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Transpired Solar Duct for Tempering Air in North Carolina Turkey Brooder Barn and Swine Nursery

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Abstract. As the price of propane (LP) increases, it is desirable to provide the extensive heating requirements of young animal barns with an alternative source of energy. Solar energy is free and plentiful. A technology that has been gaining traction recently is the transpired solar collector (TSC) technology. Sunlight heats up the dark sheet metal panels, and then warms air as it passes through the wall or duct. The purpose of this study is to look at the feasibility of using a TSC duct to provide supplemental heating animal barns in eastern North Carolina.

Transpired solar collector ducts were installed at a swine nursery and a turkey brooder farm. The TSC duct at the swine farm reduced LP use by 34% over two herds. The room with the TSC duct used 65% less LP during the first herd and 12% more LP during the second. LP uses in the test and control houses of the turkey brooder farm were comparable, showing no reduction in LP use. The TSC ducts imparted an average temperature gain of 0.61 °C and 1.14 °C, relative to every 100 W/m^2 of solar radiation, for the turkey brooder barn and swine nursery, respectively. Maximum average hourly temperature rises for the swine nursery were 7.8 °C for December 14-21, 2010 and 8.2 °C for the turkey brooder farm during November 23-32, 2010. Based on the results of this study, the TSC duct has shown potential for providing supplemental heat to animal barns in eastern North Carolina.

Keywords. Solar heating, solar duct, transpired solar collector, swine, turkey

Introduction

Young animals require a substantial amount of supplemental heat to develop normally because they produce very little body heat when they are very young. For example, newly-hatched turkey poults require an air temperature of 34 C (93 F) that is reduced gradually to 28 C (82 F) by day 21 (Edens, et al., 1998). Usually this supplemental heat is provided by burning liquid propane (LP). Burning LP is expensive, and the cost of LP is constantly going up; further, volatility in the energy market makes decision-making difficult. The cost of the LP greatly contributes to the cost of raising animals, so an alternative, cheaper, source of heat would be desirable. The burning of LP also generates CO_2, which is a greenhouse gas.

Solar energy is free and plentiful, but it is difficult to capture and harness. Photovoltaic (PV) solar panels can be used for electricity generation for animal houses, but installation cost is high ($6,000/kW) and converting the electricity to heating would be fairly inefficient. A fairly new technology that has emerged is the transpired solar collector (TSC) technology, which converts sunlight directly to heat. The TSC panels can convert up to 80% of solar radiation to heat energy (ATAS, 2009), which makes them more desirable than PV panels when heat generation is the primary energy need. These TSC panels work by drawing air through perforations in an unglazed sheet metal panel. As the panels are heated by the sun, the heat is transferred to the air as it passes through the perforations in the panel. Primarily, TSC panels are used as supplemental heat for ventilation air (US DOE, 1998). The TSCs come in two forms; the first being panels that create a façade over an existing wall of a building, with air drawn into the gap between the TSC and the building’s wall. The second form is a duct constructed from a TSC panel where the air is pulled in through the perforations.

The TSC panels have been used extensively for supplemental heating for animal barns in the cold climate of Canada, but little has been published on their use in livestock barns in the US. Godbout et al. (2004) reported that heating costs were reduced by 23-31% in a swine nursery in Canada. North Carolina has a warmer climate than Canada, but LP use during the winter can still be considerable, so the application of TSC technology is an interesting idea. A wall mounted TSC was tested in eastern NC (Shah et al., 2009), with results showing potential for substantial savings. A TSC duct could potentially be an easier retrofit for livestock barns than a solar wall, so there is a need to test the TSC duct technology in the temperate NC climate. Currently there is no research presented on TSC duct technologies in livestock farms, so their cost-benefits are not known. The payback period for TSC systems is typically low; with InSpire® TSCs the payback is generally 3 to 8 years (ATAS, 2009), but information specific to TSC ducts is not presented. Therefore, the purpose of this study is to look at the feasibility of using a TSC duct to provide supplemental heating to a swine nursery and a turkey brooder barn. To accomplish this, the LP usage between treatments will be analyzed, as well as the animal performance (weight gain/LP use), the difference in carbon dioxide (CO_2) usage. The performance of each TSC duct will be also be analyzed.

Materials and Methods

Two farms are being used for this study: a turkey brooder farm near Snow Hill, NC and a swine nursery farm near Rosoboro, NC. Two houses of the turkey farm are being utilized, a control house and a test house, each measuring 61 m x 15.2 m. Both these houses are identical except that the test house has a TSC duct as discussed later The houses have insulated drop-ceiling and are mechanically ventilated (four 0.91-m fans on the west sidewall grouped in two pairs) with sidewall inlets; sidewall curtains can be lowered for summer ventilation. Heating is provided by LP-powered pancake brooders (capacity: 30 kBtu/h or 8.79 kW) that have a thermostatically-controlled zone-heating system. Each turkey brooder house has a capacity for 9,520 poults that are placed at 0-d and removed 5-6 weeks later for placement in grow-out houses. Minimum ventilation is provided by two timer-controlled 0.91-m fans while the other fans operate on set-point temperatures.

At the swine farm, the house (15.2 m x 30.5 m) is divided into two separate rooms, designated as a control and a test room. Both rooms (7.6 m x 30.5 m) are identical except that the test room has a TSC duct, as discussed later. Each room has a capacity for 950 pigs that are brought in at ~18 d of age (5 kg) and raised to 20-22 kg in 8 weeks and are then sent to a finishing farm to be finished to market weight. These rooms have insulated drop ceiling and have curtains on one side (east side in test room, west side in control room) that are thermostatically controlled. In each room, ventilation is provided by 6 fans (2 x 0.6-m, 3 x 0.46-m, 1 x 0.91 m) that can bring in air through gravity inlets at the opposite end of the barn or through attic inlets when attic heating is required. Heating is provided by an LP-fired forced-air furnace (225,000 Btu/h or 66 kW). A variable-speed 0.46-m fan operated on a timer provides minimum ventilation while the other fans are thermostatically controlled. The two rooms are connected by a hallway with doors to both rooms.

Solar duct construction

The TSC duct is constructed by ATAS International, located in Allentown, PA. The InSpire® TSC sections are attached to an insulated sheet metal channel to form a rigid duct. The panels are black, with a solar absorptivity of 0.94 (ATAS, 2009). The panels are also corrugated for extra strength, and perforated. The dimensions for the intake areas of the turkey brooder and swine nursery systems are 2.4 m x 9.1 m (Fig. 1(a)) and 1.8 m x 24.4 m (Fig. 1(b)), respectively. Both ducts were installed at an angle of ~50° from horizontal to maximize solar heat capture during the winter months per recommendations from ATAS International. The sun does not rise as high in the sky in the winter as it does in the summer, and having sunlight incident perpendicular on the TSC panels is beneficial for greater heat gain. Both ducts are also placed so that they face due south.

Figure 1. Solar duct at (a) turkey brooder farm in Snow Hill and (b) swine nursery in Roseboro, NC

The TSC ducts were placed on top of wooden scaffolding. The purpose of the scaffolding was ensure that duct system was level, which would make it easier to properly angle the ducts; also the turkey producer wanted sunlight on his curtains which required a greater height of scaffolding on the turkey farm (Fig. 1(a)). The ducts were shipped in 3.28-m sections, which were then aligned and connected together on top of the scaffolding and an adhesive foam sealant was placed between the ducts to provide a waterproof seal.

The fan used for both TSC systems is a 0.46-m Aerotech Classic direct drive fan; hereafter, this fan is referred to as the solar fan. The fan was housed in a wooden enclosure (box) to facilitate mounting to the ductwork. A motor controlled shutter was also built into this fan box, with the damper opening when the solar fan has power. The damper prevented air from being pulled through the duct by the minimum vent fans at night, when the standard inlets would be operating. Both the fan and the shutter receive power at the same time so the fan will turn on at the same time that the damper opens, and turn off the same time the damper closes. The flow rates of both systems were measured using an Accubalance balometer (Accubalance Model 8371, 15 to 1000 L/s, ±5% reading and ±2.4% L/s).

Based on measurements with the balometer the design airflow rates for the turkey and swine systems were 1.11 and 1.06 m^3/s, respectively. The range of the balometer was not high enough to directly measure the flow rate of the fan at the turkey brooder farm, so lower flow rates were measured by lowering the speed and measuring the power drawn by the fan at those lower flow rates. The higher flow rates were then extrapolated from this data. Since the flow at the swine nursery was split between two ports, each port was measured directly and added together to get total air flow. Based on airflow rate and surface area of the TSC ducts, the superficial velocities were 0.025 and 0.048 m/s, respectively. Flexible ducting connected the TSC duct to the fan box, and then connected the fan box to the house inlet/s (Fig. 2). The outlet of the fan box at the turkey farm was connected to the rigid sheet metal duct described earlier, while the outlet of the swine farm fan box was connected to more flexible (insulated) duct to distribute the tempered air at two locations (discussed below).

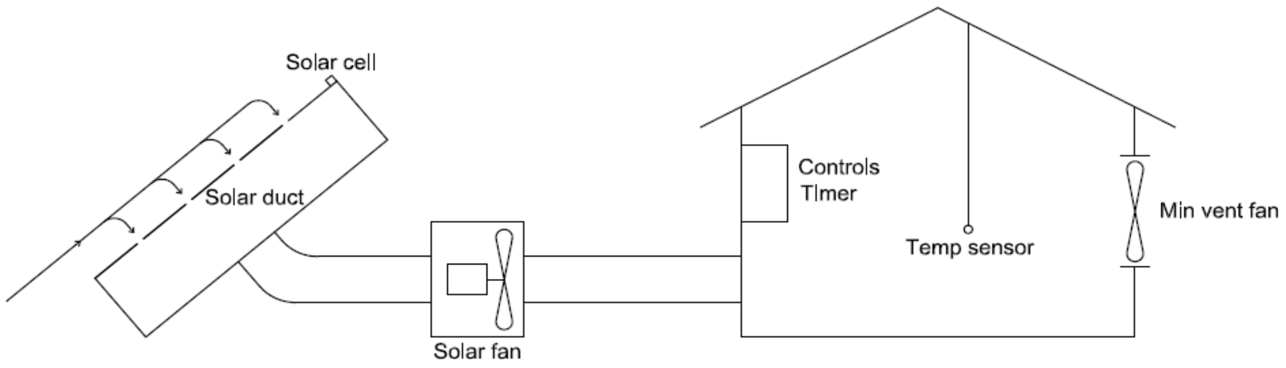

Figure 2: Layout of components and controls in both the turkey brooder farm and swine nursery

Heated air from the TSC duct is introduced into the turkey house at the very middle of the house. A sheet metal duct delivers the air into the house. This duct is angled upwards at the same angle as the ceiling, so that the warm air follows the ceiling to the top of the room. Circulation fans mounted from the roof of the house help spread out and distribute this heated air towards both ends of the house. Heated air is introduced into the swine room in two locations, at the very middle and towards the end away from the fans in equal amounts. Each port has a flow reducer to increase airspeed to cover the entire width (7.6 m) of the room.

Instrumentation and controls

There are three instruments that control the system; these instruments are the solar cell, a timer, and a temperature sensor. The solar cell senses if the sun is shining, and is placed perpendicular to the face of the duct (Fig. 2). The timer controls how much time the solar fan will be on or off, out of a 5-min cycle, based on the age of the animals or season, as specified by the respective manager. The control system (Fig. 3) is configured so that when the timer is off or it is nighttime, power is transferred from the solar fan to the house's minimum ventilation fan/s. Temperature sensors (thermistors) placed midway in the respective house or room, to capture the average temperature, are tied into a controller so that if the house or room is warmer than the desired temperature, the solar fan will not operate and the default ventilation system will operate. To control the minimum vent fans, a relay circuit was built to switch power from the minimum vent fans to the solar fan or vice-versa, depending on the conditions. The relay circuit is plugged it into an existing wall outlet, and the minimum vent fans are plugged into an outlet on the face of the circuit. The main controls communicate with this relay circuit to tell it when to send power to the outlet on the face or not.

Figure 3: TSC duct system controller

At times when the turkey barn needs a higher ventilation rate that can be provided by the solar fan, the solar fan only complements the minimum vent fan/s. There are two minimum ventilation fans at the turkey barn, and if both fans are in operation instead of just one, the ventilation needs of the house are too great for the solar fan to provide meaningful ventilation. For these times, the TSC system controls do not switch power between the two fans, but just periodically gives power to the solar fan based on the house temperature. The solar fan meets all the ventilation requirements for the swine room, since it is smaller. A speed controller was also included for each control system, but this control has not been utilized yet except for fan airflow rate testing.

Each farm has a set of sensors to monitor the conditions at the farm. The turkey brooder farm has temperature, RH, and CO_2 sensors in both the control and test houses, ambient air temperature and RH sensors, and the fan box has a temperature sensor at the inlet. There is also a sensor to monitor when the solar fan runs, and when the minimum vent fan runs. The swine farm has temperature, RH, and CO_2 sensors in both the control and test rooms, ambient air RH and temperature sensors, and a temperature sensor in the fan box. There is also a sensor to monitor when the solar fan runs and a pyranometer to measure the solar radiation perpendicular to the TSC duct. These sensors are downloaded during site visits, usually every 1-2 weeks.

Liquid propane consumption is being monitored in each house of the turkey brooder farm. There is only one LP tank supplying both rooms at the swine nursery, so one meter is placed to measure LP usage of the whole house, and another meter measures LP usage of the test room. Control room LP usage is calculated by subtracting test room usage from the whole house usage. The turkey brooder farm has separate electricity meters in each house. The LP and electric meters are read visually during site visits.

Results and Discussion

The evaluation period was from fall 2010 to spring 2011 and additional monitoring and evaluation will be performed during the heating season of 2011-2012. During the evaluation period three flocks of turkey poults were placed (Table 1). Analyses of treatment effects on bird performance and the difference in CO_2 levels in both houses are ongoing.

Table 1: Summary information for turkey flocks and LP use

Flock	Control house		Test house		Propane saving (L)
	Date in/out	Propane use (L)	Date in/out	Propane use (L)	
1	10/22-11/30/10	3470	10/26-12/2/10	3539	-69
2	1/4-2/11/11	5329	1/5-2/14/11	5316	14
3	3/12-4/19/11	3787	3/12-4/18/11	3608	179
				Total propane saving (L)	124

During the evaluation period, three herds of feeder swine were placed in the test room but the control room stayed empty during spring 2011 (Table 2). Analyses of treatment effects on swine performance and the difference in CO_2 levels in both rooms are ongoing.

Table 2: Summary information for nursery swine herds and LP use

Herd	Control		Test		Propane saving (L)
	Date in/out	Propane use (L)	Date in/out	Propane use (L)	
1	11/19-1/4/2011	3276	11/14-12/31/10	1158	2118
2	1/15-3/1/2011	2193	1/8-2/24/11	2462	-269
3	Not placed	-	3/2-4/12/11	1085	-
				Total propane saving (L)	1849

Propane use

Turkey brooder farm

Propane use in the test and control houses in the turkey brooder farm were comparable (Table 1), indicating that the TSC duct did not reduce LP use. The turkey poults were provided zone-heating inside brooder rings during the first 5 d when the heat demand is the highest; during this time, the producer indicated that the air temperature outside of the brooder rings was not as important. However, ventilating with tempered air should reduce LP use. Further, there was concern about cold air drafts (early in the morning) as well as proper air distribution inside the barn.

The solar fan was not utilized to its full potential. The main reason for this was that the temperature sensors controlling the TSC duct system and the house environmental controllers had different outputs; this variability, in conjunction with a small deadband between the set-point temperature in the house and the minimum vent fan cut-on temperature reduced the run time of the solar fan. Also, the producer turned off the solar fan on cloudy days when the TSC duct could have still provided higher (about 1.5 C) than ambient air temperatures due to long-wave heating. During the 2011-2012 heating season, modifications will be made to the air distribution system to eliminate cold air drafting and improve air distribution, and maximize solar fan run times because the heating effect of the TSC duct was apparent (discussed later).

Swine nursery

Averaged over two herds when swines were placed in both the control and test rooms, the TSC duct saved 1849 L or reduced LP use by 34% (Table 1). For herd 1, the TSC duct reduced LP use by 65% but in herd 2, LP use increased by 12% in the test house. Higher LP consumption in the test house for the second herd was likely due management error. During the week of January 13, 2011, 1 week after the piglets were placed, the minimum vent fans were set to run for far longer than required. This week was also the coldest week during the testing period, based on heating degree days (HDD) (data not presented) and LP usage for that week was 1045 L. Excessive ventilation likely resulted in the high LP use.

During the 2011-2012 heating season, there will be closer coordination with the swine nursery manager to ensure that the ventilation system is operated per established protocol. Also, a timer will be installed to allow the producer to activate the solar fan during certain hours of the day. This was necessitated by the fact that the solar fan activated as soon as sunlight hit the TSC duct even though it had not warmed up; this resulted in cold air being pushed into the room instead of the warmer attic air.

Temperature increase in the TSC duct

Solar radiation and temperature rise data for a typical day for the turkey farm TSC duct are presented in figure 5 with the morning (before solar noon) and afternoon observations displayed in different shades. As expected, temperature rise increased with solar radiation but more interestingly, for the same level of solar radiation, temperature rise was greater in the afternoon than morning (Fig. 5) because it took more time for the system to heat up in the morning (thermal mass effect). The data show that there is a warming period in the morning, and a cooling period in the afternoon. It is interesting to observe that the morning observations are generally lower than the whole day trend, demonstrating the thermal mass of the duct; as the solar radiation decreased in the afternoon, the temperature gain tended to be higher than at the same solar radiation values in the morning.

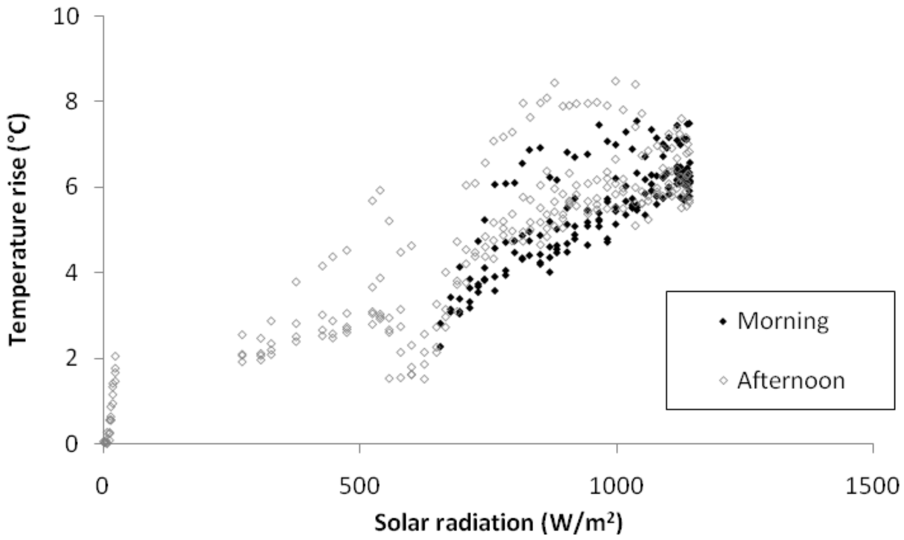

Figure 4: Solar radiation compared to temperature gain imparted by TSC duct for 12/20/2010

Solar duct temperature rise per 100 W/m^2 of solar radiation was 0.61°C at the turkey brooder farm vs. 1.14°C at the swine nursery (data not presented). The superficial velocity (fan airflow rate divided by the TSC duct intake area) at the swine site was 0.048 m/s vs. 0.025 m/s at the turkey site. Greater temperature rise at the swine site despite having ½ the TSC duct area and comparable airflow rates was surprising. Better performance at the swine site may have been due to factors such as, differences in solar radiation receipts at the two sites, time-of-the day effects (e.g., greater temperature rise in the afternoon vs. morning), and also the fan duty cycle during that period. While the temperature rise per 100 W/m^2 was calculated only for those times when the solar fan was running, if the fan duty cycle is low, the TSC duct gains more heat while the fan is not running and can thus heat the air to a higher temperature.

Temperature rise in the turkey unit TSC duct as a function of diurnal fluctuation in solar radiation on a sunny day is presented in figure 5. Temperature gain closely mimics solar radiation (Fig. 5).

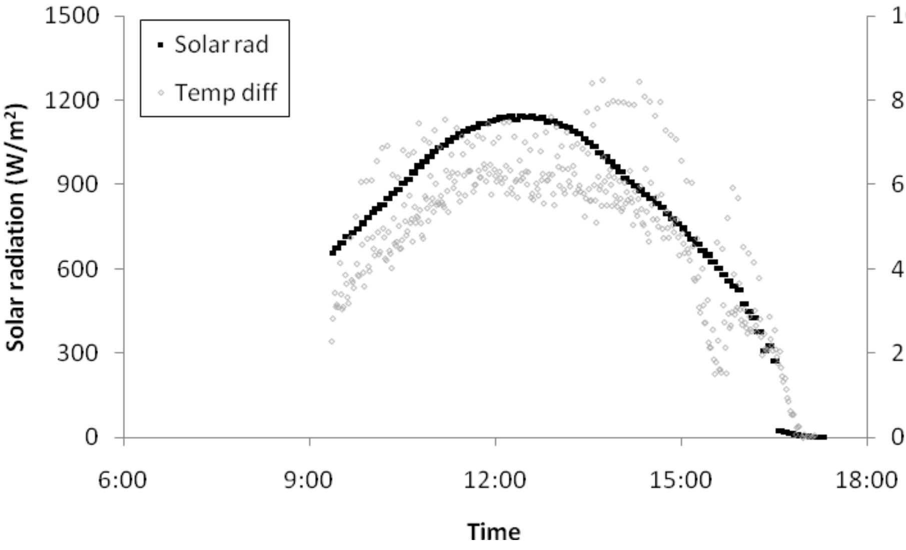

Figure 5: Typical day solar radiation and ambient temperature for December 20, 2010

Table 3 shows hourly averaged values for temperature gain, ambient air temperature, and temperature in the fan box when the fan was running during December 14 to 21, 2010, at the swine farm, and is presented as a representation of the hourly breakdown of energy addition by the solar system.

Table 3: Typical average hourly solar duct performance data at the swine nursery for December 14-21, 2010

Hour	Time on (%)	Average box temp (°C)	Average ambient temp (°C)	Average temperature gain (°C)	Heat addition (J)
6:00 – 7:00 am	0.01	-10.1	-7.5	-2.6	-700
7:00 - 8:00 am	0.6	-1.2	-0.6	-0.6	-12268
8:00 - 9:00 am	0.64	2.9	0.3	2.6	58232
9:00 - 10:00am	0.56	5.6	1.3	4.4	84992
10:00 - 11:00 am	0.58	9.5	2.6	6.9	136850
11:00 - 12:00 pm	0.53	11.2	3.4	7.8	143253
12:00 - 1:00 pm	0.51	10.5	3.3	7.2	125382
1:00 - 2:00 pm	0.5	9	3.6	5.4	92026
2:00 - 3:00 pm	0.58	8.1	4.4	3.7	72769
3:00 - 4:00 pm	0.66	5.8	4.8	1	23123
4:00 - 5:00 pm	0.59	3.9	4.3	-0.4	-7897
5:00 - 6:00 pm	0.18	2.8	3.7	-0.9	-5503

Averaged over 6:00 am to 6:00 pm during December 14-21, 2010, the temperature gain at the swine nursery TSC duct was 2.9 °C and the maximum average hourly temperature gain was 7.8 °C (Table 3). Similarly, the average temperature gain at the turkey farm TSC duct during 6:00 am to 6:00 pm during November 23-30, 2010, was 3.7 °C and the maximum average hourly temperature gain was 8.2 °C (data not presented). The heat production (in joules) in table 3 is the product of dry-air mass flow rate, specific heat of air, and average temperature gain. Table 3 shows that early in the morning and late in the afternoon, the system added no heat to the house and caused undesirable cooling before 8:00 am and after 4:00 pm. Therefore, the TSC duct should have been operated only between 8:00 am and 4:00 pm, though this duration will vary with time of the year. Table 4 also shows that the TSC system adds the most heat during the 11:00 am hour, with heat addition decreasing before and after that time. The highest ambient temperature was at 3:00 pm, but the average temperature gain and heat addition were much lower because of reduced exposure of the TSC duct to the sun; the sun was most perpendicular with the duct, and was therefore transferring the most energy, at 11:00 am.

The values for the average gains in table 3 do not seem very high, but the data also included cloudy days. The solar cell used for this study was fairly sensitive, so even the diminished sunlight on completely cloudy days was enough to trigger the system into operation. There is a very low, but non-zero, gain on cloudy days, which is why the average box temperature and average temperature gain are so low. When cloudy days are factored out of the average temperatures, the temperature gains go up about 50% during the middle of the day, and more during the morning and afternoon. For example, the highest average gain in the period above is 7.8 °C, but with cloudy days factored out, the average gain would be 12.3 °C.

Conclusion

The TSC duct at the swine farm reduced LP use by 34% over two herds. While the TSC duct reduced LP use by 65% for the first herd, the room with the TSC duct had 12% higher LP use in the second herd, most likely due to management error resulting in excessive ventilation at the beginning of the herd, when it was coldest. There was little difference in LP usage between the control and test houses of the turkey brooder farm, showing that the TSC duct provided little heat addition to the test house. The TSC ducts imparted an average temperature gain of 0.61 °C at the swine nursery and 1.14 °C at the turkey brooder farm, relative to every 100 W/m^2 of solar radiation. Average temperature gain for the TSC duct at the swine nursery over 6:00 am to 6:00 pm during December 14-21, 2010, was 2.9 °C and the maximum average hourly temperature gain was 7.8 °C. Similarly, the average temperature gain at the turkey farm TSC duct from 6:00 am to 6:00 pm during November 23-30, 2010, was 3.7 °C and the maximum average hourly temperature gain was 8.2 °C. Based on these results, the TSC duct has shown potential for providing supplemental heat to animal barns in eastern North Carolina.

Moving forward, both TSC systems will be monitored again during the winter of 2011-2012. There will be three herds and flocks worth of data during this second heating season. For the next heating season, some modifications will need to be made to optimize the performance of both TSC ducts. Timers will be added to both systems so the systems will not run early in the morning and late in the afternoon, when the gain is negative. The system will be operated certain hours during daytime. Changes will be made to the air distribution system in the turkey brooder farm test house, and smoke tests will be performed to evaluate the effects of air drafting. Also, the installed system at the turkey brooder farm will be modified to work better with the environmental controllers in the house. The temperature sensors will be placed at different locations, or tied together to control both systems. Further analysis will also be performed. For both systems, the weight of live weight produced will be correlated to the amount of LP used. Also, the CO_2 levels between the treatments will be analyzed.

If, at the end of the study, this TSC system is deemed desirable and economically feasible, a plan will be developed for installing these systems at farms in North Carolina. Extension meetings will be held with both farmers and integrators to disseminate information gained through this study.

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