb for the control

nursery (data not presented). Higher livability, daily weight gain, and feed conversion in the fourth herd in the test nursery (Table 1) indicated that the TSW may not have excessively heated the nursery or reduced air exchange compared to the control treatment. (Total weight gain in the 4th herd was lower in the test nursery because the pigs in the control nursery stayed for 3 more days.) Hence, it seems unlikely that the TSW adversely impacted pig performance.

Table 1. Pig populations and performance parameters^a for four herds in the control and test nurseries.

Herd #	Date in & out		Total placed		Livability (%)		Daily gain (lb/d)		Total gain (lb/pig)		Feed conversion (%) ^b	
	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test
1	11/9 - 12/22/08	11/22/08 -1/6/09	1648	1747	97.33	95.31	0.79	0.61	33.21	26.57	78.7	68.9
2	1/4 - 2/18/09	1/19 - 3/4/09	1495	1900	98.86	98.42	0.80	0.68	35.35	29.55	70.9	60.2
3	3/1 - 4/15/09	3/16 - 4/29/09	1615	1877	98.02	98.77	0.73	0.68	32.58	29.66	68.4	65.3
4	4/26 - 6/12/09	5/10 - 6/23/09	1733	1882	98.33	98.72	0.67	0.71	31.57	31.36	61.3	67.1
Average for 4 herds			1623	1852	98.14	97.81	0.75	0.67	33.18	29.29	69.8	65.4

^aData provided by Prestage Farms

^bRatio of mass of live weight produced per 100 lb of feed consumed

Internal Conditions

Temperature: Average internal and ambients temperature are compared by herd between the control and test nurseries in Table 2 (details by herd and age are given in Figures 3(a) – 3(d)). Hourly average temperature and RH values were obtained from the NC CRONOS weather station at the Horticultural Crops Research Station, Clinton. On average, the test nursery was slightly warmer than the control except for herd 1; however, given that the combined accuracy of the two sensors is ± 1.52 F (± 0.76 F for one sensor), the test nursery is warmer than the control nursery only in herds 2 and 4. It may be noted that internal temperature data collection in the control nursery began 10 d after pig placement in herd 1 and the test nursery data from day 25 to day 38 was lost for herd 4 (Table 2); hence, the temperature difference calculation between the two nurseries for those two herds can be considered to be less

reliable than for the other herds. However, average ambient temperatures were higher for herds 3 and 4 in the test nursery than in the control nursery (Table 2), particularly, herd 3. Hence, taking into account the higher ambient temperature and higher pig populations, the extent to which the TSW affected the internal temperature of the test nursery during summer was likely minor. Problems with the operation of the linear actuator that controlled the bypass damper may have contributed to some undesirable heating and these problems will be resolved during fall 2009 and confirmed through monitoring during fall 2009 through spring 2010.

Table 2. Average^a ambient and internal temperature (F) by herd.

House	Herd								Average	
	1		2		3		4		ambient	internal
Control	46.0	80.9	43.8	85.5	53.7	83.3	70.7	83.9	53.6	83.4
Test	47.5	80.0	43.4	87.1	58.0	83.8	71.8	86.5	55.2	84.3
Test-Control	1.5	-0.9	-0.4	1.6	4.3	0.5	1.1	2.7	1.6	0.9

^aObtained by averaging all logged internal and hourly ambient temperature values during herd placement

^bData collection began 10 d after pig placement

^cTemperature data from day 25 to day 38 was lost

The impact of the TSW on short-term temperature cycling inside the nursery is difficult to judge because pigs were placed in the two nurseries at different times and thus had different desired room temperatures (DRTs) and ambient temperatures. To normalize for the age of the pigs in the two nurseries and hence, the different DRTs in Figures 3(a) through 3(d), for each herd one graph depicting internal temperature minus DRT (INT-DRT) vs. date of placement is presented. Also in Figures 3(a) through 3(d), to explain the effects of different ambient temperatures (with pig age) in the two treatments, for each herd, a graph depicting ambient temperature vs. date of placement is presented. The temperature data in Figure 3(a) through 3(d) were smoothed using the loess function ($q = 0.2$) (NIST/SEMATECH, 2006) to remove diurnal variations that allowed for a meaningful trend comparison between the two treatments.

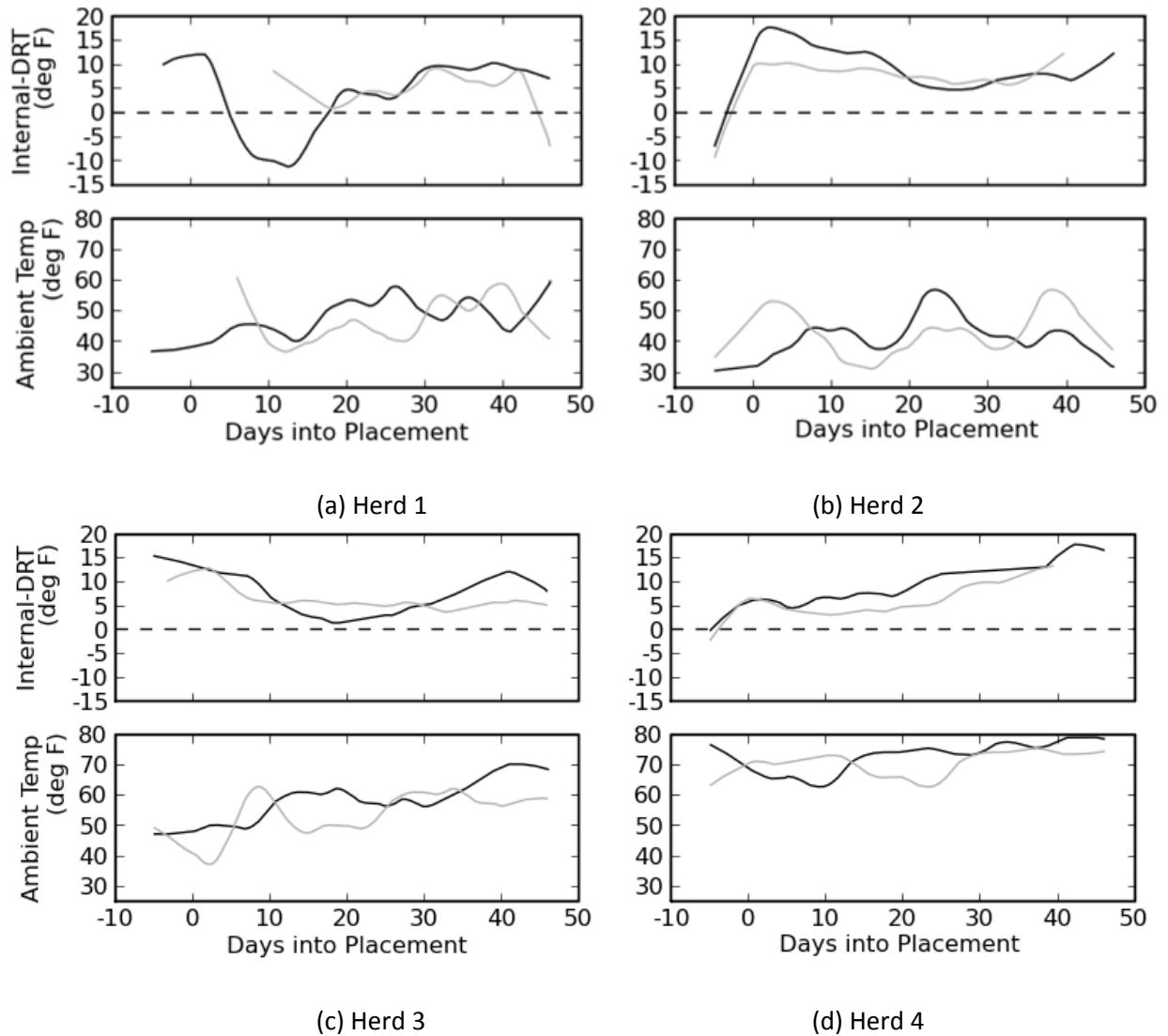


Figure 3. Comparison of internal temperature – DRT for the two treatments. The test nursery trend line is the solid black line while the control is shown as a solid grey line. The DRT coincides with 0 F on the y axis and is indicated by dashed black line.

In herd 1, the INT-DRT in the test nursery showed higher fluctuations vs. the control (Fig. 3(a)) and this may partly be attributed to the fact that the TSW installation was only completed 16 days after the pigs were placed. After day 18, the INT-DRT trendlines of the two treatments mimicked one-another except for a decrease in temperature in the control nursery which could have been due to decrease in ambient temperature during the dates of placement of the control herd (Fig. 3(a)). For herd 2, despite

differences in ambient temperatures, the INT-DRT trendlines mimicked one-another, with the test nursery running slightly warmer during the first 17 d (Fig. 3(b)). The INT-DRT lines for both treatments in herd 3 differed somewhat from one-another though it was surprising to observe that the control INT-DRT line was higher despite lower ambient temperature (Fig. 3(c)). For the 4th herd, the INT-DRT for the test nursery was higher than the control between day 15 and day 38 (Fig. 3(d)). It was observed that both nurseries were operated at temperatures higher than DRT for herds 2 through 4.

Figures 3(a) through 3(d) do not capture short term variability in internal temperature. Figures A(a) through A(b) (Appendix A) present plots of desired room temperature (DRT), test nursery internal temperature (t-internal-temp), test nursery ambient temperature (t-ambient-temp), control nursery internal temperature (c-internal-temp), and control nursery ambient temperature (c-ambient-temp) vs. days into placement.

Generally, the internal temperatures in both treatments were similar (Figure A, Appendix A), except during the first 18 d of the first herd. While temperature fluctuations in the test nursery were slightly greater than the control nursery, the test nursery internal temperature did not fluctuate much in response to changes in ambient temperature (except in the first 18 d of herd 1 placement) (Figure A, Appendix A). For example, in herd 2 during days 17 to 20 of the test herd placement, when the ambient average daily temperature increased from ~22 F to 58 F, the change in internal temperature was ~5 F (Figure A(b), Appendix A).

It seemed that internal temperature fluctuations in the test nursery were slightly higher than in the control nursery which may be due to the fact that the south-side inlet in that nursery was kept open about ½ in. because both nurseries were very loose. Another, more important reason could be that while the minimum ventilation fans in the test nursery were run at 100% speed because it had less leakage, in the control nursery, they were operated 80, 85, 90, and 95% during weeks 1, 2, 3, and 4, respectively, during the winter season. Hence, the fan run times in the test nursery were shorter during

winter and this could have contributed to increased temperature fluctuations. Both houses will be tightened in fall 2009 to ensure that fresh air is brought in only through planned inlets. Hence, there will be no need to keep the south-side inlet open in the test nursery cracked open and minimum ventilation fans will be run at variable speed in both houses; this may lower temperature fluctuations which will be confirmed through monitoring during the fall 2009 through spring 2010 period.

Relative humidity: Since the treatments were expected to affect RH and RH can affect pig performance (Eisenmenger, 2003), average internal and ambient RH values by herd are presented in Table 3. The difference in average internal RH values between the two treatments is less than the combined accuracy ($\pm 6\%$) of the RH sensors in the control and test nurseries and it is difficult to say with confidence that the test nursery was drier. Since the test nursery had more pigs (Table 1) and the heaters were vented, higher internal RH values had been expected than in the control; it is likely that slightly less humid ambient conditions in the test nursery during herds 2 and 3 (Table 3) may have also contributed to lower internal RH than the control nursery. Overall, both nurseries had similar RH levels. The daily average internal and ambient RH values for the two treatments are plotted vs. days of placement for the four herds in Figures B(a) through B(d) (Appendix B). The average internal RH values were $<65\%$ and are thus considered to be not harmful to herd health (Eisenmenger, 2003).

Table 3. Average^a ambient and internal relative humidity (%) values by herd.

House	Herd								Average	
	1		2		3		4		ambient	internal
Control	75.9	50.4	70.7	45.7	71.6	50.3	78.4	63.4	74.1	52.4
Test	77.4	45.4	68.0	41.9	70.1	48.2	80.3	61.2	73.9	49.2
Test-Cont	1.4	-5.0	-2.7	-3.8	-1.4	-2.1	1.9	-2.1	-0.2	-3.3

^aObtained by averaging all logged internal and hourly ambient RH values during herd placement

^bInternal data collection began 10 d after pig placement

^cInternal RH data from day 25 to day 38 was lost

Carbon dioxide concentrations: Internal CO₂ concentrations are indicative of the ventilation status of the structure and high CO₂ concentrations can impact pig performance. Average CO₂ concentrations by herd are compared between the two treatments in Table 4. Data for herd 1 was not included in Table 4 since very little data were available for the control treatment.

Table 4. Average internal CO₂ concentration (ppm) by herd.

Nursery	Herd			Average
	2	3	4	
Control	2,381	1,639	1,011	1,677
Test	2,382	1,583	1,038	1,668
Test-Control	1	-56	27	-9

From Table 4 it is clear that the difference in CO₂ concentrations between the treatments is negligible for any of the herds since it is much lower than the combined accuracy of the two sensors. With more pigs, CO₂ concentrations would have been higher in the test nursery but increased ventilation rate may have diluted the house air resulting in comparable CO₂ concentrations between the two treatments. Table 4 clearly shows the impact of the season on CO₂ concentration and hence, ventilation rate; CO₂ concentrations were higher in winter (herd 2) due to reduced ventilation and decreased as the weather warmed up leading to increased ventilation. Fifteen minute CO₂ concentrations and ambient temperatures vs. days into placement for the two treatments are plotted in Figures C(a) through C(c) for herds 2 through 4. As is clear from Figure C(b) (Appendix C), during cold weather (when ventilation was reduced), CO₂ concentrations in both treatments reached 3,000 ppm on several occasions, the upper limit of the range of measurement of the CO₂ sensor. Hence, it can be reasonably assumed that the average internal CO₂ concentrations for herd 2 presented in Table 4 were somewhat underestimated.

Propane consumption

Parker Gas (Clinton, NC) began supplying separate receipts for the propane tanks in the control and test nurseries beginning 2 December 2008. It was assumed that the propane added to the tank equaled consumption when summarized over the entire period from 2 December 2008 through 27 March 2009 (Figure 4). Greater propane additions to the test nursery during the peak winter periods (1/27/09 and 2/9/09) was unexpected. The total propane added to the control and test nursery tanks were 2,268 and 2,733 gal, respectively; hence, the test nursery consumed 20% more propane than the control.

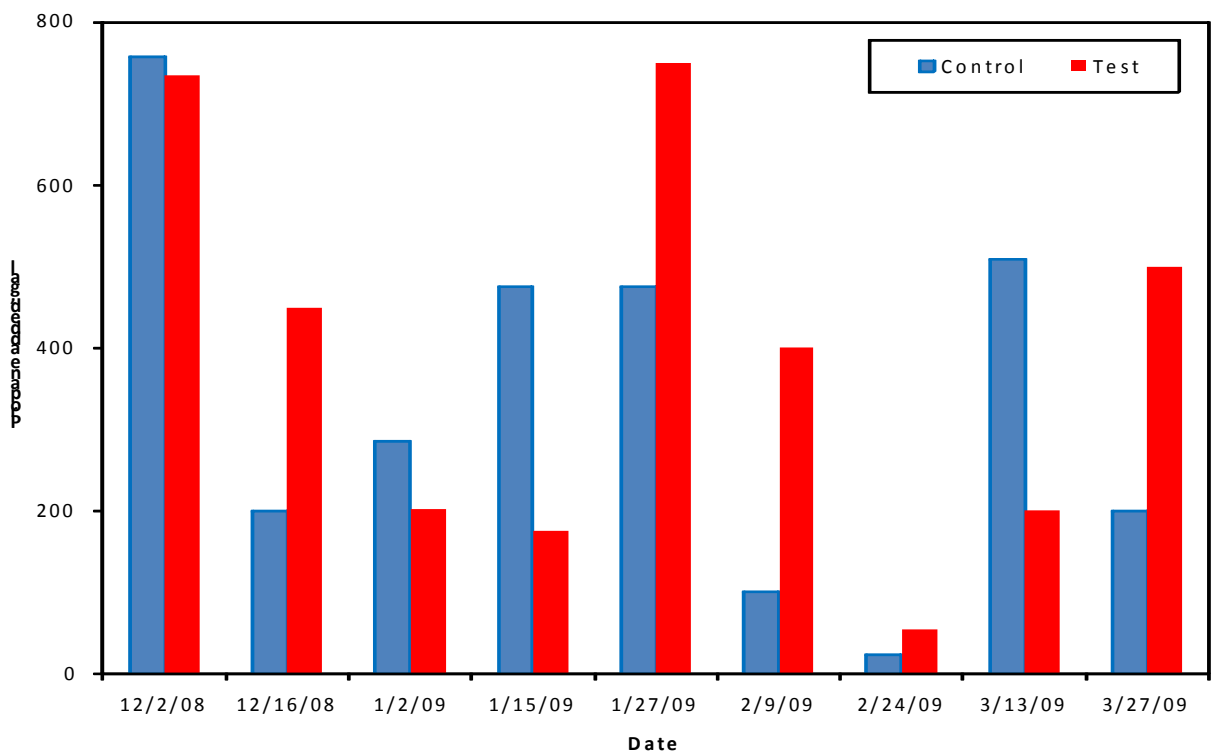


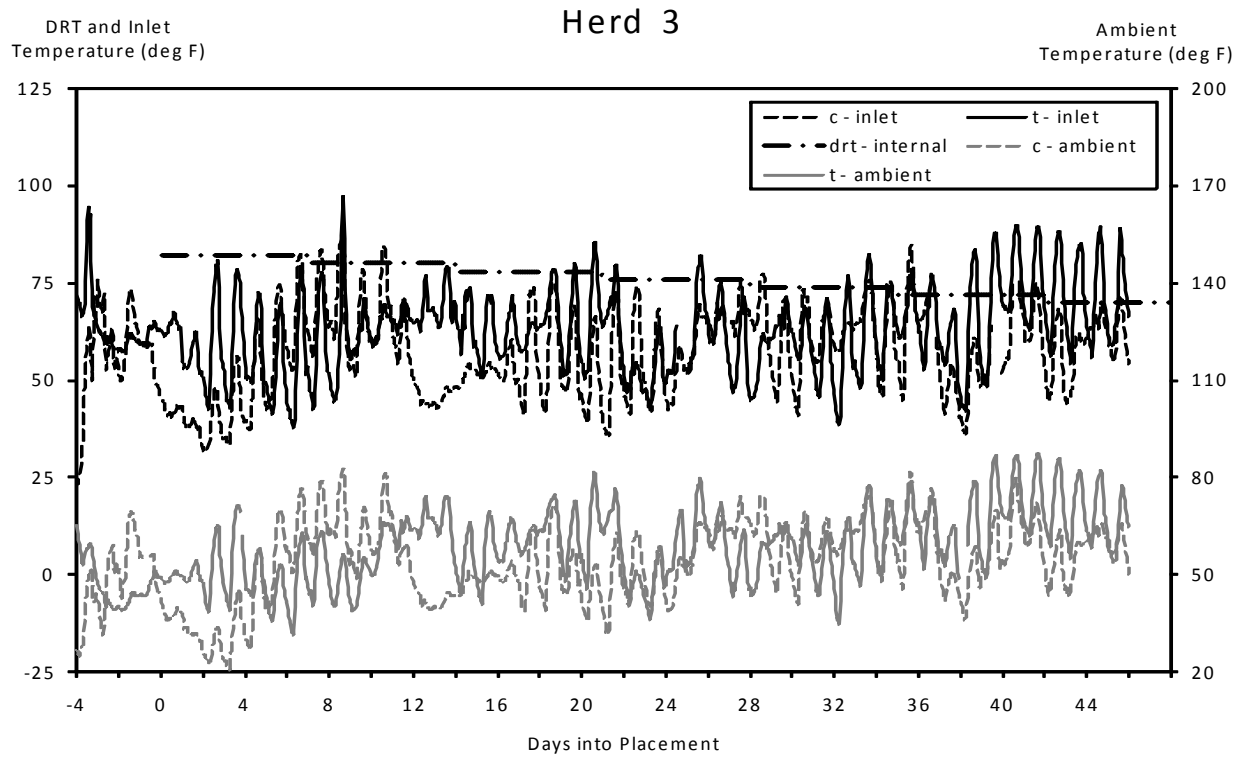
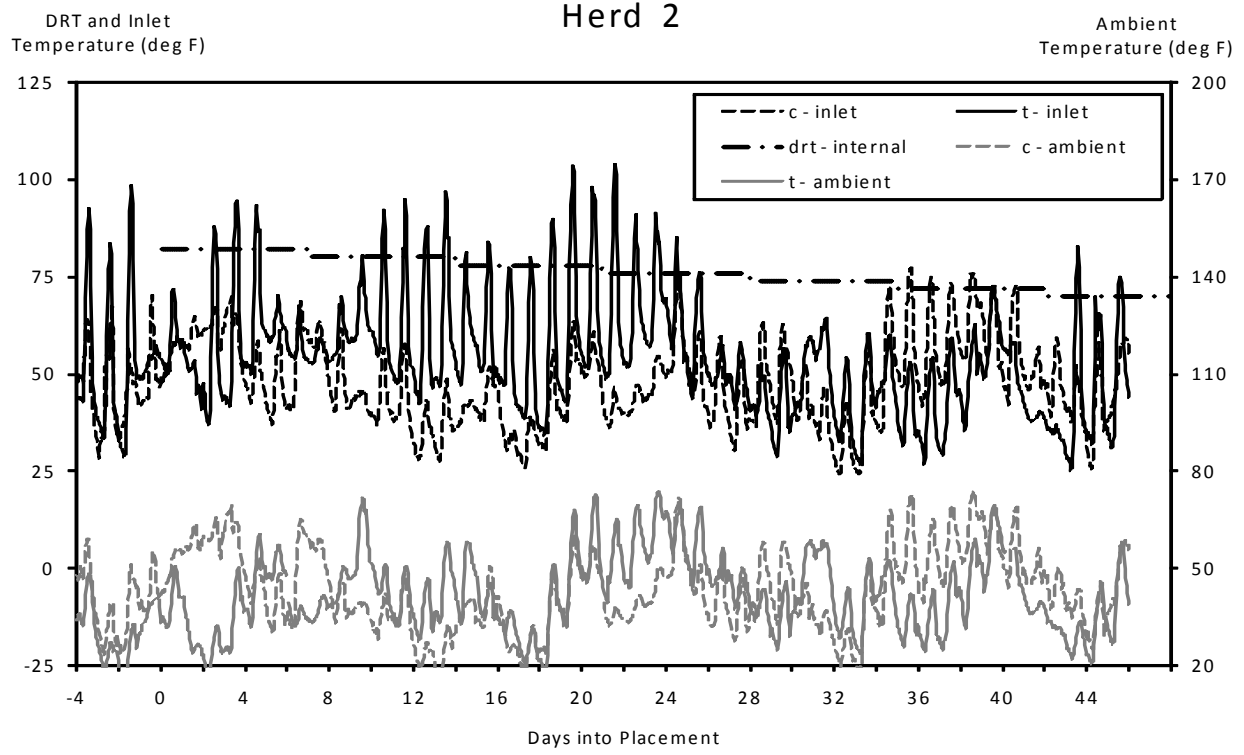
Figure 4. Propane added to the control and test nursery tanks.

It had been expected that using the TSW would result in a reduction in propane consumption, but the results indicated otherwise. The higher pig population in the test nursery may partly explain greater propane use. Different placement dates in the two nurseries (hence, different ambient temperatures) somewhat confounds the treatment effect on propane use. Also, if the first herd in both houses had been started on full tanks of propane, the confounding effect of the carry-over of propane from one

herd to another could have been avoided. For most of the winter, the minimum ventilation fan schedules in the two nurseries were different during the first four weeks of the herd (discussed earlier). In the test nursery, the minimum ventilation fans were running at 100% speed though for a shorter period of time than the control nursery. Hence, it is possible that the test nursery had higher ventilation rates than the control nursery which is supported by comparable CO₂ levels in the two nurseries (Table 4) despite higher pig populations in the test nursery (Table 1). Very importantly, failure of the actuator system in the latter half of herd 2 (discussed earlier) in the test nursery left the damper in the open position, resulting in untempered air being pulled into the house, increasing propane use. During the fall 2009 through spring 2010, the fan schedules in both nurseries will be identical based on pig age. When the test nursery minimum ventilation fans are operated at slower speed (as the control nursery), airflow rate through the TSW will decrease and this may improve its heating efficiency and reduce propane use. Propane consumption (not addition to the tanks) will be monitored directly using propane meters that will be installed in early-October 2009, in time for the new herds that will be placed on October 8 and 22, 2009, in the control and test nurseries, respectively. A complete cost-benefit analysis incorporating the reliable consumption data from these sensors will be conducted in spring 2010. While propane addition indicated that the TSW increased propane use, analysis of the nursery inlet temperature data (below) indicated that the TSW substantially heated the fresh air going into the test nursery.

Inlet temperature

Temperatures measured on the south-side inlet of the control and test nurseries vs. days into placement are plotted for herds 2 through 4 in Figure 5(a) through 5(c), respectively; additionally, ambient temperature data are also presented. Herd 1 data are not presented because most of the inlet temperature data for both treatments are missing.



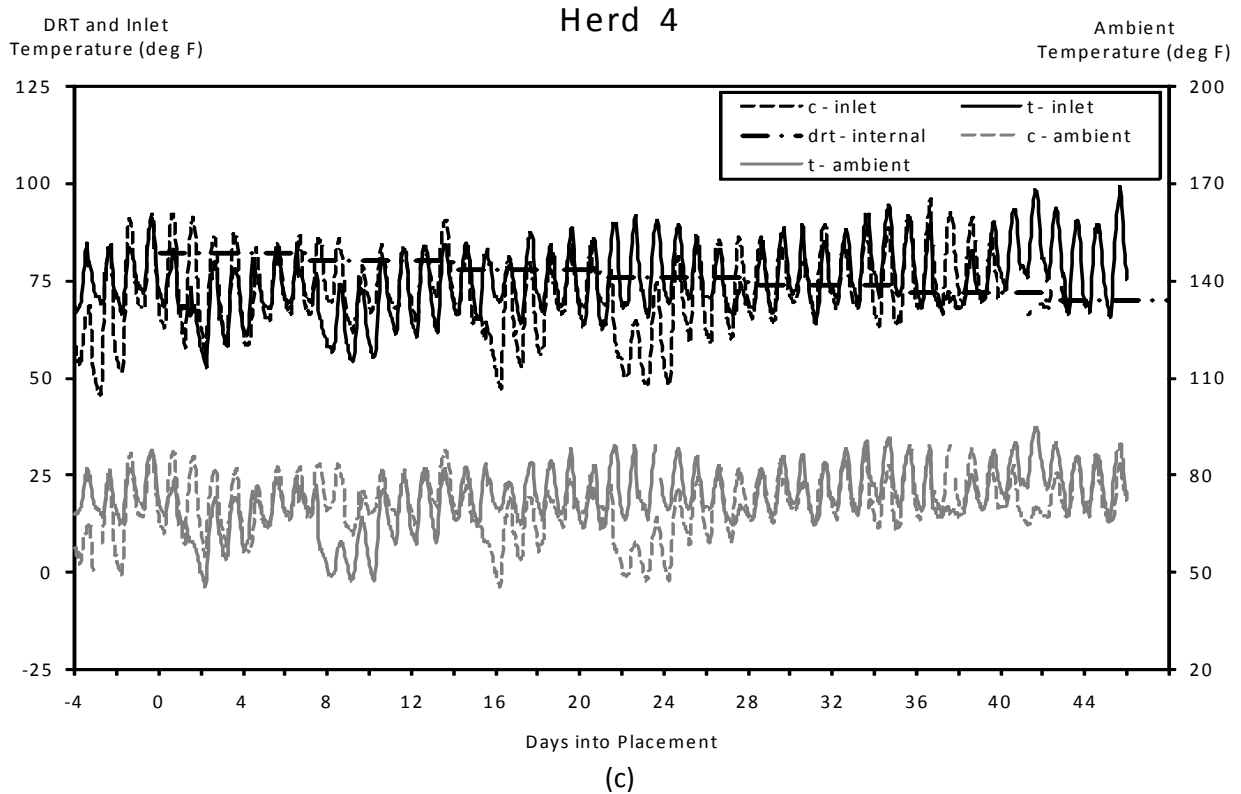


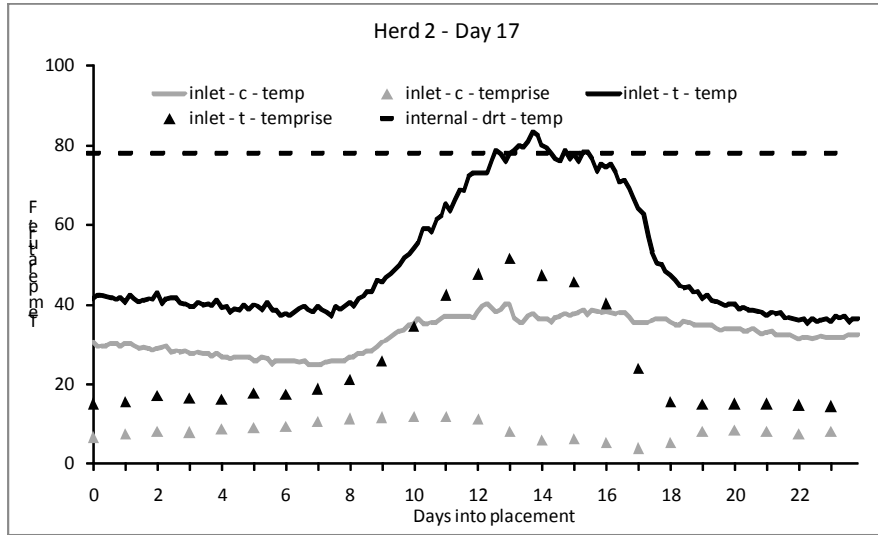
Figure 5. Inlet, desired room temperature (DRT), and ambient temperatures vs. days of placement for the control and test nurseries for (a) herd 2, (b) herd 3, and (c) herd 4. The abbreviations in the legend are: c-inlet: control inlet temperature, t-inlet: test inlet temperature, drt-inlet: DRT, c-ambient: ambient temperature corresponding to the control herd, and t-ambient: ambient temperature corresponding to the test herd. The ambient temperatures for Clinton were obtained from NC CRONOS. The scales on the primary and secondary y axes are different.

For herd 2, when the weather was the coldest of three herds, the temperature rise in the test nursery was much greater than the control nursery for the same calendar day (Fig. 5(a)). For example, on 2 February 2009, the maximum inlet temperatures for the test and control nurseries were 103.5 and 75 F, respectively; the corresponding ambient temperature was 63.4 F (Fig. 5(a)). However, beginning day 27 in the test nursery, inlet temperatures (Fig. 5(a)) decreased because the linear actuator failed, leaving the bypass dampers in the open position. As the weather became warmer (herds 3 and 4), the

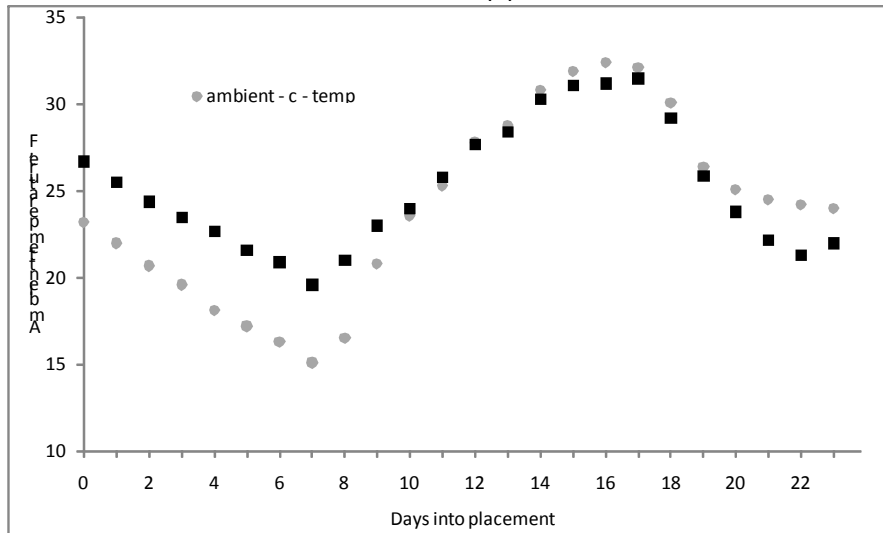
inlet temperatures in the test and control nurseries became closer to one another because the bypass damper opened to let in fresh air into the test nursery. For example, for herd 3, on 6 April 2009, the maximum inlet temperatures in the test and control nurseries were 85 and 84.1 F, respectively; the corresponding ambient temperature was 81.4 F (Fig. 5(b)). For herd 4, on 2 June 2009, the maximum inlet temperatures in the test and control nurseries were 88.3 and 90 F, respectively; the corresponding ambient temperature was 87.2 F (Fig. 5(c)).

The TSW not only converts the solar energy into useful heat energy but also recycles some of the lost heat back into the nursery. The inlet temperature rise in the test nursery on 21 January was compared with the control nursery on 5 February, 2009 (Fig. 6(a)); on these dates, pigs in both nurseries were 17 d old and the average ambient temperatures were very similar (within 1.1 F) in both treatments (Fig. 6(b)).

It is clear from Figure 6 that the TSW greatly increased the inlet temperature in the test nursery over the ambient temperature or the control inlet temperature. Average test nursery inlet temperature was 50.3 F while the ambient temperature was 25.1 F. In the control nursery, the average inlet and ambient temperatures were 32.3 and 24 F, respectively. Hence, there was a slight increase in inlet temperature in the control nursery probably because some heat that escaped from the nursery accumulated under the eave where the sensor was placed; there may have also been some radiational heating from the metal roof during daytime.



(a)



(b)

Figure 6. (a) Inlet temperatures and DRTs as well as the temperature rise for the test and control nurseries on day 17 for herd 2 and (b) ambient temperatures for that day for the two treatments. Legend: inlet-c-temp: inlet temperature in the control nursery; inlet-t-temp: inlet temperature in the test nursery; internal-DRT-temp: desired room temperature; inlet-c-temprise: increase in control inlet temperature over the ambient temperature; inlet-t-temprise: increase in test inlet temperature over the ambient temperature; ambient-c-temp: ambient temperature in the control nursery on 1/21/2009; and ambient-t-temp: ambient temperature in the test nursery on 2/5/2009.

In the control nursery, during 0:00 to 7:00 and 18:00 to 23:00, the average ambient and inlet temperatures were 21.9 and 30.2 F, respectively. In the test nursery, during 0:00 to 7:00 and 18:00 to 23:00, the average ambient and inlet temperatures were 23.5 and 40.1 F, respectively. Hence, during nighttime hours, the temperature increase (due to heat capture) in the test nursery was 16.6 F vs. 8.3 F in the control nursery. During the 8:00 to 17:00, in the control nursery, the average ambient and inlet temperatures were 27 and 35.2 F, respectively; the corresponding values for the test nursery were 27.4 and 64.8 F, respectively. Hence, during the daytime hours, solar radiation and more efficient heat capture resulted in 41 F temperature increase in the test nursery vs. 8.2 F in the control nursery.

Total energy gains were also calculated for the test and control nurseries (only south-side vents) for herd 2, day 17. It was assumed that the south-side vents provided 40 and 50%, respectively, of the total ventilation for the test and control nurseries. A lower fraction of 40% was assumed for the test nursery because the additional pressure drop caused by the solar wall will reduce air flow rate. (The extent of air flow reduction due to the TSW will be calculated in October 2009 after the houses are tightened.) It was assumed that on day 17, the control and test nurseries had 1,495 and 1,900 pigs, respectively (Table 1); hence, mortalities were neglected. It was also assumed that cold weather ventilation was provided at 2.5 cfm/pig (MWPS, 1993).

Based on the above assumptions, on day 17 of herd 2, total energy added by solar radiation and heat capture in the test nursery was 1.36 million Btu; 64.7% of the 1.36 million Btu was added by solar radiation and some heat capture (and possibly, roof radiational heating) during daytime. By comparison, the control nursery gained 0.43 million Btu through heat capture and roof radiational heating. Hence, the test nursery saved or generated 0.93 million Btu that day which is equal to 10.15 gallons of propane saved. Reduction in propane consumption reduced CO₂ emission by 127 lb.

In the test nursery the heat lost through the wall or curtain is trapped between the nursery wall and the TSW. However, in the control nursery, this heat can rapidly dissipate due to wind and with low fan

run times (small pigs and cold weather); hence, while the inlet temperature may be high, only a fraction of the energy associated with that temperature may be pulled into the house. Hence, there is need to confirm that heat recycling occurs even in the absence of the TSW during the fall 2009 through spring 2010 monitoring. This validation will be performed by measuring air temperature and air speed at 5 sec intervals at the inlet of the control nursery. These measurements will quantify the amount of heat accumulating under the eaves that is transported inside by the fresh air.

Summary and Conclusions

A transpired solar wall (TSW) (440 ft²) was installed on the south-side wall of a 1,520-pig nursery near Clinton, NC. Pig performance, energy use, internal conditions, and temperature rise at the inlet in the test nursery were compared to those in an identical control nursery located adjacent to it during November 2008 through June 2009. To prevent excessive heating during warm weather or with larger pigs, the TSW was equipped with a bypass damper that opened to allow the fresh air to bypass the TSW when necessary. Some important conclusions are summarized below.

1. Over the four herds monitored, the test nursery had 14% more pigs than the control nursery. More pigs in the test nursery could have reduced livability (-0.33%), daily weight gain (-0.08 lb/d), total weight gain (-3.89 lb/pig), and feed conversion (-4.4%) in the test nursery.
2. Internal conditions (temperature, RH, and CO₂ concentration) were comparable in the test and control nurseries.
3. Propane use was 20% higher (2 December 2008 – 27 March 2009) in the test nursery vs. control nursery.
4. During winter, air at the test nursery inlet was substantially warmer than the control inlet temperature. For example, on 2 February 2009, the test and control inlet temperatures were 103.5

and 75 F, respectively. During warm weather, with the bypass damper open, the test and control inlet temperatures were comparable.

5. For herd 2, day 17, when the ambient control and test temperatures were comparable, the TSW supplied 0.93 million Btu of energy resulting in saving of 10.15 gallons of propane. This reduction in propane use reduced CO₂ emissions by 127 lb.

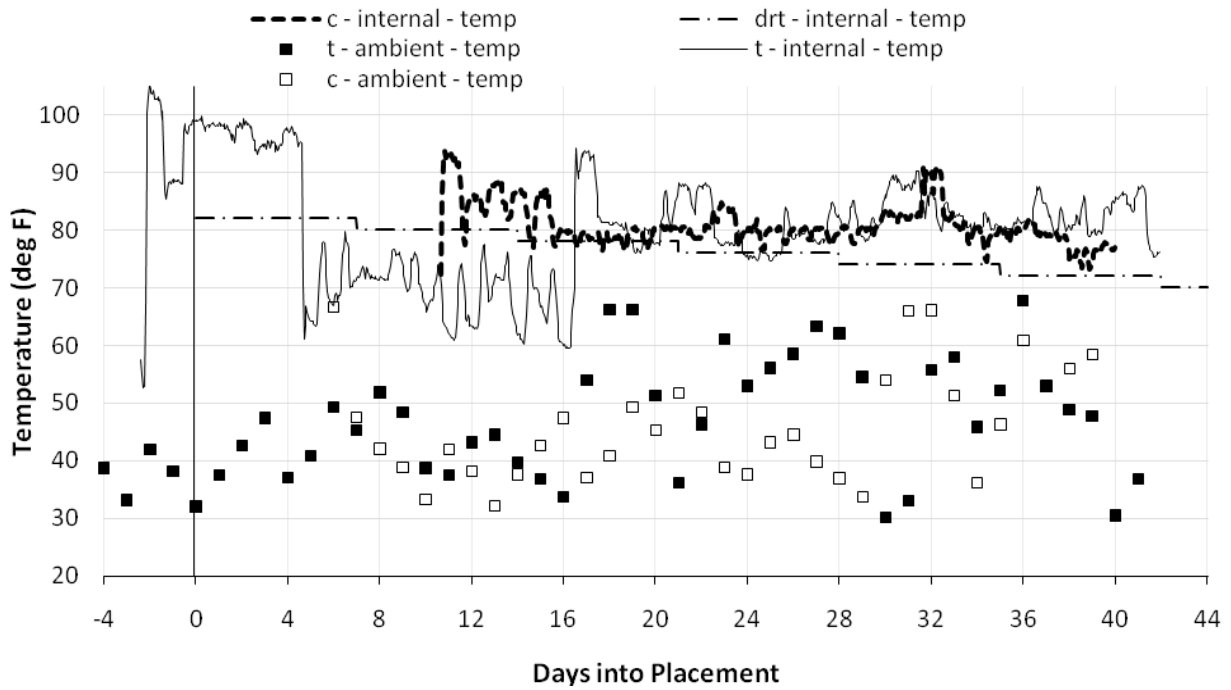
Additional monitoring will be undertaken during fall 2009 through spring 2010. Both nurseries will be tightened to allow for a better comparison of the treatments. Minimum ventilation fans in both houses will be run on the same fan schedule; this will allow for a more accurate calculation of ventilation rates in the two houses. Propane and electricity consumptions will be monitored using more accurate meters. Finally, the economics of using the TSW will be determined.

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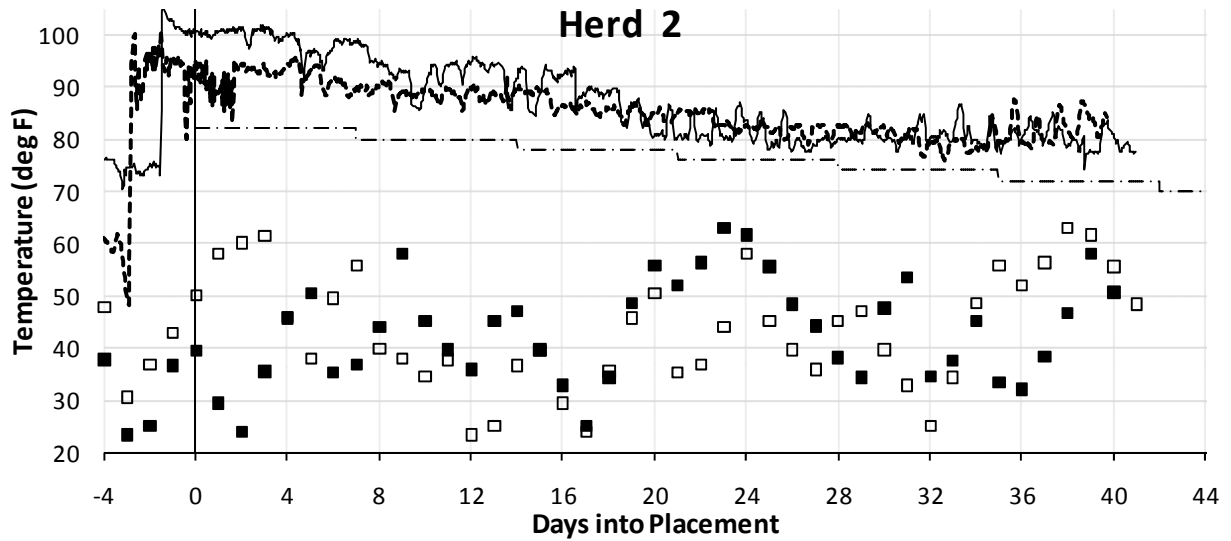
APPENDIX A. INTERNAL AND AMBIENT TEMPERATURE

Herd 1

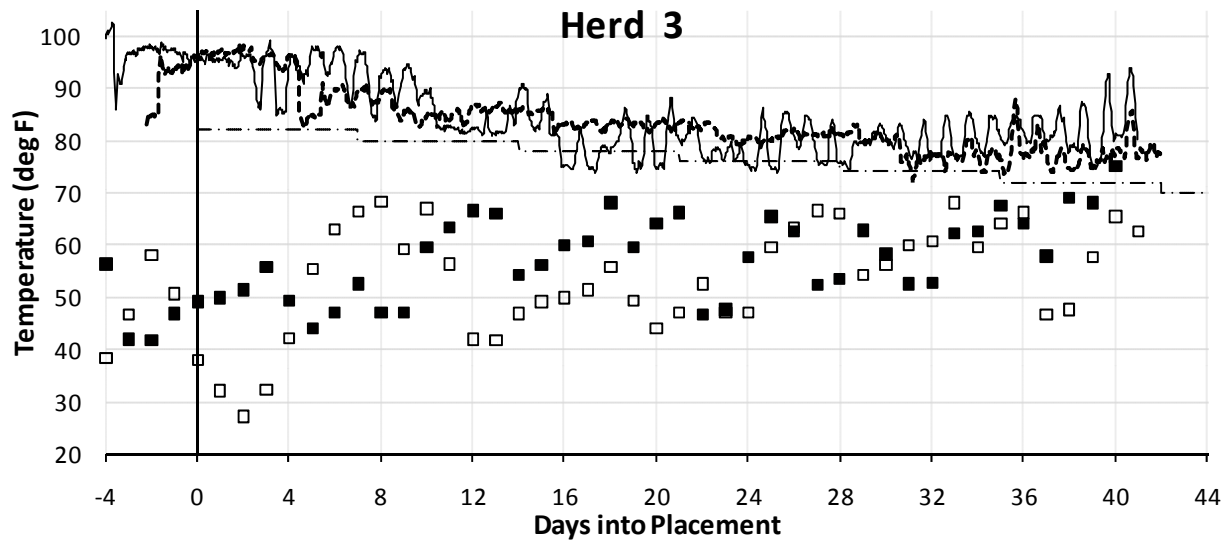


(a)

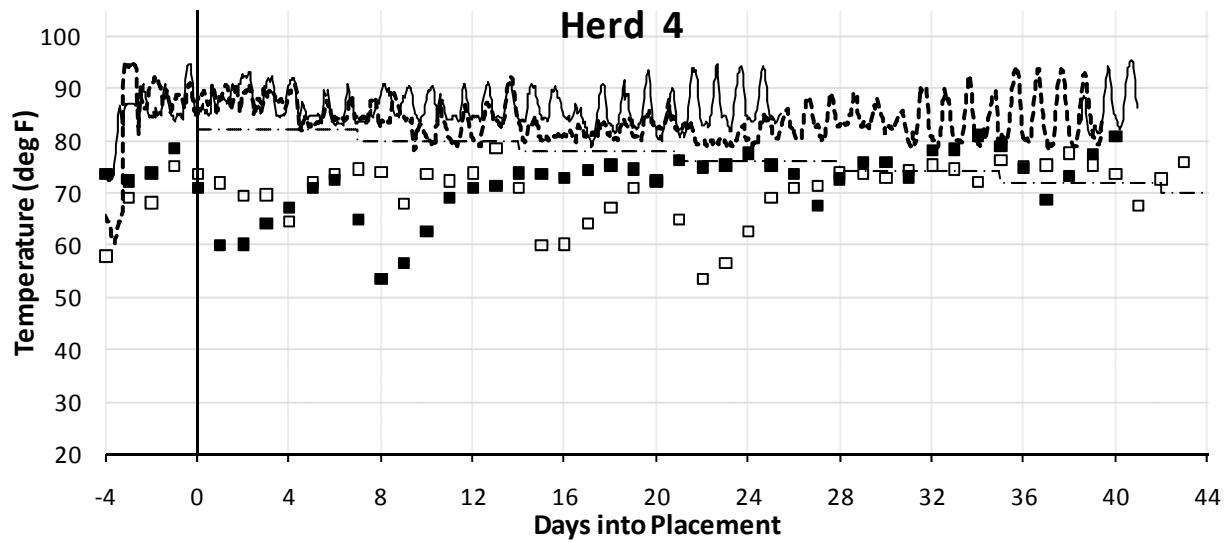
Herd 2



(b)



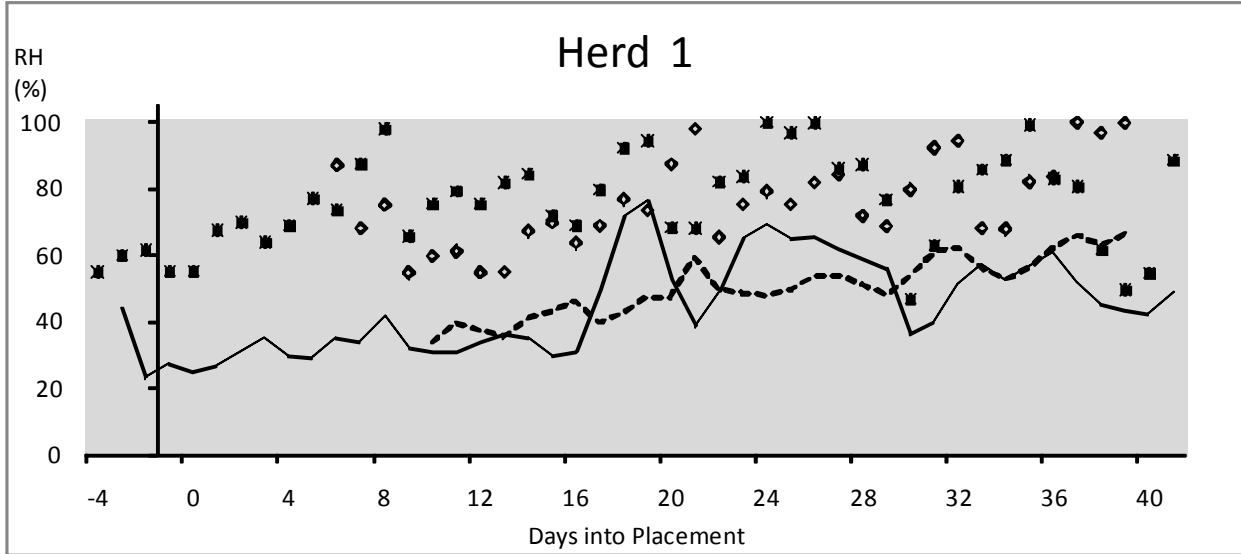
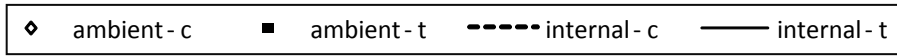
(c)



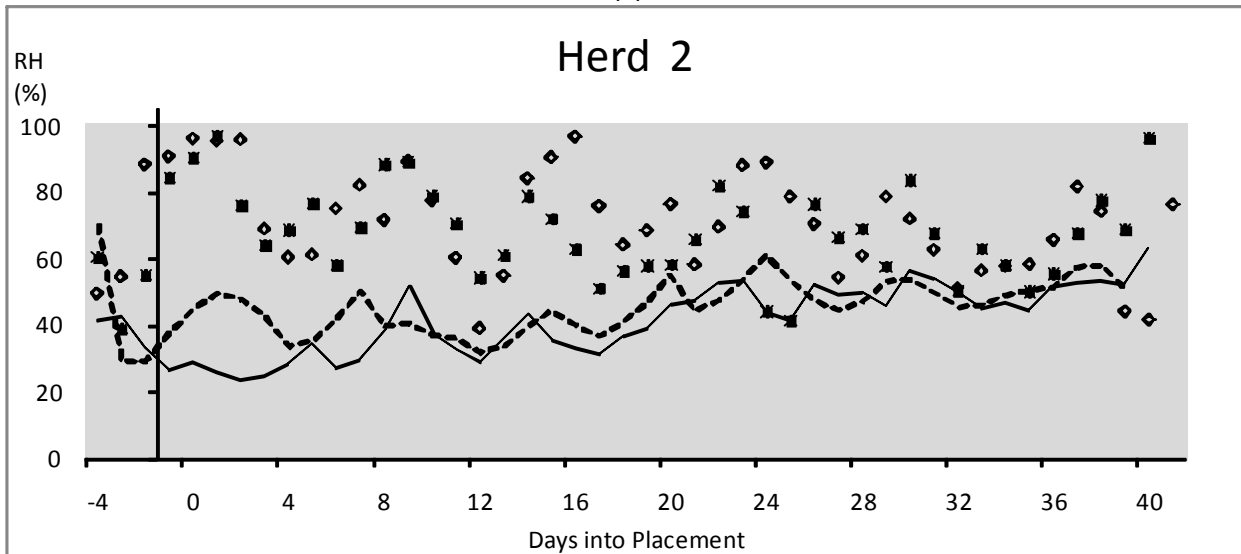
(d)

Figure A. Internal and ambient temperatures and desired room temperature (DRT) vs. days into placement for the two treatments by herd, beginning 4 d prior to placement. Legend: c-internal-temp: control nursery internal temperature; t-internal-temp: test nursery internal temperature; c-ambient-temp: ambient temperature corresponding to control; t-ambient-temp: ambient temperature corresponding to test; and drt-internal-temp: DRT.

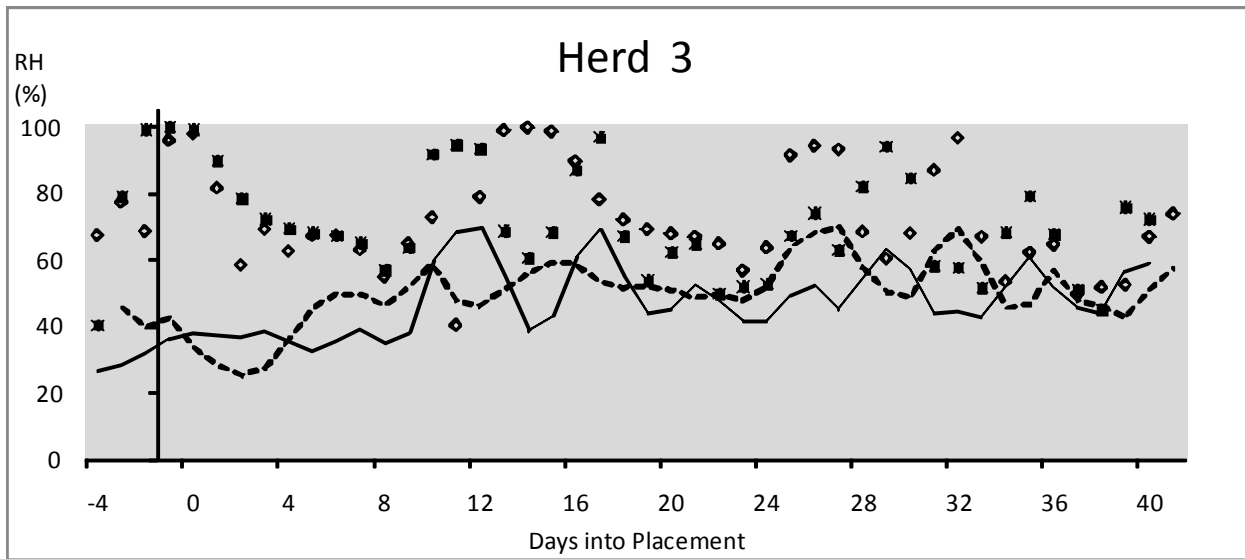
APPENDIX B. INTERNAL AND AMBIENT RELATIVE HUMIDITY



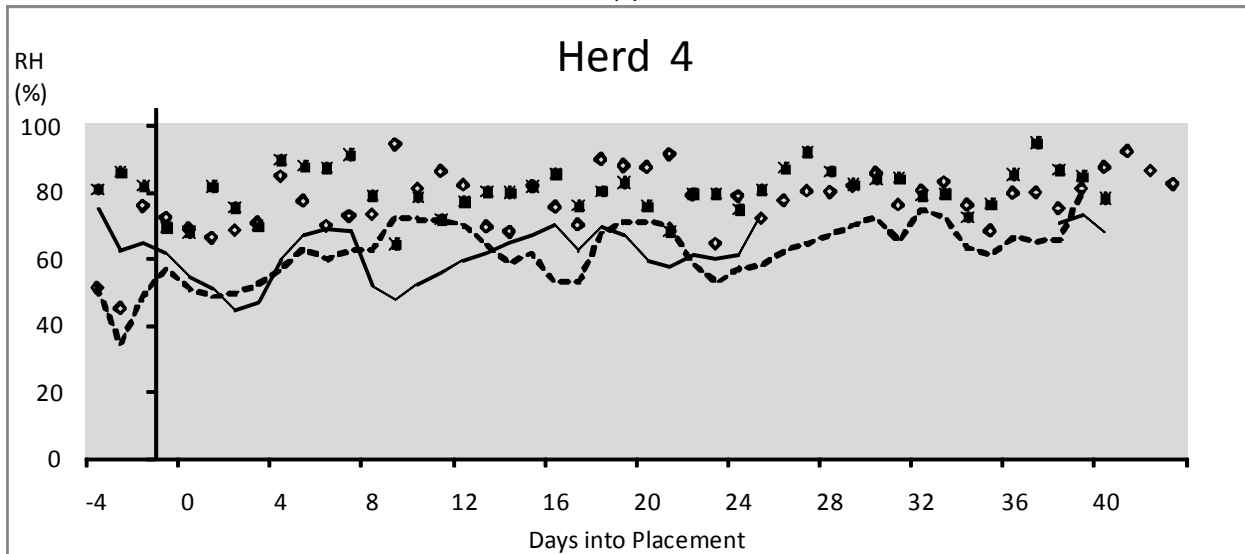
(a)



(b)



(c)



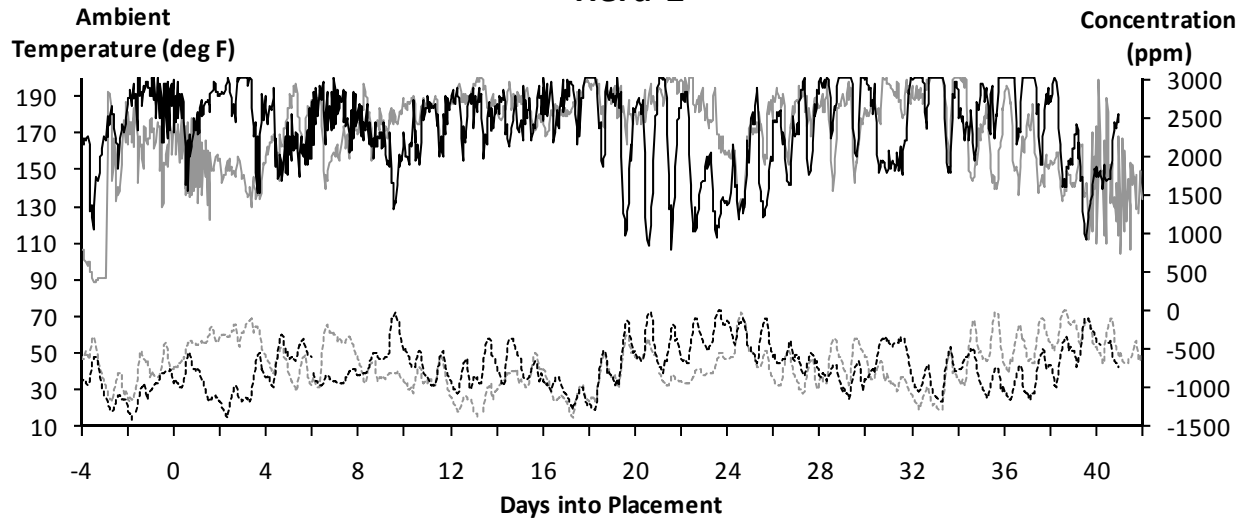
(d)

Figure B. Internal and ambient RH values vs. days into placement for the two treatments by herd, beginning 4 d prior to placement. Legend: internal-c: control nursery internal RH; internal-t: test nursery internal RH; ambient-c: ambient RH corresponding to control; ambient-t: ambient RH corresponding to test.

APPENDIX C. INTERNAL CARBON DIOXIDE CONCENTRATIONS

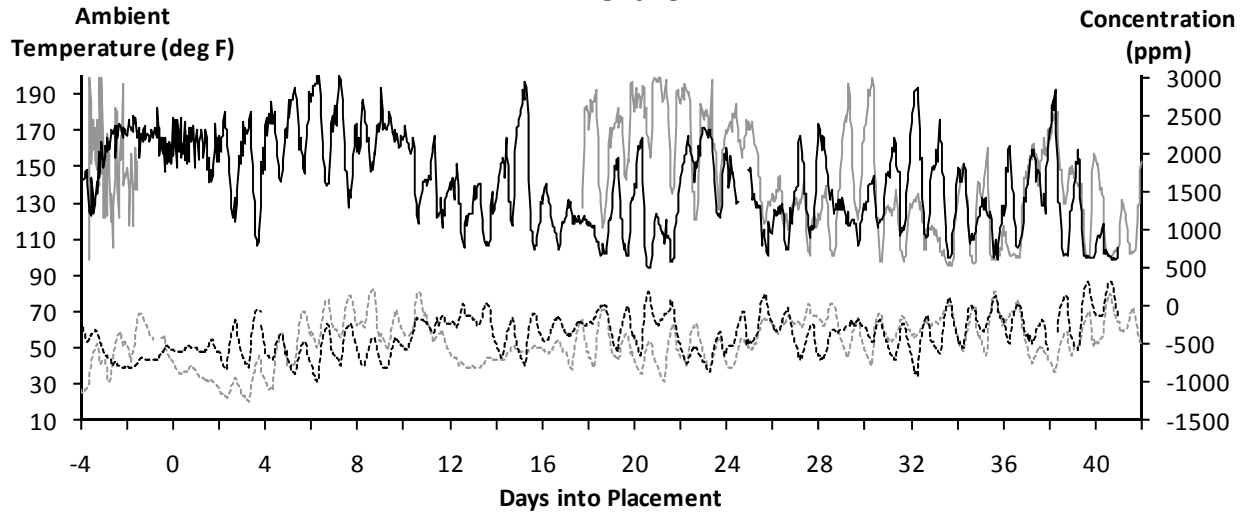
----- c - temp - - - - - t - temp _____ c - conc _____ t - conc

Herd 2

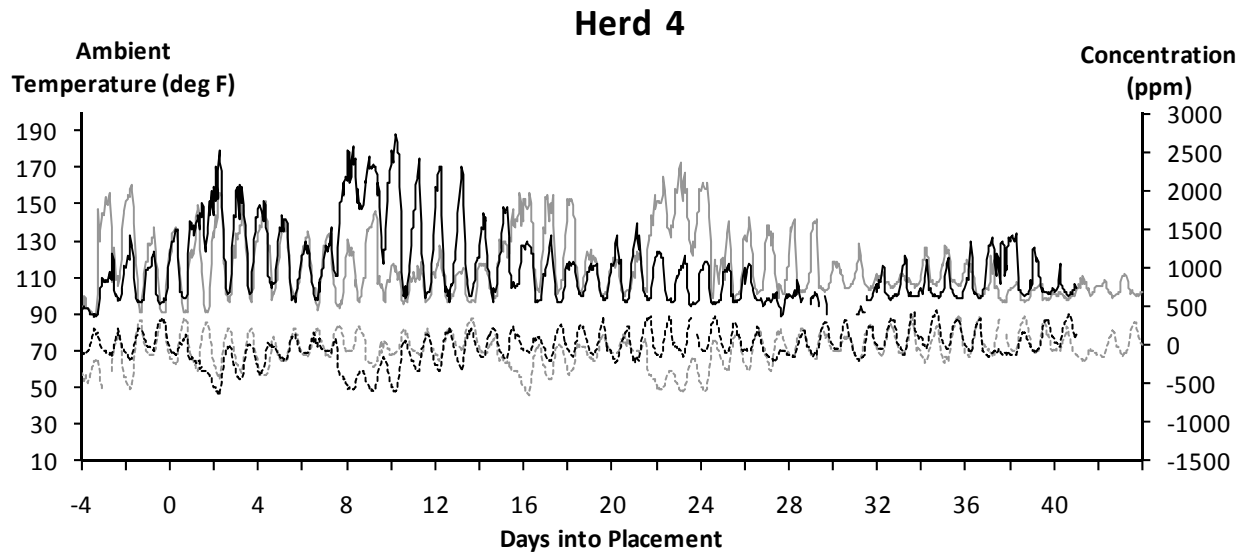


(a)

Herd 3



(b)



(c)

Figure C. Internal CO₂ concentrations and ambient temperatures vs. days into placement for the two treatments by herd, beginning 4 d prior to placement. Legend: c-temp: ambient temperature corresponding to control; t-test: ambient temperature corresponding to test; c-conc: CO₂ concentration in the control nursery; and t-conc: CO₂ concentration in the test nursery.