Review of Research and Development Work on Forced Convection Solar Drying in Thailand

Somchart Soponronnarit
School of Energy and Materials
King Mongkut's Institute of Technology Thonburi
Bangkok, Thailand

ABSTRACT

Research and development work on solar forced convection drying conducted in Thailand during the past ten years was reviewed. Technical and economic results indicated that solar drying for some crops such as paddy and multicrops was feasible. However, farmers' acceptance of solar drying was still very limited. This may be due to a too long pay back period or to socio-cultural factors. Further research and development work should be continued in order to reduce cost and increase reliability. Research into the barriers to acceptance by farmers should also be carried out.

INTRODUCTION

It is generally accepted that drying is one of the most efficient and economic methods of food preservation. The traditional method of drying crops at farm level in Thailand is open-air drying. At the industrial level, however, they may be mechanically dried with circulated air when quality has to be high or spoilage must be avoided.

A drying unit usually comprises a drying chamber, a fan to circulate air through the drying product, and a heater if hot air is needed. Fuel for heating air may be available from electricity, gas, kerosene, fuel oil, agricultural wastes, or solar energy, etc.

Research and development work on solar drying has been undertaken in Thailand since the last decade. The type of solar drying units covered includes direct/indirect drying, natural/forced convection, and products covered include cereal grain, fruit, tabacco, meat, marine product, etc. A solar natural convection dryer requires a smaller amount of investment compared to a solar forced convection dryer. Also, it is simpler to operate and maintain. However, drying rate is slower because of lower air flow rate. In addition, a high quality of product is sometimes more difficult to obtain if it rains or there is no sunshine. These problems were highlighted in a study of a solar natural convection dryer used for drying fruits such as bananas and tamarind, etc. in a small food processing plant in Phitsanuloke province. The dryer performed quite well during the summer but did not reach the required standard during the rainy and winter seasons. During the rainy season, there was not enough sunshine and excessive moulds occured. During the winter, sunshine was sufficient but the temperature inside the dryer was not high enough to kill the eggs of insects (Rakwichian, 1987).

Recently, Ong (1986) presented a state-of-the-art report on solar drying in ASEAN countries. Wibulswas (1984) also reviewed the development of solar drying in Thailand. As research and development work has made significant progress, it seems that a review of recently developed solar drying units is appropriate.

The objective of this paper is to review the research and development work on forced convection solar drying conducted in Thailand during the last ten years. It is hoped that this review may be useful for further development work.

FORCED CONVECTION SOLAR GRAIN DRYING

Thongprasert *et al.* (1983) conducted research on solar paddy drying. The solar collector had a plywood casing 10 mm thick, a corrugated galvanized iron sheet was used as an absorber. There was styrofoam 25 mm thick under the absorber. The transparent cover was made of clear glass. Air flowed in the gap between the transparent cover and the absorber in a perpendicular direction to the corrugation. The dimension of the collector was 1.55 m x 1.12 m x 0.21 m, and it was installed at an angle of 15° facing south. Approximately 50 kg of paddy was dried by the ambient air which was forced by a blower through an air heater and heated up to 31- 40.9°C. The moisture content was reduced from 17.4-18.7% wet basis to 14% wet basis in 2.75 - 4.25 hours. An air flow rate of about 55 m^3/min per cubic metre of grain was measured. The thermal efficiency of the collector was 79%. A mathematical model of the system comprising drying chamber and solar air heater was formulated. The simulation results were obtained through the aid of a computer.

A solar hut dryer was developed for grain drying (Soponronnarit and Tiansuwan, 1984a and Soponronnarit, 1984). It comprised a storage hut and a forced convection solar air heater. The hut had a floor of 2.4 m x 3.6 m and a height of about 2.0 m. A fixed vertical-bed drying bin was installed inside the hut. The 3.7 m wide x 5.1 m long solar air heater had a galvanized iron sheet which acted as the absorber and also the roof of the hut. A styrofoam sheet of 25 mm thick was placed at a distance of 20 mm beneath the absorbing plate. Air was forced through the dryer by an electrically driven fan (Fig. 1).

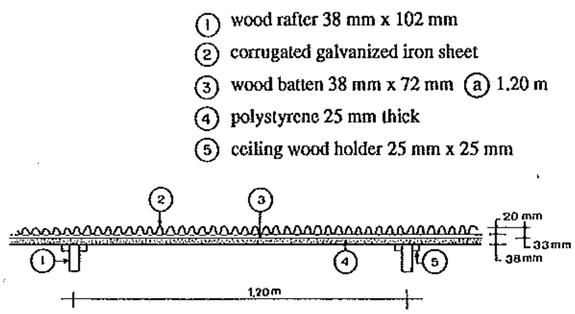


Fig. 1 Cross - section of the solar collectors, Soponronnarit *et al.*, 1986 (perpendicular to the direction of air flow).

Collector tests with an air flow rate of 0.34 kg/s indicated that the maximum efficiencies of unpainted and black painted collectors were 30 and 34% respectively. The absorber plate was left unpainted for grain drying because of preferred lower cost. Drying results during dry season showed that 1 ton of paddy could be dried from 22% to 16% moisture content (dry basis) in 1 day. A 24-hour air circulation was employed with only ambient (unheated) air being circulated during periods of no sunshine and through the night. Energy consumption was estimated to be 4.5 MJ/kg of water evaporated.

A mathematical model for predicting the performance of the solar air heater was developed. It was found that the simulated and experimental results were in good agreement. A mathematical drying model was also developed (Tiansuwan, 1984).

At the end of 1984, the National Energy Administration of Thailand launched two projects involving an economic evaluation of solar rice dryers. With regard to the first project details of the research can be found in Soponronnarit *et al.* (1985) and Soponronnarit *et al.* (1986). An integrated paddy drying-storage solar hut functioning as a solar dryer and storage unit was constructed and tested at a farmer's house in Kampaengsaen, Nakornpathom province. (Fig. 2 and Fig. 3). The unit was easy

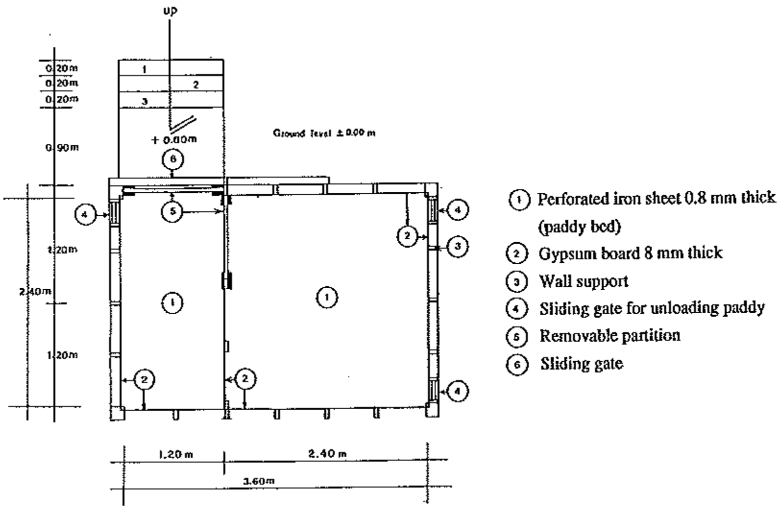


Fig. 2 Plan of the solar hut's floor, Soponronnarit *et al.*, 1986.

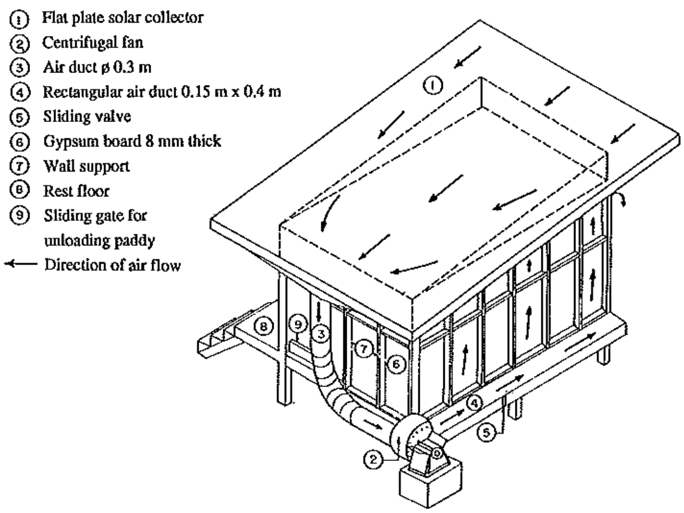
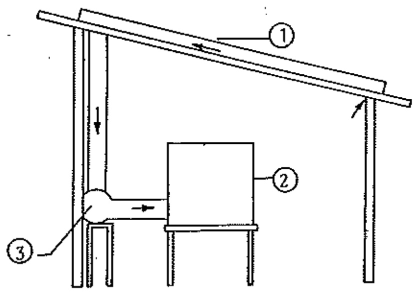


Fig. 3 Isometric 30° showing the solar hut, Soponronnarit *et al.*, 1986.

to construct and operate, both for loading and unloading. It cost about 27,600 Baht of which 21,600 Baht was material cost, except for the engine, which could be made available from a walking tractor, or an electric motor could be used if electricity was available. In operation, air was sucked from a bare plate solar air heater (same as that in Fig. 1) modified from the roof by a centrifugal fan and delivered through an air plenum which was underneath a perforated steel sheet. It then passed through the paddy bed, in which heat and mass transfer took place. When an engine was used to drive the fan it required about 1.13 and 2.08 litres of diesel oil per ton of dry paddy per one per cent wet-basis of moisture reduced for the first crop and second crop respectively. The corresponding drying rate was 0.64% and 0.3% wet-basis per ton of dry paddy per hour. The maximum storage capacity was 10 tons.

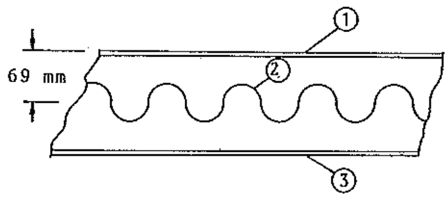
Collector test with air flow rates ranging from 0.50 to 0.76 kg/s indicated that the daily efficiency varied from 7-29%. A very high fluctuation of efficiency resulted from variation of air flow rate and wind speed above the solar air heater. It was noted that the efficiency was very low when wind speed was high. Thus, the bare plate solar air heater should not be used in regions where wind speed is high.

The second project launched by the National Energy Administration of Thailand was conducted by Thongprasert et al. (1985). A solar dryer was constructed and tested at a farmer's house in Pathumthani province. The schematic diagram of the system is shown in Fig. 4. It was composed of 3.74 m wide x 4.48 m long solar air heater (Fig. 5) and a vertical fixed bed drying bin having a capacity



① Solar air heater
② Drying bin
③ Blower
→ Direction of air flow

Fig. 4 Solar dryer developed by Thongprasert *et al.* (1985).



① glass cover
② absorber
③ asbestos cement

Fig. 5 Cross-section of the solar collector developed by Thongprasert *et al.* 1985 (perpendicular to the direction of air flow).

of 1.2 tons of paddy. Air flowed through the solar air heater, between the glass cover and the absorber, and then downward through the drying bin.

Drying tests with an air flow rate of 0.82 kg/s indicated that one ton of paddy could be dried from the moisture contents of 17-21% wet-basis to 14% in 1-4 days, depending on weather conditions. The efficiency of solar air heater varied from 40-70%. Average electrical energy consumption for a blower was estimated to be 7 kWh per drying batch. Compared to paddy dried in the open-air, the quality of paddy dried in the solar dryer was better.

SOLAR TOBACCO CURING

The process of flue-curing involves promoting the yellowing of the leaves and preventing them from becoming brown. This is done by controlling the temperature and relative humidity so that after about four days of gradual increase in temperature and the commensurate reduction in relative humidity, the final product is in the form of golden to yellowish dried leaves with 10-20% moisture content.

Solar-assisted curing of tobacco leaves was developed by Boonlong *et al.* (1984). The experimental prototype system consisted of a 3.6 m x 3.6 m x 4.8 m scaled-down (1:4 scale) tobacco curing barn with 1 ton fresh leaves loading capacity (Fig. 6), an array of 38.5 m^2 flat-plate solar air heaters (Fig. 7), and a 6 m^3 rock-bed unit. Forced convection was induced through the system by one 1.5 kW and one 0.75 kW blower. LPG was used directly as an auxiliary heating fuel.

Experiments using only LPG as a fuel for curing tobacco leaves were initially carried out. The results from four tests produced an average LPG consumption of 0.63 kg, or an equivalent of 28.9 MJ per kg of cured leaves. From the three solar-assisted tests, an average LPG consumption of 0.48 kg

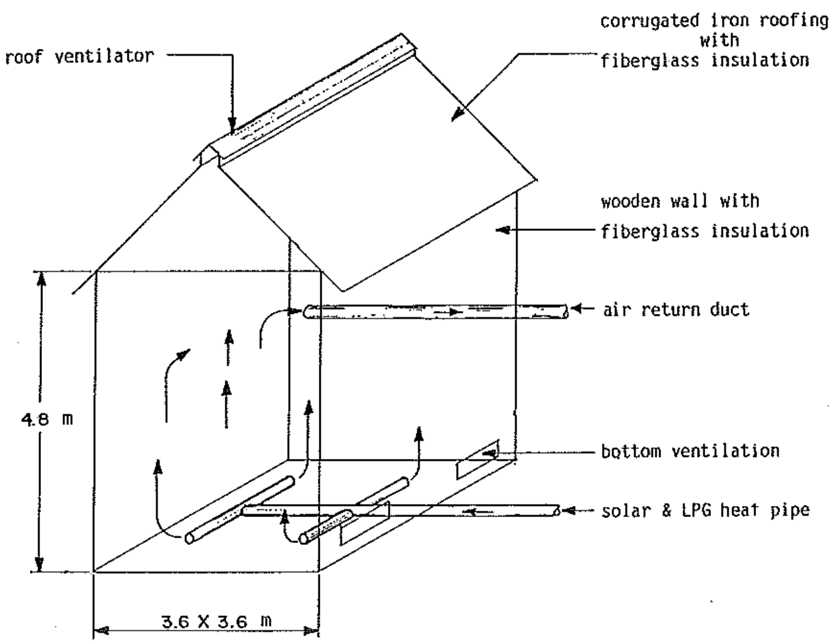


Fig. 6 The modified prototype tobacco curing barn, Boonlong *et al.*, 1984.

or 22.2 MJ per kg of cured leaves was achieved. Comparing results of the three solar-assisted test runs with a similar LPG run, it was found that an average fuel saving of about 28% was possible. An average overall curing thermal efficiency was found to be 40.5%. The usefulness of a rock-bed thermal storage unit was still inconclusive.

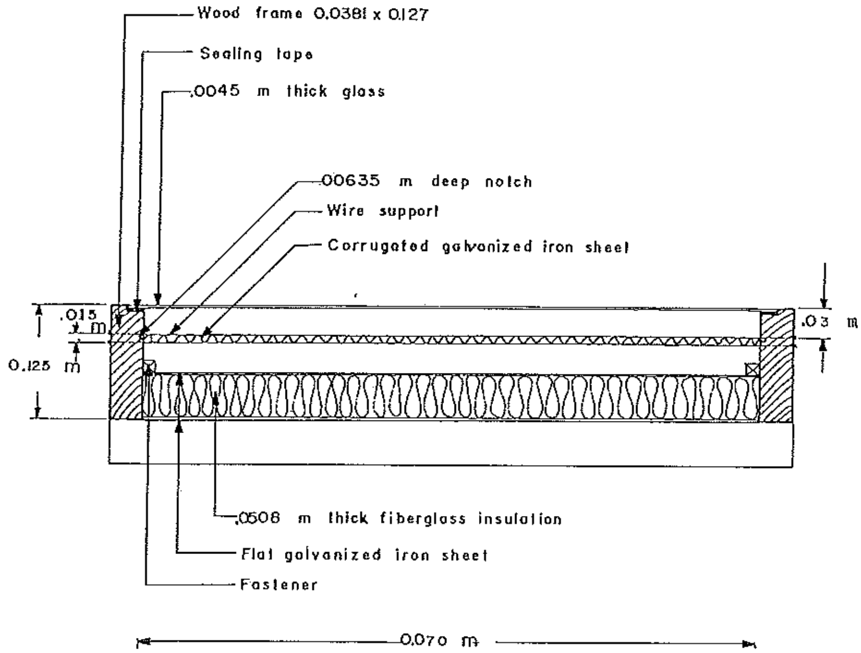


Fig. 7 Cross-section view of the solar air heater, Boonlong *et al.* 1984.

FORCED CONVECTION SOLAR FRUIT DRYING

The solar tobacco curing barn described in the previous section was converted into a dryer for other crops (Sitthiphong *et al.*, 1987). The main objective was to increase the utilization of the dryer from a limited seasonal use to a year-round basis, which should help increase its economic attractiveness. The drying experiments included two crops, i.e., 5 runs of tobacco curing and 2 runs of longan drying. The loading capacity of the dryer was 1000 kg of fresh tobacco leaves, or 700 kg of fresh longan fruits.

Drying results indicated that solar energy accounted for 25-30% of the total energy consumed. These figures were achieved by comparing the energy consumption between drying or curing using LPG alone and drying or curing using solar energy plus LPG. Thermal efficiencies of tobacco curing and longan drying were estimated to be 36-43% and 23-24%, respectively. Or in terms of energy consumption per kilogram of water evaporated, they were 5.5-8.0 MJ/kg water evaporated and 12.3-13.2 MJ/kg water evaporated for tobacco curing and longan drying, respectively.

ECONOMIC AND SOCIAL ASPECTS OF SOLAR DRYING

On the basis of the benefit received from LPG fuel saving, Sitthiphong (1987) showed that the benefit/cost ratio of solar-assisted tobacco curing was 0.63. This ratio increased to 1.34 when longan fruit was dried in the same dryer. It was estimated that utilization of the dryer was increased from three months for curing tobacco only to six months per year when longan was dried after the tobacco curing season. The pay back period for the latter case was 7 years.

Economic evaluation of solar hut dryer (developed by Soponronnarit and Tiansuwan, 1984a, done by Soponronnarit and Tiansuwan, 1984b) indicated that it was economical when the benefits were obtained from 7% reduction of paddy loss, better price of dry paddy, and also better price after 5 months of storage. The minimum economical cultivation area was 17 rai (1 ha ≈ 6.175 rai, paddy yield was about 0.5 ton per rai or 3.12 ton per hectare) and two crops per year had to be practiced. It was not economical for a paddy field where only one crop per year was cultivated.

Soponronnarit *et al.* (1985) also indicated that the drying-storage solar hut was economical only for the paddy field where two crops per year were cultivated. Employing assumptions similar to those used in the economic evaluation of the solar hut dryer, it was found that the cultivation area should be 9-27 rai (0.5 ton of paddy per rai) and the pay back period was 2.3-14.8 years.

Theeravanichkul (1987) also conducted an economic evaluation of the drying-storage solar hut. However, he assumed that there was no benefit from the reduction of paddy losses. The results indicated that it was economical but much less attractive.

Thongprasert *et al.* (1985) divided paddy fields into several small plots. Loss assessment during the chain of post-harvest production was done. The results indicated that the paddy yield obtained from the field of which the paddy would be dried by the solar dryer was about 7-10% higher than that obtained from the field of which the paddy was open-air dried. Assuming this was only the benefit, it was concluded that the solar paddy dryer was economical. It was much less economically attractive when the benefit only came from better price of dry paddy.

Solar dryers appear to be not commercially used or accepted by farmers except in Phitsanuloke though the economic analysis indicated that they were economical. This may be due to a too long pay back period. Or it may be due to certain socio-cultural factors. Amyot and Sirisambhand (1982) discussed the reasons why a solar paddy dryer (natural convection) at farm level was not accepted by Thai farmers. Some of the barriers to wider use of solar farm dryer pointed out at the meeting on "Solar Drying" held at FAO Bangkok are as follows (Anon, 1986):

1). Initial cost - poor farmers cannot afford them.
2). Lack of durability - constant breakdown due to using low cost building materials.
3). Misuse - due to lack of training and technical skills.
4). Lack of dependability and reliability - during the wet season when drying is critical solar energy is not sufficiently available.
5). The wider use of solar drying system has been limited by other factors which are not necessarily of a technical or technological character.

Also, suitable designs of solar dryers were identified as follows (Anon, 1986):

1). Large-scale dryers capable of handling tonnes of material are more promising than small-scale ones rated in the order of kilogrammes.
2). The dryer should be designed to have a maximum utilization factor of the capital investment, i.e. multi-product and multi-use.
3). In general, an auxiliary heat source should be provided to assure reliability, to handle peak loads and also to provide continuous drying during periods of no sunshine. Rock-bed storage is not considered viable.

4). Forced convection indirect dryers are preferred because they offer better control, more uniform drying and because of their high heat collection efficiency. However, parasitic power should be kept to a minimum.
5). Retrofit systems should be examined.

CONCLUSIONS

Solar drying of some crops such as paddy and multicrops, fruit and tobacco, has proved technically and economically feasible. However, there is limited acceptance of solar dryer among farmers. This may be due to too long pay back period or it may be due to socio-cultural factors.

RECOMMENDATIONS FOR FURTHER DEVELOPMENT

Development of large-scale solar drying is attractive economically. The system should be designed to have maximum utilization factor, i.e. multi-product and multi-use in order to share the cost of dryer. An auxiliary heat source and forced convection are recommended for assuring reliability and better control, respectively. Products having high value added may significantly increase economical attractiveness.

REFERENCES

Amyot, J., and N. Sirisambhand (1982), *Social and Economic Factors in the Process of Technology Transfer*, Chulalongkorn University, Social Research Institute, Bangkok.

Anon (1986), *Solar Drying in ASEAN Countries*, RAPA Publication : 1986/27, FAO, Bangkok, pp.2-3.

Boonlong, P. *et al.* (1984), Solar-assisted tobacco curing, Paper presented at the *Regional Seminar on Solar Drying*, Yogyakarta, Indonesia, 28-30 August.

Ong, K.S. (1986), *State-of-Art Report on Solar Drying in ASEAN Countries*, RAPA Publication: 1986/27, FAO, Bangkok.

Rakwichian, W. (1987), *Development of Industrial Fruit Dryer*, Research Proposal submitted to the National Research Council of Thailand.

Sitthipong, N. *et al.* (1987), *Large-Scale Solar-Assisted Multiple-Crop Dryers*, Department of Mechanical Engineering, Chiang Mai University, Chiang Mai, Thailand.

Soponronnarit, S. (1984), *Forced Convection Hut Drying*, Final report, USAID-Thai Renewable Non-conventional Energy Co-operation Project, KMITT, 110 p.

Soponronnarit, S. and J. Tiansuwan (1984a), Low cost solar air heater : Application to paddy drying, *Proceedings of the Regional Seminar on Simulation and Design in Solar Energy Applications*, King Mongkut's Institute of Technology Thonburi, Bangkok, Thailand, 8-11 May 1984.

Soponronnarit, S. and J. Tiansuwan (1984b), Technical and economic evaluation of a forced convection solar hut dryer, Paper presented at the *Regional Seminar on Farm Machinery and Rural Industry*, Seaview Hotel, North Pattaya, Thailand, 26-28 November 1984.

Soponronnarit, S., W. Watabutr, A. Therdyothin, and B. Kunjara (1985), *A Feasibility Study of Solar Paddy Drying*, Final report submitted to National Energy Administration of Thailand (in Thai).

Soponronnarit, S., W. Watabutr, A. Therdyothin, and B. Kunjara (1986), A drying-storage solar hut: the technical aspect, *Renewable Energy Review Journal*, Vol. 8, No. 1, pp.49-60.

Theeravanichkul, Y. (1987), *Technical and Economic Evaluation of a Paddy Drying-Storage Solar Hut*, M.Sc. Thesis, KMITT, Bangkok (in Thai).

Thongprasert, S. *et al.* (1983), *Solar Rice Dryer*, Research Project No. 34, AMRD, 1978, Faculty of Engineering, Chulalongkorn University, Thailand (in Thai).

Thongprasert, S. *et al.* (1985), *An Economic Study on Solar Rice Dryer*, Final report submitted to National Energy Administration, Bangkok (in Thai).

Tiansuwan, J. (1984), *Low-Cost Solar Air Heaters for Drying Paddy*, M. Eng. Thesis, KMITT, Bangkok (in Thai).

Wibulswas, P. (1984), Recent development on solar drying in Thailand, Presented at the *Regional Seminar on Solar Drying*, Gadja Mada University, Yogyakarta, Indonesia, August 1984.