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Investigation of Solar Roof Collectors for Preheating of Air at Drying Facilities in Northern Thailand

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Abstract

Longan is an important product in Northern Thailand that is a supporting component for the local economy. A significant amount of the annual harvest is dried and commercially exported as a commodity. Conventional longan drying is done in convection dryers at a temperature of 80° C using liquefied petroleum gas for heating the air. The increasing price of such fuels threatens the competitiveness of Thai longan in the international market. Nevertheless, with the ample solar radiation in Thailand, the roofs of the drying facilities could be adapted to serve as solar collectors to preheat the drying air and reduce the energy requirement from fossil fuels.

In this study, eight longan drying facilities were surveyed to collect general information and measure roof characteristics and process parameters. Simulations were made using a mathematical model for a solar air heater. The thermal output that can be achieved throughout the drying season was estimated for each facility with different collector sizes and air channel heights. The potential monetary savings were estimated based on current fuel prices.

Results showed that, under average weather conditions, solar air heaters can provide a temperature rise between 14 and 33° C during midday with entire roofs serving as collectors and an air channel of 10 cm. Solar collectors can replace up to 19.6% of the thermal energy demand during the drying season. Bigger collectors and smaller air channels result in more useful heat, but attention has to be paid to costs and pressure drop, respectively. Annual monetary savings can reach up to THB 56,000 (≈ US$ 1,800 at US$ 1 = THB 31).

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Introduction

Fruit production and trade is an important component of the Thai economy. Longan is one of the fruits with more harvested area reaching almost 100,000 ha in 2003 (Office of Agricultural Economics). Together, fresh and dried longan make up around 90% of longan exports in monetary terms. From January to September 2007, total longan exports amounted to 3.26 billion THB, of which dried longan was some 954 million (Ministry of Commerce 2007). Longan production occurs mainly in the northern region of the country, and Chiang Mai is the most important producing province with a share of around 35% of the country's total. Usually, small to medium scale facilities dry unpeeled longan in fixed bed convection dryers using liquefied petroleum gas (LPG) as thermal energy source to heat the drying air to around 75 to 80° C. These dryers have a capacity of 1400 to 2500 kg of fresh product and one batch takes 48 to 72 hours to dry. Thus, this process demands a significant amount of energy.

Although world prices of petroleum and its products have been rising steadily, the LPG market in Thailand has been controlled by the government by means of subsidies. However, in 1999 a program started to deregulate this market and this process is expected to be finished in the near future (Ministry of Energy 2007). As a result, one of the main concerns at longan drying facilities is the cost of the fuel. If the LPG price increases substantially in the near future due to a complete market deregulation, the competitiveness of Thai dried longan in international markets could be affected. However, alternative energy sources like biomass and solar can be employed in drying processes in order to partially or completely replace fossil fuels. The use of solar energy is especially interesting in cases where high availability of solar radiation and energy demand coincide (Keller & Kyburz 1987). Although Thailand is located close to the equator, and has several dry months per year, the in-season longan harvest (when most of the dried production occurs) takes place in months with frequent and heavy rains and highly variable levels of radiation. This does not allow a beforehand affirmation that solar drying is feasible for this case. Therefore, the aim of this study was to investigate the potential of solar energy to preheat air for longan drying in Northern Thailand using roof-integrated solar air heaters.

Materials and methods

Eight longan drying facilities of varying capacity from 2 to 21 dryers were surveyed in Chiang Mai province. Interviews using questionnaires were carried out with the facility operators to collect general information about the process, how it is managed, drying equipment, current fuel demand and the drying procedure. Roof dimensions and their azimuth and slope angles were measured. Average air speed out of the longan bed was measured with a hot-wire anemometer to calculate the airflow rate. Locally available materials to serve as insulation and transparent covers for solar collectors were determined, and their prices and their relevant physical properties were documented. A mathematical model programmed in Fortran was used to simulate the thermal performance of a flat-plate single cover solar air heater with flow over the absorber. This model was integrated into TRNSYS 15 software to simulate a collector/auxiliary heating system. An hourly weather data file with the typical meteorological conditions throughout the year for the city of Chiang Mai was utilized.

Single-day simulations were done for each facility under cloudy, average and sunny conditions during the harvest season. The collector size was set equal to the entire roof area of each facility and the air channel height to 10 cm. Seasonal simulations were done for different collector sizes up to the whole roof area. Air channels were set to 15, 10 and 5 cm to determine the difference in output. The average calculated utilized capacity of each facility was also considered to set an average total airflow rate requirement. Outputs from the simulations were hourly temperature rise, total radiation on collectors, useful energy and auxiliary heating required to meet the required drying temperature. Additionally, the pressure drop through the solar air heaters was calculated for each case using mathematical equations for non-circular ducts. Collector efficiency and solar fraction were calculated, and given the current LPG price in the study region and its heating value, monetary savings could be estimated.

Results

Solar radiation in Northern Thailand varies greatly during the longan drying season, which usually lasts about two months. In this time, the weather changes from cloudy and rainy days with less than 10 MJ/m^2 to very sunny days with up to 25 MJ/m^2. Figure 1 shows radiation, ambient temperature and collector outlet temperatures for two surveyed facilities if their entire roofs were used as solar collectors with an air channel of 10 cm. The usual drying temperature of 80° C is also shown. For these two facilities the temperature rise was of 14.3 and 32.9° C. All other facility curves lie between these two.

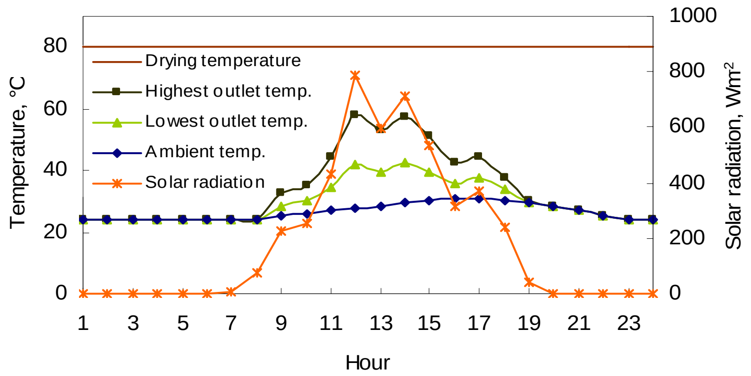

Figure 1. Collector outlet temperatures during an average day (16.6 MJ/m^2) for the two facilities with highest and lowest temperature rises. Entire roofs used as solar collectors.

During the drying season, flat-plate solar air heaters can supply a fraction of the thermal energy demand depending on collector size, required airflow rate and air channel height as shown in Figure 2. Here, the airflow rate through the collectors was calculated for each facility according to their average utilized capacity. This utilized capacity ranged from 16 to 80%, which indicates something about the difference in management between these facilities. It is seen that solar fraction rises asymptotically with collector area, tending toward a maximum for each facility. When the air channel decreases the performance improves giving higher solar fractions.

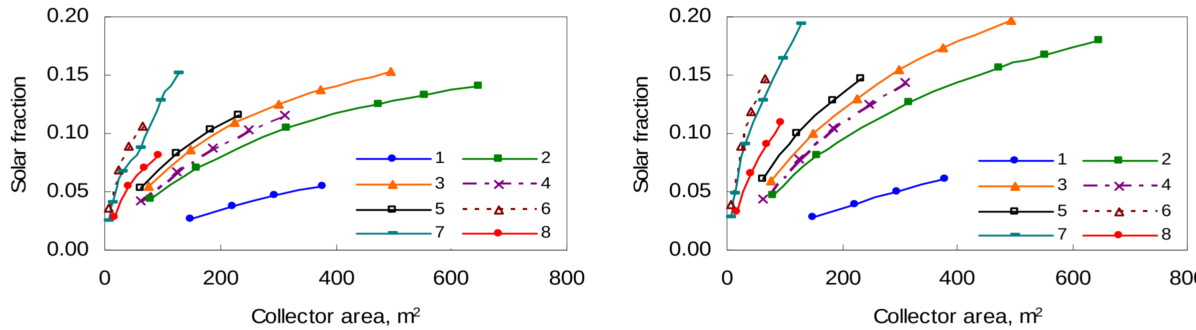

Figure 2. Seasonal solar fraction for the eight facilities according on collector area. Air channel of 10 cm (left) and 5 cm (right).

Economic savings provided by solar collectors simulated in this work are shown for four facilities in Figure 3. Facility 1 obtains the most benefit with up to THB 56,284. As collector size decreases and air channel height increases, savings drop. Figure 3 also shows the local cost of polycarbonate cover and fibreglass insulation, which were the best options to construct solar collectors considering availability, price and physical properties. It is evident that the relation of material costs to economic savings grows as collector area increases.

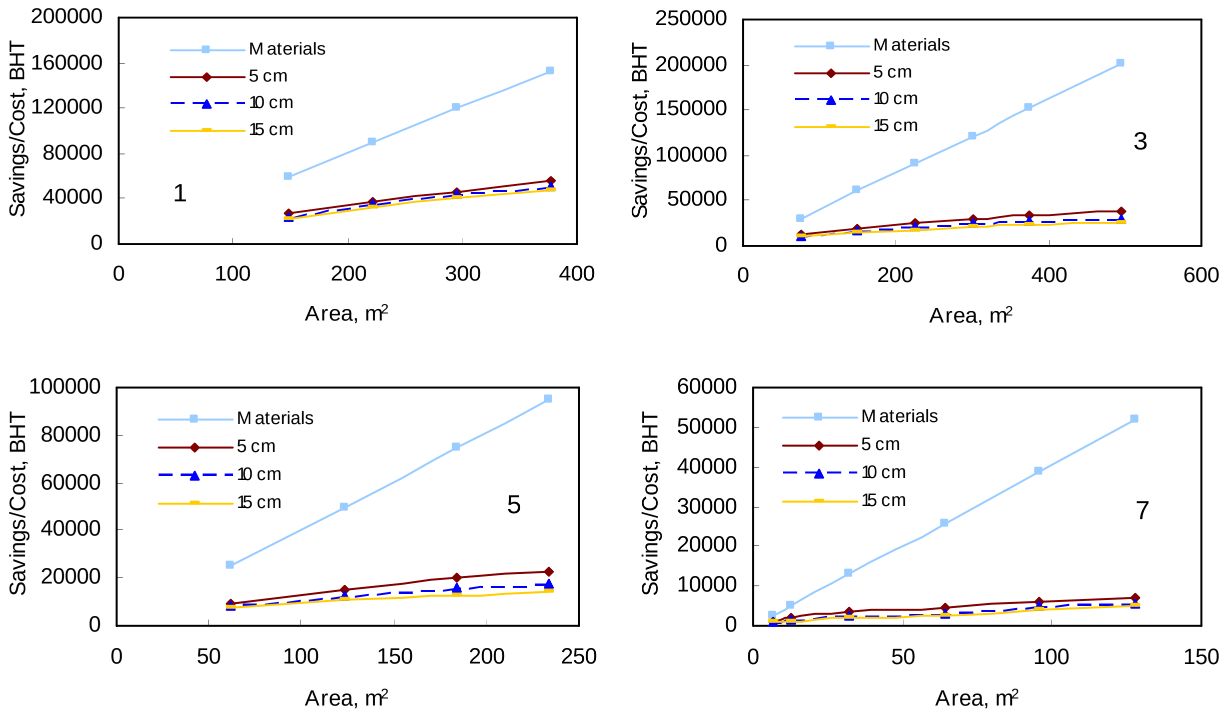

Figure 3. Monetary savings and cost of cover and insulation materials for Facilities 1, 3, 5 and 7 according to collector size and air channel height.

Discussion

Since longan drying is usually a 24 hours operation and the radiation levels during the season vary significantly, auxiliary heating with other energy sources like fossil fuels or biomass would still be required. Even at midday hours on optimal days, solar air heaters alone could not heat the air to the required drying temperature. However, solar energy can provide a good fraction of the energy demand, especially during average or very sunny days, reducing LPG expenses.

The asymptotical behaviour of the solar fraction with increasing collector areas is explained by the fact that as collector size increases, the efficiency drops. With larger collectors, the last sections only render a small temperature rise (Keller & Kyburz 1987). Facility 1 was the biggest facility with 21 dryers and the one that works the closest to maximum production capacity. Because of this, its average required airflow rate and, therefore, energy demand was by far the greatest. That is why this facility shows the smallest solar fraction in Figure 2.

Reducing the air channel height significantly improves the performance of collectors, but on the other hand, increases the pressure drop through them. Therefore, there is an optimum channel height which corresponds to an efficient system, in both the thermal and the electrical aspects (Choudhury et al. 1988). This also depends on the characteristics of the fan that is moving the air, which should be investigated in order to set a maximum acceptable pressure drop. When solar collectors are installed, ducts are necessary to join them to the dryers. These ducts create additional pressure drop that should also be accounted for. During passage through these ducts, air temperature can drop several degrees (Janjai & Tung 2005). Measures must be taken to minimize these effects by appropriate sizing of the ducts and insulation.

Although larger collectors provide the highest monetary savings, they require larger investment. Smaller air channels provide more savings with the same collector size, which means same costs. Channels should be as small as the pressure drop allows. It must be noted that from the results above, Facility 1 had the lowest solar fraction and, nevertheless, showed also the highest potential for monetary savings. This is because this factory is the largest and the most efficiently used, so a relatively small solar fraction becomes important when converted to absolute economic values. Others, like Facility 3, also showed important potential savings, but with comparatively larger collectors, which supposes higher investment costs and a longer payback period. For economic feasibility, it is important to maximize the use of the equipment both during the longan drying season and throughout of the year. Currently, all facilities surveyed operate only for drying longan. It would be a big advantage for these factories to utilize the equipment year-round. That way the payback time for the investment would be significantly reduced (Hollick 1999). This is especially true in the presented cases, because during other periods of the year, Thailand has a dry season when the solar radiation is much higher and less variable.

Conclusions

Climatic conditions are highly variable during the longan drying season, and so would be the potential thermal output of solar collectors used at this time in this region. For a given collector area, smaller air channels result in more useful energy. Therefore, optimum sizing of solar air heaters for a given facility must include total area as well as channel height, the latter of which should be reduced as much as the created pressure drop allows. Monetary savings vary greatly between facilities. A higher solar fraction does not mean higher absolute savings and more important is maximizing use of the equipment. Some facilities could save significant amounts of money by substituting part of the fossil fuel requirement with solar energy. Longan drying lasts less than two months each year. For solar energy to be more feasible, drying facilities should operate over a longer period each year. The use of these facilities for rice drying during other seasons might be a feasible solution.

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