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SOLAR WATER HEATING FOR LIVESTOCK INDUSTRY IN TAIWAN

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Abstract

Solar water heating systems have been proven to be reliable and economical for producing hot water. In Taiwan, the cumulative area of solar collectors installed by the end of 2014 was approximately 2.39 million m^2, in which approximately 98% of the systems were installed in the domestic sector. Further, preheating water for livestock processing plants, where hogs are killed and processed for consumption, is potential of cost-effective application. Heated water can be used in the plants for evisceration, sanitation during processing, and the daily cleanup of the plant. In Taiwan, the number of pig farming was 8,457, and the supply for slaughtering was approximately 7.47 million heads in 2013. A livestock processing plant using combined solar thermal and heat pumps systems was chosen as the case study by the field measurements. The results showed that the hot water consumption, mass flow rate, operation of circulation pumps and heat pumps would affect the thermal efficiency, economic viability and attractiveness of a system. This study would provide useful information for all parties related to this market, manufacturers, potential users and policy-makers in Taiwan and other countries.

Keywords: *solar water heating; livestock industry; Taiwan*

1. Introduction

Besides the energy savings, applications of renewable energy technologies (e.g. solar, hydroelectric, biomass, wind, ocean and geothermal energy) have environmental benefits, like a reduction in air pollutants and greenhouse gases (Kikuchi, 2011). Therefore, tremendous efforts have been made to formulate and implement favorable policies by the governments throughout the world. In Taiwan, imported fuel accounted for 97.58% of its energy demands in 2013 (BEMOEA, 2014). Thus, renewable energy has received increasing support, particularly with the Renewable Energy Development Bill enacted in April 2010, and is projected to reach 3% of the total energy supply by 2020. Further, water heating constitutes one of the major types of energy consumption in both domestic and commercial sectors (Roulleau and Lloyd, 2008). Taiwan has a subtropical climate (latitude 22° to 25° North). The yearly global solar radiation ranges from 1200 to 1700 kWh/m^2, which is favorable for the use of solar heat. With 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), the cumulative area of solar collectors installed was approximately 2.39 million m^2 by the end of 2014, in which approximately 0.3 million systems (or 1.6 million m^2) are in operation. Moreover, dissemination of SWHs in Taiwan was reviewed by Chang *et al.* (2009, 2015) and Lin *et al.* (2012). The major factors included system design, economic/financial considerations, degree of urbanization, and legislative support. More than 98% systems were installed in the domestic sector, and limited commercial application for industrial heat process was due to lack of experience in system design and uncertainty of expected benefits. Nevertheless, solar water heating is still the most successful account of renewable energy application in Taiwan.

Process heat generation is an unexploited application for solar heat in the sectors like food, agro-food, paper, textiles, chemicals and beverages (Karagiorgas *et al.*, 2001; Lauterbach *et al.*, 2012; Mekhilef *et al.*, 2011),

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in which the required temperatures for industrial heat processes range from 60°–260°C (Kalogirou, 2003). Lauterbach *et al.* (2014) also indicated that a solar thermal system for industrial applications under a low process temperature and constant load can result in higher system yields. However, the hydraulic setup, solar collectors and hot water consumption patterns on system performance need to be addressed. Further, livestock industry has favorable conditions to use solar heat for evisceration, sanitation during processing, and the daily cleanup of the plant. In Taiwan, pork is the major meat (≈ 40%) and its per capita consumption in average was 37.91 kg/person/year in the period of 2005–2013. The number of pig farming was 8,457, supplying approximately 7.47 million heads in 2013 (NAIF, 2013). To promote SWHs in livestock industry, it is important to analyze system performance and their financial viabilities. Also potential benefits of combined solar thermal with heat pumps for hot water production have been studied (Carbonell *et al.*, 2014). Therefore, field measurements of a combined system installed in a slaughterhouse were conducted in this study.

2. Setup of field measurements

According to the statistics by the NAIF (2013), Yunlin County (1,270 pig farms) was the top one for pig production (24.36%). As mentioned previously, solar heat can be used for evisceration, sanitation during processing, and the daily cleanup of the plant. Therefore, Yunlin meat market, located in southern Taiwan near the Tropic of Cancer, was chosen as our case study (yearly solar radiation = 6,712 MJ/m^2) for evaluating the performance of a combined solar thermal and heat pump system. Note that a boiler using low sulphur light fuel oil is also available. Figure 1 shows the two independent SWHs and heat pumps for scalding and dehairing (required temperature = 60–65°C). The A_{sc} (glazed flat-plate type) was 123.5 m^2 (system 1) and 115.8 m^2 (system 2), respectively. Note that the appropriate A_{sc} of a SWH is in the range of 130 m^2 to 160 m^2 for more reasonable energy and economic performances (Li *et al.*, 2014). The solar collectors facing south were installed on the roof with a tilt angle of 18.5°. One 10-ton and two 7-ton storage tanks were installed. Pumps were also employed for forced circulation. The setup of mass flow rate was 0.028 and 0.019 kg/m^2/s for system 1 and system 2, respectively. The flow rate of heat pumps ranged from 105 to 118 liters per minute. The systems have been in operation since March 2013.

To evaluate the actual performance of the systems, several monitoring devices were installed. A precision spectral pyranometer (Eppley Laboratory, Inc., model PSP) was installed to measure the incident horizontal solar radiation. Seven Macnaught flow meters (Model M2SSP-1R) were located in the cold water supply line to the hot water storage tank (hot water consumption) and in the circulation line from the bottom of the storage tank to the inlet of the collectors (circulation flow rate), respectively. There were 14 platinum resistance thermometers (T_a, T_0–T_{12}, Izuder Enterprise**,** 1/10 DIN Class B) installed to monitor the ambient and local water temperature. In addition, energy consumption of the heat pumps (HP1: 38.4 kW; HP2, HP3: 40.6 kW) was recorded by the power meters. The data from the monitoring devices were sampled every 10 seconds by National Instrument (NI) data acquisition system (Model cFP-AI-110 and cFP-RTD-124) and transmitted synchronously to the host computer at the Energy Research Center, National Cheng Kung University

3. System operating performance

3.1. SWHs and heat pumps

Certifications of a solar collector or a SWH, in which the standards have been enforced by the BEMOEA, are required when filing for a rebate. The thermal efficiency η (≥ 0.5, Chinese National Standard 12558-B7277) of a SWH is calculated using the following formula. Note that the test conditions under the standard specify the daily horizontal solar radiation per square meter (≥ 7 MJ/m^2).

$$\eta = mC_p(T_f\text{-}T_i)/(A_{sc}G)$$

C_p: specific heat, MJ/(kg°C)
m: water mass flow, kg
T_i: initial temperature in the hot water storage tank, °C
T_f: final temperature in the hot water storage tank, °C
A_{sc}: effective area of solar collectors, m^2

G: daily horizontal solar radiation per square meter, MJ/m^2

In this study, the data from March 25, 2013 till June 30, 2013 were used to investigate the system's performance. Take the daily record on March 25, 2013 for example. The outdoor temperature ranged from 20 to 30 ^oC, and a peak solar radiation of approximately 870 W/m^2 was recorded. The daily solar radiation was approximately 5.77 kWh/m^2, and the solar energy was 712.6 kWh and 668.2 kWh for system 1 and system 2, respectively. For hot water consumption, it was in periods from 08:00 to 17:00. The daily hot water consumption was 26,045 liters. It is also noted that he daily hot water consumption in system 1 is sufficiently lower than that in system 2 in the period of March 25 to June 30, in which the peak values were 13,098 L/day and 26,573 L/day, respectively. For thermal performance of system 1, η increased with G ($\geq$ 6 MJ/m^2). The peak value was 0.476. For system 2, there was large variation of η with G while the peak value reached 0.641. Therefore, hot water usage is considered to be a critical factor for thermal efficiency of SWHs. Further, Li *et al.* (2014) indicated that the combination of SWHs and heat pumps is a very attractive option for hot water production. The COP of heat pumps varied from 2.6 to 4.9 when T_a = 18– 33°C. It is also noted that the COP of HP1 is higher than that of HP2 and HP3.

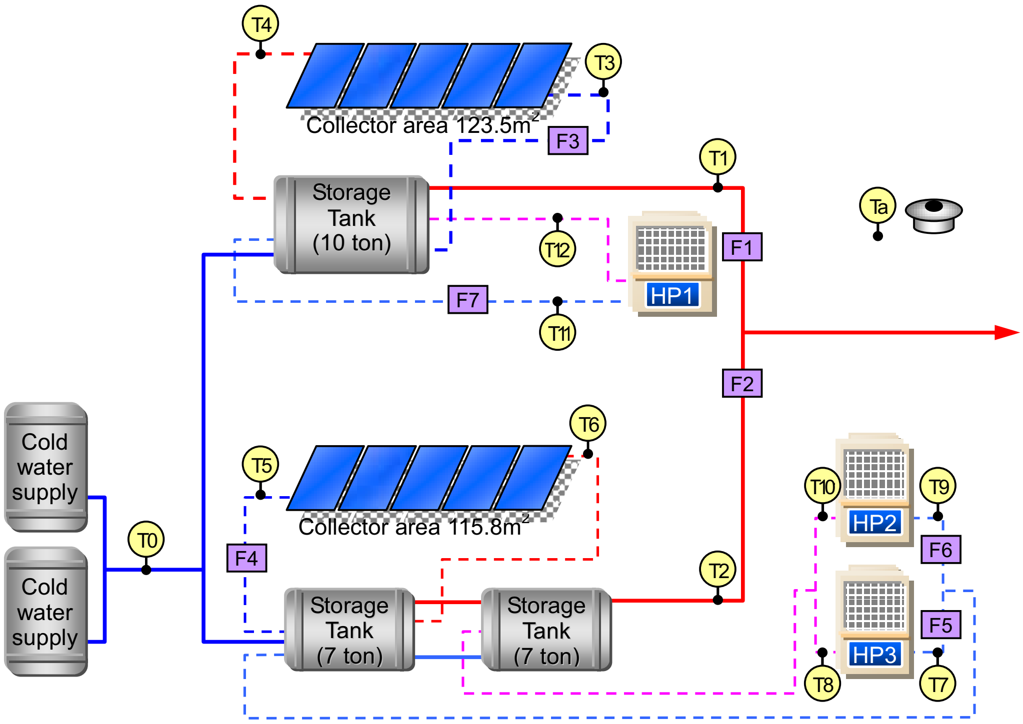

Fig. 1: A schematic drawing of SWHs and monitoring devices

3.2. Operating performance

As mentioned previously, the thermal performance of a SWH is associated with the entering water temperature and water consumption pattern. From April to June, the useful energy gain by the SWHs and HPs are shown in Table 1. For SWHs, the collected solar energy was 44,282 MJ and 58,109 MJ for system 1 and system 2, respectively. Since HP1 was least used or usually kept off in the measurement period, the ratio of collected solar energy divided by total supplied energy of the combined system is 70.8% and 27.8% for system 1 and system 2, respectively. In Table 1, it is also found that only 68% of total collected energy for system 2 was consumed. Inadequate operation of HPs is the major concern and should be taken into account to realize energy savings. Heat loss from the storage tank and piping to the environment during the night hours is also needed to be addressed. Further, the electricity consumption for the circulation pump of system 2 is sufficiently higher than that of system 1. Thus, a suitable control strategy is definitely required to ensure efficient energy savings of the system. Nevertheless, the net energy savings in the period of March 25 to June 30 was 150,655 MJ (or 1,537 MJ/day).

The monthly system operating performance from April to June is shown in Table 2. It can be seen that the solar thermal efficiency (η = 0.170–0.419) is sufficiently lower than the CNS standard, i.e. $\eta \geq 0.5$, particularly in April. This may partially corresponds to lower monthly solar radiation in April. The peak daily hot water consumption of system 1 is approximately half of that of system 2. Thus, it can postulate that a SWH with greater hot water consumption gives better system efficiency. Also, the mass flow rate was 0.028 and 0.019 kg/m^2/s for system 1 and system 2, respectively. Furbo (2005) indicated that a low mass flow rate of a SWH can result in a higher thermal efficiency. Therefore, a reduction in mass flow rate for system 1 may be required to ensure system economics. Also note that the monthly COP for HP1 (= 3.76–4.09) is slightly higher than that for HP2 (= 3.50–3.66) and HP3 (= 3.13–3.53). Further, the system economics is of interest. A simplified break-even analysis is given as below. Note that the maintenance cost and annual price change of the substituted fuel is not included. The initial cost for the SWHs and heat pumps is 2.15 and 1.15 million NT$ (1 US$ ≈ 31 NT$), respectively. The subsidies for the SWHs, based on the area of solar collectors installed, was approximately 0.7 million NT$ by the BEMOEA and Yunlin County. Further, the sales price of low sulphur light fuel oil was 22,779 NT$/kL in 2014, and its heating value is 40.19 MJ per liter (BEMOEA, 2014). Taking heating efficiency of 80%, the substituted fuel savings is estimated to be approximately 0.4 million NTD/year. Therefore, the payback period is estimated to be 6.5 years, which is less than the expected service period of a SWH (≈ 15 years). This validates the financial viability for a combined solar thermal and heat pump system for industrial heat process. As mentioned previously, the thermal performance of a SWH is associated with the entering water temperature and water consumption pattern. From April to June, the useful energy gain by the SWHs and HPs are shown in Table 1. For SWHs, the collected solar energy was 44,282 MJ and 58,109 MJ for system 1 and system 2, respectively. Since HP1 was least used or usually kept off in the measurement period, the ratio of collected solar energy divided by total supplied energy of the combined system is 70.8% and 27.8% for system 1 and system 2, respectively. In Table 1, it is also found that only 68% of total collected energy for system 2 was consumed. Inadequate operation of HPs is the major concern and should be taken into account to realize energy savings. Heat loss from the storage tank and piping to the environment during the night hours is also needed to be addressed. Further, the electricity consumption for the circulation pump of system 2 is sufficiently higher than that of system 1. Thus, a suitable control strategy is definitely required to ensure efficient energy savings of the system. Nevertheless, the net energy savings in the period of March 25 to June 30 was 150,655 MJ (or 1,537 MJ/day).

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Tab. 1: Energy collection and consumption (March 25-June 30)

	system 1	system 2	Sum
Collected energy, SWHs, MJ	44,282	58,109	102,391

Collected energy, HPs, MJ	18,271	150,691	168,962
Total collected energy, MJ	62,523	208,800	271,353
Energy consumption, MJ	62,523	142,350	204,873
Circulation pump, kWh	195	1,129	1,323
Heat pumps, kWh	1,422	13,654	15,076

Tab. 2: System operating performance

		System 1		System 2		
Month	**G, MJ/m^2**	η	**COP-HP1**	η	**COP-HP2**	**COP-HP3**
April	10.72	0.170	3.76	0.260	3.50	3.13
May	13.81	0.272	4.22	0.419	3.51	3.35
June	14.18	0.277	4.09	0.351	3.66	3.53

4. Conclusions

The renewable energy usage is critical for its economic development and reduction in greenhouse gas emission. Also thermal uses constitute one of the major types of energy consumption. The need of raising solar thermal energy as a significant energy source is important. So far, solar water heating is the most successful account of renewable energy application for domestic hot water preparation in Taiwan. In the commercial sector, industrial process heating is a very promising application for SWHs. In addition, there are more systems with the combination of solar collectors and heat pumps available on a commercial level during the last decade. Therefore, field measurements of a combined system installed in a slaughterhouse were conducted in this study. The results identify the system as a suitable device for industrial heat process in livestock industry. A simplified break-even analysis also shows the financial viability. However, adequate operation of the system (circulation and heat pumps) is required to maximize energy savings.

Acknowledgements

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Despite the fact that solar water heating kits are much cheaper than they were couple of years ago, they are still considered expensive and luxury appliances especially is Provinces where electricity or natural gas are cheap (as in Quebec or Manitoba) and / or annual Solar Insolation is very low (British Colombia and Newfoundland).Â So making a smart piping system choice, is crucial for the long term feasibility and pay ability of every solar water heating project. Available Piping Options. There are an infinite number of available piping system in market, the right piping system shall have physical and thermal properties in excess of Solar Water Heating peak operating conditions (such as temperature, pressure, etc.â€¦). Conference: ISES Solar World Congress 2015. Authors: kung-Ming Chung. 31.07. National Cheng Kung University. Yi-Mei Liu. Keh-Chin Chang.Â Thermal performance evaluation of solar water heating systems in Australia, Taiwan and Japan â€“ A com April 2015 Â· Renewable Energy. Edward Halawa. Keh-Chin Chang. M. Yoshinaga. Read more. Last Updated: 28 Sep 2020. Solar water heating systems can be used to provide space heating in addition to domestic hot water. These systems are common in Europe and are referred to as â€˜solar combisystemsâ€™. In Germany and Austria in particular, this technology is widespread and make up ~60 % of the solar collectors installed in these counties each year.Â 6.4) while the SWHs, which are fitted with heat exchangers, are called indirect systems (shown in Fig. 6.5 [16]). In a direct system, the service water is directly circulated between the water tank and the collector, while in an indirect system, a heat transfer fluid, usually antifreeze, distilled water, or an organic fluid, is circulated through the solar collector. The solar water heater tank is a non-pressurized tank, and has an opening to the ambient atmosphere. Solar water heater tank should always be filled with water to avoid damage caused by dry high temperature working conditions.Â 6. Ideal for many solar water heating applications. 7. Can be used for heating water, room and floor. Factory Supplier pressurized solar water heatersolar powered livestock water heater with A Discount. US $80.00-$500.00 / Set.Â About product and suppliers: 949 solar powered livestock water heater products are offered for sale by suppliers on Alibaba.com, of which solar water heaters accounts for 10%, electric water heaters accounts for 1%. A wide variety of solar powered livestock water heater options are available to you, such as direct-plug, split.