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ScienceDirect
Solar Energy 102 (2014) 308–317
SOLAR ENERGY
www.elsevier.com/locate/solener

Transpired solar collector duct for tempering air in North Carolina turkey brooder barn and swine nursery

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Available online 19 December 2013

Communicated by: Associate Editor I. Farkas

Abstract

Transpired solar collector (TSC) ducts were installed at a swine nursery and a turkey brooder farm in eastern North Carolina (NC), USA. Each farm had a Test (TSC duct-equipped) and an identical, adjacent Control treatment. Five swine herds and six turkey brooder flocks were monitored over two heating seasons (2010–2012). Propane uses were reduced by 55 and 27 L/m^2-yr, respectively, in the swine and turkey barns; reductions were highly variable among herds or flocks and the modest reductions were due to warm weather and use of attic ventilation. Over a 14-d period, both the swine and turkey TSC units increased ambient temperature in the barns by ~6 °C with a maximum increase of 22.5 °C in the turkey TSC. In the swine and turkey houses, calculated energy additions by the TSC were 433 and 81 MJ/yr-m^2 of collector surface area, or 16 and 3 L/m^2, respectively, of propane saved. Calculated propane savings were much lower than measured values. Short-term efficiencies were higher in the swine TSC (>61%) vs. the turkey TSC (39–50%) probably due to the lower face velocity of the turkey TSC which increased collector heat losses. While barn CO_2, RH, and temperature values were unaffected by the TSC, it was unclear why animal performance in the Test treatment was better. Simple payback periods for the TSC ducts at both farms were favorable (<5 yr) with government incentives. The TSC ducts were both technically and economically feasible, with incentives.
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Keywords: Solar heating; UTC; Propane saving; Simple payback period

1. Introduction

North Carolina (NC) is the second biggest producer of swine and turkey in the US (NCDA&CS, 2012). Swine and poultry farms require large amounts of heating fuel (usually propane) for brooding. Propane prices have been volatile in recent years, making it difficult for farmers to plan in the short term. Solar energy could supplement propane as a heat source for animal houses. The unglazed transpired solar collector (TSC), which consists of an unglazed, dark-colored, perforated metal sheet could be a potential solution for air heating because it is highly efficient (⩽80%) (Kutscher, 1996). Wall-type TSCs can be built onto an existing wall, forming a façade with a plenum behind the collector to pull tempered air into the building. Duct-type TSCs can be installed separate from the building, with one side of the duct acting as the solar radiation absorbing surface.

In livestock barns, where ventilation is constantly needed to maintain healthy oxygen levels and exhaust noxious waste gases, the TSC could be useful for providing supplemental heating. However, there are only a few studies on TSC use in livestock heating applications. In Quebec, Canada, TSC systems have been evaluated in a swine nursery (Godbout et al., 2004) and a broiler house

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0038-092X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.solener.2013.11.028

(Cordeau and Barrington, 2011). In an NC swine nursery, Shah et al. (2010) evaluated a TSC wall with a damper to allow the fresh air to bypass the TSC when heating was no longer needed. While the TSC wall system recycled heat lost through the wall, its damper system was complicated, requiring a signal from the house environmental controller to activate an actuator that opened or closed a set of 10 1.2-m wide dampers using a cable and pulley system (Shah et al., 2010). The TSC duct system requires a much-simpler bypass system. We are unaware of any TSC duct studies.

We evaluated the technical and economic feasibilities of a TSC duct to provide supplemental heating in a swine nursery and turkey brooder barn in eastern NC. Specific objectives were to: (1) compare propane consumption between the Test (TSC duct-equipped) treatment with an adjacent and identical Control treatment, (2) evaluate TSC system performance (temperature gain, heat output, and efficiency), and (3) determine simple payback period for different scenarios.

2. Materials and methods

This study was conducted in eastern NC during the two heating seasons of 2010 to 2012. The swine nursery was in Roseboro and the turkey brooder farm was in Snow Hill. Pertinent details about the two TSC duct systems are provided below; additional details are in Love (2012).

2.1. Farms

The swine nursery was divided into two identical rooms (7.6 m × 30.5 m), each room housing 950 pigs. The east-facing room, equipped with the TSC duct was the Test treatment, and the west-facing room was the Control. Weaned piglets were placed at ~18 d of age (~6.1 kg each) and in ~7 weeks the feeder pigs (~19.8 kg ea.) were sent to another farm to be raised to market weight. Each room was heated by a 66-kW propane forced air furnace. Minimum ventilation (MV) (with supplemental heating) was provided by a timer-operated 0.46-m fan (1.9 m^3/s at 25 Pa). Other thermostatically-operated fans were used for cooling. Desired room temperatures (DRTs) were set weekly by the producer starting at 28.3 °C on day 1, decreasing to 21.7 °C on day 36; there was no cooling system. For heating, fresh air was brought in through the attic inlets; otherwise, gravity inlets were used. In many barns that require supplemental heating, fresh air is pulled through the attic which heats up due to both solar radiation and heat gain from the barn.

Two identical and adjacent houses were monitored at the turkey brooder farm, each house measuring 61.0 m × 15.2 m. Both houses were oriented with the major axis running east-west. Turkey poults (~9,500) were brought in at 0-d of age, raised to ~2 kg ea. in ~5–6 weeks and sent to grow-out houses where the birds were raised to market weight. For their first 5 d, the turkey poults were confined inside cardboard rings around the brooders to provide adequate radiant heat. Each house had 32 propane-fired pancake brooders (8.8 kW each). The DRT was 28.9 °C on day 1 and reduced weekly until it reached 22.8 °C on day 42; there was no cooling system. The poults were raised on fresh pine shavings, ~0.15 m deep. Minimum ventilation (with supplemental heating) was provided by two (one in winter) 0.91-m fans (5.2 m^3/s at 25 Pa) on timer; additional ventilation was provided by two more 0.91-m fans on thermostat. During heating, warm fresh air was brought from the attic; otherwise, untempered air was brought through the sidewall inlets. During warmer weather, when ventilation demand was higher, the curtains were lowered thermostatically. The northern house equipped with the TSC duct (described below) in addition to the conventional heating system was the Test house; the southern house, with only the conventional heating system was the Control.

2.2. Solar collectors

The aluminum TSC ducts were painted black (solar absorptivity = 0.94) and corrugated for rigidity. The ducts were medium flow (nominal face velocity of 0.015–0.031 m/s) and had vertical, rectangular slits (~0.51 mm × 6.35 mm) with an open area of 0.8% for optimal heat gain and efficiency (J. Flaim, ATAS, Inc., personal communication, May 31, 2013). Both ducts were angled 50° above the horizontal, facing south based on the site latitude to maximize solar heat gain per ATAS (Fig. 1).

At both sites, tempered air was pulled through the TSC duct using a 249-W (1/3 hp) 0.46-m ϕ direct drive fan (Make: Aerotech; Model: AT18G). In the turkey house, the tempered air was released at mid-length of the house (Fig. 1a) and distributed by opposing mixing fans throughout the length of the house. In the swine barn, the tempered air was distributed through two insulated ducts at the end (opposite to the location of MV fan) and mid-length of the house (Fig. 1b). Adequate air mixing and the absence of undesirable draft at animal height were confirmed using smoke tests and air speed readings (Love, 2012). At both locations, the stale air was exhausted through the fan shutters. The specifications of the two systems are presented in Table 1.

The swine TSC face velocity (Table 1) was higher than recommended (0.015–0.031 m/s) by ATAS (2011) while the turkey TSC face velocity was in the recommended range. Different face velocities of the two units allowed us to evaluate the technical and economic performance of the TSC as a function of face velocity. Based on the growth curve of male turkey poults (toms) (Aviagen, 2011), the TSC fan airflow rate (Table 1) provided minimum ventilation for 9,500 birds ⩽ 21 d of age (Midwest Plan Service, 1987). At an MV rate of 9.5e-5 m^3/s for a piglet up to 13.6 kg (Midwest Plan Service, 1987), the swine TSC fan could provide adequate ventilation for 950 piglets for the first few weeks for placement weight of 6.1 kg ea. Hence, the TSC fan ventilation rates were adequate for the early

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