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Research paper

Retrofitting of a pig nursery with solar heating system to evaluate its ability to save energy and reduce environmental pollution

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A B S T R A C T

The objective of the present experiment was to evaluate the efficiency of an active solar space heating system to save energy and reduce the emission of CO_2. The system was installed in an experimental nursery pig building and consisted of evacuated tube collectors (south-facing), hot water tank, regulatory pump and copper pipes mounted on the side wall to distribute heat inside the house. The efficiency and output of the collector was calculated using the ambient temperature, collector temperature and solar radiation. The average efficiency of the evacuated tube collector was 64.8% and its calorific contribution was 125 kWh/m^2/day. The internal temperature and humidity, pig performance, energy use, CO_2 emission and cost were compared to an identical, adjacent conventional house. Internal temperature and humidity were comparable in both houses, except that the bottom temperature in the center and back of the solar house was higher than in the conventional house. Piglets in the solar house had a slightly higher body weight and lower feed intake than those in the conventional house. The electricity use in the solar house was reduced by 15% (261 kWh) relative to the conventional house. The reduction in electricity use reduced the CO_2 emission by 15% (128 kg) relative to the conventional house. Overall, the results of this study indicate that active solar heating systems can successfully reduce energy use and CO_2 emission. Consequently, future studies should be conducted to evaluate other green house gas emissions and the costs associated with use of the developed solar system.

1. Introduction

Energy is the basic foundation that determines the stability of the economic development of any nation (Chow et al., 2007). However, problems associated with limiting the main sources of energy, such as crude oil and electricity, as well as other natural sources of non-renewable energy, rising energy prices and recognition of the environmental impacts of using fossil fuels, increasing awareness and incentives to seek alternative sources of energy. Renewable energy technologies such as biomass, wind, solar thermal, solar electricity, and geothermal energy appears to be a viable solution to the energy crisis and environmental problems caused by non-renewable energy sources as most of them are abundant, and free of cost and green house gas emission (Rabah, 2005).

Since pigs are housed according to their age, maintaining their specific heating and ventilation requirements is an important prerequisite of their environmental control. Weaning of pigs at an early stage (3–5 weeks of age) require an air temperature ranging from 27 °C to 35 °C depending on pen design and air velocities (Bodman et al., 1989). Therefore, the fuel cost for heating pig building represent a significant and growing portion of the total cost of swine production. Swine producers are interested in alternative sources of energy to reduce their heating costs to remain competitive. Solar thermal technologies comprise a type of alternative energy source that can partially fills the need for heating porcine production facilities because solar energy is abundant, inexhaustible and free once the initial cost of the system is recovered. Similar to other forms of renewable energy, solar energy offers an opportunity to stabilize energy costs while decreasing pollution and greenhouse gases (GHGs). Solar thermal technologies can be used to provide space and water heating or to generate electricity to provide power for a variety of applications. Space heating by solar thermal technologies can be either active or

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passive. Active solar heating requires facilities and equipment for collecting, transferring and storing solar energy. Active solar heating systems with in-floor heat distribution and storage systems were applied in swine housing by Bodman et al. (1989, 1987) and Kocher et al. (1993); however, active solar systems with evacuated tube collectors have not yet been widely applied in pig houses.

Pig farmers who raise animals in enclosed buildings can incorporate both electric and thermal solar technologies to provide supplemental heat in cold weather and power to operate ventilation systems (Chikaire et al., 2010). In this experiment, we constructed an active solar space heating system with evacuated tube collectors together with electrically-powered ceiling mounted radiant heaters to heat a mechanically ventilated nursery pig building. The objectives of this study were to calculate the efficiency of evacuated tube collectors and to evaluate the impact of solar heating on pig performance, reduction in energy use and CO_2 emission in a pig nursery.

2. Materials and methods

2.1. Experimental building and animals

The experiment was carried out for two weeks (10 September 2013 to 24 September 2013) at the pig nursery building of the Sunchon National University experimental farm (latitude: 34° 59′ 57.948″ N), Republic of Korea. The nursery has two separate houses that are each 3 × 8 m (10 × 26 ft) and subdivided into ten pens. Each house is designed to hold 50 piglets ranging in weight from 4 to 25 kg. The nursery is well insulated and has a plastic-slatted floor. The temperature and ventilation of the nursery are automatically controlled according to the adjustment chart provided by the technical advisor. A total of 60 weaned piglets weighing an average of 7.92 ± 0.09 (SE) kg were divided into two treatments (each with 30 piglets) and housed in the two environmentally controlled houses. Feed and water were provided *ad-libitum* and lighting and other management practices were carried out in accordance with general practices.

2.2. Construction of active solar space heating system

Among the two house of the nursery building, the north house (conventional) was used as conventional facilities and the south side house (solar) was used to construct the solar heating system. A total of three evacuated tube collectors (Apricus AP-30 solar collector, consisting of 30 evacuated tubes, Apricus Solar Co., Ltd., Jiangsu, China) were installed in one array in the roof of the experimental house (south facing at a 60° angle) to collect heat from solar radiation (Fig. 1, a). The total area of collector panel was 15.75 m^2. Each glass tube (58 mm in diameter) contained a copper pipe (heat pipe) and was able to transfer solar heat via convection of its internal heat transfer fluid to a hot bulb that indirectly heats a copper manifold (heat exchanger). These copper pipes are all connected to a common manifold, which is connected to a storage tank (300 L capacity), where it heated (Fig. 1, b) the water in the storage tank. The heat transfer fluid was a lubricant oil to prevent freezing at low temperatures and the oil circulation was controlled by a regulatory pump. The hot water from the storage tank was circulated through copper pipes (9.52 mm in diameter) mounted on the longitudinal wall of the experimental house (Fig. 1, c) using a regulatory pump, which enabled transfer of the heat to the air of the house via radiation. The cold water was then transferred back to the water tank, which cooled the oil of the copper pipe (19.05 mm in diameter) that collected heat. This cold oil was then again sent to the evacuated tube collector to collect heat using solar energy. A schematic diagram of the whole system is presented as Fig. 2.

The automatic environment control system maintained the required room temperature by heat from six supplemental electric heaters that were hanged from the ceiling during night and cloudy weather. Before commencement of the experiment, a total of 10 days served as a development period, during which time the equipment calibration, reliability of installation and acquisition system were verified.

2.3. Instrumentation

The solar collector fluid inflow and outflow temperature, as well as the temperature of the hot water tank inflow and outflow were measured using a copper-constantan thermopile, type T. Outside the building, a meteorological station (HR Vaisala, HMP35C, Campbell Scientific, Inc., Edmonton, AB, Canada) containing temperature (°C) and relative humidity (RH %) sensors were installed. This station was equipped with a radiation protector (UT12VA radiation shield, Campbell Scientific, Inc., Edmonton, AB, Canada), and was mounted on a UT10 tower leg about 1.5 m high from the ground. A solar radiation sensor (CMP6-L Kipp and Zonen Pyranometer, Campbell Scientific, Edmonton, AB, Canada) was fixed at the middle of the evacuated tube collector to measure the solar radiation intensity. To measure the temperature of the conventional and experimental house, thermo-couple temperature sensors (type T) wires were hanged from the ceiling at the entry (near the door), center and back of the house to measure the temperature at two points; 10 cm below the ceiling (upper point) and 10 cm above the floor (lower point). All measurement instruments were connected to a data acquisition system (CR10X data logger, Campbell Scientific Inc., Edmonton, AB, Canada) to record the data every hour (Fig. 1, d). The RH of the houses was measured with a digital hygrometer two times a day. Two separate electric watt-meters with current transformers were installed for both nurseries to measure electricity consumption for heating and running all machineries of the active solar heating system during the experimental period.

2.4. Measurements and analyses

The efficiency of the solar collector was calculated according to the following formula (Trier, 2012):

$$\eta_{collector} = \eta_o - a_1[(T_m - T_a)/G] - a_2\left[(T_m - T_a)^2 \Big/ G\right].$$

Where, $\eta_{collector}$ = efficiency of solar collector (%)

η_o = optical efficiency (0.717 for Apricus AP evacuated tube)
a_1 = 1st order heat loss coefficient [1.52 W/m^2K for Apricus AP evacuated tube]
a_2 = 2nd order heat loss coefficient [0.0085 W/m^2K^2 for Apricus AP evacuated tube]
T_m = mean collector temperature $(T_{outlet} + T_{inlet})/2$ (°C)
T_a = ambient air temperature and
G = Solar radiation (W/m^2)

To calculate the output of the solar collector, we used the following formula:(Krishnamurthya and Banerjee, 2012)

$$\text{Energy Output}\left(kWh/m^2\Big/day\right) = \text{Solar radiation}\left(kWh/m^2\Big/day\right) \times \text{Collector efficiency} \times \text{Aperture Area}\left(m^2\right)$$

To convert electricity consumed in kWh to kg of carbon dioxide (CO_2), the energy should be multiplied by an emission factor.

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