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Solar thermal application for the livestock industry in Taiwan

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ABSTRACT

Solar water heating systems have proven reliable and economical. In Taiwan, the cumulative area of installed solar collectors at the end of 2014 was approximately 2.39 million m^2 and approximately 98% of those systems were installed in the domestic sector. Preheating water for livestock processing plants is cost-effective since heated water can be used for evisceration, sanitation during processing and for daily cleanup of plant. In this case study, detailed measurements are reported for parallel combined solar thermal and heat pump systems that are installed in a livestock processing plant. These results confirm that the hot water consumption, the mass flow rate and the operation of circulation and heat pumps affect the system's thermal efficiency. The combined operational effect is a factor in system design. The estimated payback period is less than the expected service period of the system, which validates the financial viability.

1. Introduction

Using renewable energy yields energy savings and environmental benefits. In Taiwan, imported fuel accounted for 97.58% of the energy supply in 2013 [1], so renewable energy has received increasing support, particularly with the passing of the Renewable Energy Development Bill in April 2010. Water heating constitutes a major form of energy consumption in the domestic and commercial sectors [2]. Taiwan has a subtropical climate (22–25° North), so the annual global solar radiation ranges from 1200 to 1700 kWh/m^2 [3]. The subsidy programs (1986–1991, 2000–present) introduced by the Bureau of Energy under the Ministry of Economic Affairs (BEMOEA) for solar water heaters (SWHs) mean that the cumulative area of solar collectors installed was approximately 2.39 million m^2 in Taiwan at the end of 2014 and approximately 0.3 million systems (or 1.6 million m^2) are currently operational [4]. Dissemination of SWHs in Taiwan was reviewed by Chang et al. [5,6] and Lin et al. [7]. More than 98% of SWHs have been installed in the domestic sector and the limited commercial application of industrial heat generation is attributable to the lack of experience in system design and uncertainty about the potential benefits to end users.

Industrial heat processes represent an area where solar heat applications can be used in various sectors [8] and the required temperatures range from 60 to 260 °C [9]. Lauterbach et al. [10] showed that the process temperature, the collectors and the load profile are the most important factors for system performance in a brewery. An increased in the return temperature from 20 °C to 40 °C results in a 35% reduction in system yield. A shorter operation with doubled mass flow also reduces the system yield. Plants in the livestock industry could make good use of solar heat for evisceration, sanitation during processing and daily plant cleaning. In Taiwan, pork is the most commonly consumed meat (comprising 40% of total

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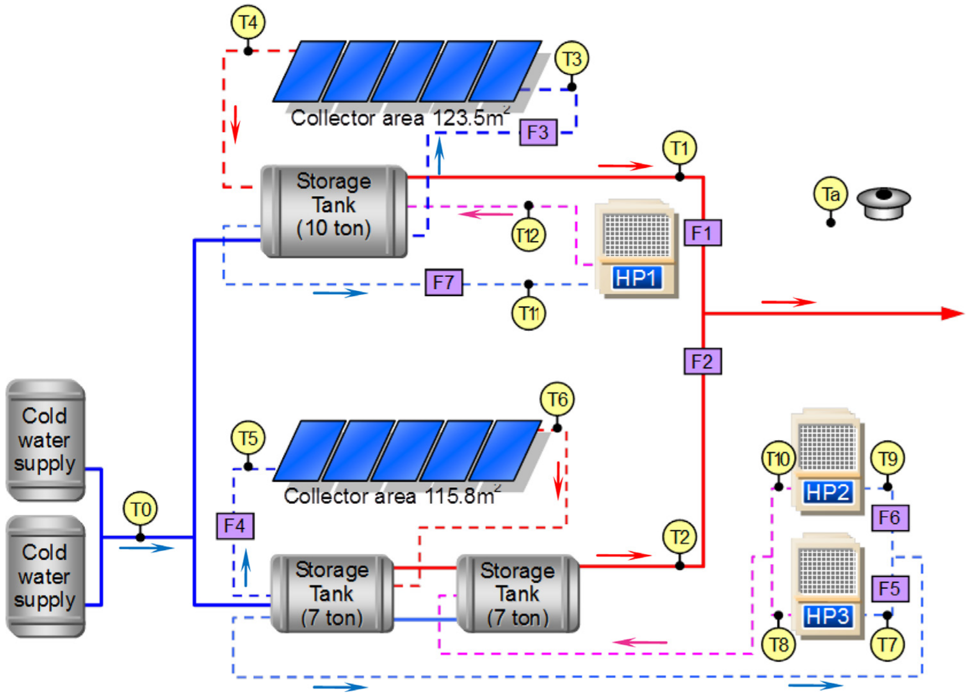

Fig. 1. A schematic drawing of the SWHs and the monitoring devices.

meat consumed). 8457 pig farms in Taiwan also supplied approximately 7.47 million pigs in 2013 [11]. To promote SWHs in the livestock industry, SWH system performance and financial viability must be determined. Furthermore, heat pumps (HPs) allow high thermal efficiency. In terms of the ambient air temperature, a suitable dead-band temperature is essential for air-to-water HPs. The potential benefits of combining SWHs and HPs for hot water production have also been studied [12]. However, the financial viability depends upon heating operation conditions. In this case study, HPs are used as a back-up heating source. Both SWHs and HPs supply heat to water storage tanks independently. Field measurements for the system in a slaughterhouse are conducted. The data is then used to estimate the real benefits for end users and provide justification for the use of solar thermal energy in the commercial sector.

2. Field measurement setup

Yunlin County (1270 pig farms) ranks first in terms of pig production (producing 24.36% of all pigs in Taiwan) [11]. Therefore, the Yunlin meat market (23°43′40″N, 120°25′43″E) in Southern Taiwan near the Tropic of Cancer (annual solar radiation = 6712 MJ/m^2) was chosen for the case study to evaluate the performance of a combination of solar thermal and HP system. Fig. 1 shows the two independent SWHs and HPs that were used for scalding and de-hairing. The effective area of the solar collectors A_{sc} (glazed flat-plate type) was 123.5 m^2 for System 1 (installed in March, 2012) and 115.8 m^2 for System 2 (installed in August, 2010). The south-facing solar collectors were installed on the roof at a tilt angle of 18.5°. One 10-ton and two 7-ton storage tanks were also installed. Temperature set control (= 5 °C) was used to control pump operation for the SWHs. The mass flow rate setup was 0.028 and 0.019 kg/m^2/s for Systems 1 and 2, respectively. As a back-up heating source, the HPs were switched on when the temperature in the storage tanks is less than 50 °C and their flow rate ranged from 105 to 118 L/min. A boiler that uses low sulfur light fuel oil was also available for the required temperature of 63 °C.

Several monitoring devices were installed to determine the system performance. A precision spectral pyranometer (PSP, Eppley Laboratory, Inc.) measured the incident horizontal solar radiation. Seven Macnaught flow meters (M2SSP-1R, denoted as F1–F7) were positioned along the cold water supply line to the hot water storage tank (hot water consumption) and along the circulation line from the bottom of the storage tank to the inlet of the collectors (circulation flow rate). Fourteen platinum resistance thermometers (denoted as T_a, T0–T12; 1/10 DIN Class B, Izuder Enterprise) were installed to monitor the ambient and local water temperatures. The energy consumption of the HPs (HP1: 38.4 kW; HP2 and HP3: 40.6 kW) was recorded using power meters. Data from the monitoring devices was sampled every 10-s using a National Instrument's data acquisition system (cFP-AI-110 and cFP-RTD-124).