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Solar Drying in Thailand

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ABSTRACT

Research and development work on solar drying conducted in Thailand during the past fifteen years was reviewed. Technical and economic results indicated that solar drying for some crops such as paddy, multicrops and fruit was feasible. However, farmers acceptance of solar drying was still very limited in numbers and places. This may be due to a too long pay back period and high initial investment cost. Research and development work on solar air heater was also reviewed. Most of the solar air heater developed in Thailand was modified from a roof of a building. Both bare and glass covered solar air heater were technically and economically feasible when compared to electricity but could not compete with fuel oil. Further research and development work should be continued in order to reduce cost. A standard test of solar air heater should be developed.

Key Words: Solar drying, solar air heater, solar collector

INTRODUCTION

Drying is one of the most practical method in preserving quality of agricultural product. Direct sun drying has been practicing since ancient time. However, it is not suitable for some hygienic product which is easily contaminated in open air. In addition, it depends upon weather condition because there is no shelter for preventing product from rain. As a result, new drying methods with conventional heat sources have been widely developed and used in order to solve these problems. Due to energy crisis and intensive energy consumption in drying process, solar drying has been studied widely in many countries in order to reduce cost and substitute conventional energy. Thailand is one of those which activities of research and development work on solar drying have been carried out over 15 years. The outcome of this effort is the acceptance of some simple-designed solar dryers by farmers though the amount of unit is not significant.

Review of research and development work on solar drying in Thailand was done by Wibulswas [13] and Soponronnarit [19]. In addition, Ong [8] presented a state-of-the-art report on solar drying in ASEAN countries. As work made progress, it seems that a new trial of review is appropriate.

The objective of this paper is to review research and development work on solar drying including solar air heater in Thailand. Important work from outside is selectively included. Timber drying and tobacco curing are not contained in this paper.

SOLAR AIR HEATER

A solar air heater may be defined as a device which converts solar radiation into heat in terms of increasing enthalpy of air. The device is usually very simple. It comprises an absorber which acts as an energy converter, air channel, and clear top cover as an option. While air is flowing through the air channel in the device, heat is extracted from the absorber to the air, resulting in a temperature rise or, in other words, hot air is obtained. The hot air may be used for space heating or drying. Given Thailand's hot and humid climate opportunities for space heating are extremely limited. However, this is not the case with drying by means of a solar air heater. The potential for accepting solar air heaters in the near future is relatively high and they may become as popular as the solar water heater, for which a local market now exists.

Foster and Peart [5] summarized the research and development work on solar grain drying in the United States of America. Several types of solar air heater have been developed and tested. They may be classified broadly into three categories: 1) flat-plate solar air heaters; 2) non flat-plate solar air heaters; and 3) integrated collector-storage heaters. A flat-plate solar air heater may consist of an absorber for converting solar radiation into heat in terms of increasing enthalpy of air, an air channel through which air flows and extracts heat from the absorber, a top transparent cover and bottom insulation for preventing heat loss, both of which are optional. Figure 1 shows three general types of flat-plate solar air heaters namely: a) bare flat-plate; b) transparent-cover flat-plate without still air gap; and c) transparent cover flat-plate with still air gap. The bare flat-plate solar air heater (Fig. 1 a) is the simplest and cheapest but the thermal efficiency, which depends strongly upon wind speed above the solar collector, is the lowest. Thermal efficiency is improved when the solar air heater is fabricated in the form of a transparent cover flat-plate without still air gap (Fig. 1 b). Fabrication is a bit more difficult and the cost is a bit higher. Thermal efficiency is even higher when a still air gap is introduced as shown in Fig. 1 c. However, its fabrication is the most difficult and its cost is the highest among the three types.

Flat-plate solar air heaters may be fabricated in modules and then installed on the ground or on a building roof. Roofs and walls of buildings can also be modified so that they become solar air heaters. In this case, the cost can be significantly reduced. For regions having low degree of latitude like Thailand, the installation of a solar air heater on vertical walls may not be appropriate because transmission and absorption may not be effective and this results in low thermal efficiency. For regions in the northern hemisphere, flat-plate solar air heaters should be facing south. Deviation from the south may be plus or minus 30 degrees without significant loss in total solar radiation. Inclination angle of the flat plate is usually equal to latitude or about 0.9 times latitude. However, it may deviate from the latitudeby about plus or minus 15 degrees without significant loss in total solar radiation.

Non flat-plate solar air heaters are air heaters constructed from plastic film which may or may not be inflated and which do not have a flat shape. Figure 2 shows some typical designs of inflated solar air heaters. This type of solar collector has the following advantages: its cost is low, it is easy to construct and can be kept off-site when not in use. However, rapid degrading of the plastic film seems to be a serious problem. Inflated solar air heaters are usually installed in the form of a long air channel. They can have an east-west or a north-south orientation.

The last type of solar air heater mentioned is the integrated collector-storage type. It consists of a solar collector and a rock heat storage connected together in series. Heat storage functions as a temperature regulator. When drying certain products, however, regulation of temperature may not be critical. Heat storage is hence not suggested. Soponronnarit and Peyre [20] compared, experimentally, the solar drying of sorghum without and with rock heat storage connected in series. Results indicated that drying rates for the two cases were not different. Therefore, heat storage was not suggested. It was also concluded by experts during a meeting on solar drying at the FAO office in Bangkok that rock heat storage was not considered viable [3].

In Thailand some research and development work on solar drying has been conducted. Most of the solar air heaters developed have been the flat-plate type and were aimed for agricultural drying purposes (Soponronnarit [19]). Solar air heaters employed in forced convection solar dryers were mostly made from corrugated galvanized iron sheet normally used in building roof (Thongprasert et al. [24], Soponronnarit et al. [22], and Boonlong et al. [12] or Sitthiphong et al. [10]). Solar air heaters which were integrated in natural convection solar dryers have also been investigated. These were plastic film solar air heaters used in an AIT solar rice dryer (Exell [17]), and a flat-plate solar air heater in a cabinet solar dryer (Wibulswas and Thaina [15], Patranon [16]). Due to natural convection of air through the solar air heater, air flow rate varies. Hence, thermal efficiency varies throughout the day. Solar collecting efficiency is usually less than that of forced convection.

Studies of bare and glass-cover flat-plate solar air heaters were conducted by Soponronnarit et al. [21]. The solar air heaters were developed by modifying the roof of a building (3.7 x 5.1 m) and having forms similar to Figures 1 a or 1 c. Experimental results showed that use of bare flat plate solar air heather was technically viable under low wind speed. Air speed inside solar air heater should be around 4-6 m/s, corresponding to the specific air flow rate of 0.015-0.023 kg/s per m^2 of the solar collector area (Figure 3). Use of transparent-cover flat-plate solar air heater was also technically viable with much greater efficiency under low or high wind speed. The same air speed inside the solar air heater should be used (Figure 4). Economic analysis indicated that there was a high potential for acceptance particularly when compared to electricity. It could not, however, compete with fuel oil (Figure 5). The mathematical models developed for both types of solar air heaters were for steady state conditions and was accurate enough for predicting thermal efficiency.

Biondi et al. [11] analysed theoretically how convective heat transfer coefficient in a solar air heater (h) depended on specific mass flow rate of air (G) and geometrical coefficient of the solar air heater (K), which was defined as K = (L/b)*D**0.25 where L, b and D were length, thickness of air channel and hydraulic diameter of the solar air heater, respectively. Results showed that the convective heat transfer coefficient, h = 0.0158*k*(G*K/μ)**0.8 where k and μ were thermal conductivity and dynamic viscosity of air, respectively. Thermal efficiency of a solar air heater depends significantly on the convective heat transfer coefficient. Details about the theory of solar air heater are available in Duffie and Beckman [7].

FORCED CONVECTION SOLAR DRYING

Solar drying may be divided into forced/natural convection or indirect/direct types. 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. A direct solar dryer is usually more efficient compared to an indirect solar dryer. However, drying temperature is difficult to control. In addition, it is not suitable to solar radiation sensitive product.

Forced convection solar grain drying has been studied in Thailand since 1983. At the end of 1984, the National Energy Administration of Thailand launched two projects involving an economic evaluation of solar paddy dryers. With regard to the first project details of the research can be found in Soponronnarit et al. [22] and Soponronnarit et al. [23]. 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 Nakornpathom province (Figure 6). In operation, air was sucked from a bare plate solar air heater modified from the roof by a centrifugal fan and delivered through an air plenam which was underneath a perforated steel sheet. It then passed through the paddy bed. When an engine was used to drive the fan it required, on the average, 1.6 litres of diesel oil per ton of paddy per one percent wet-basis of moisture reduced. The corresponding drying rate was 0.5 % wet-basis per ton of dry paddy per hour. The maximum storage capacity was 10 tons. Economic analysis, assuming that benefits were from reduction of loss and better price of paddy, drying-storage solar hut was economical only for the paddy field where two crops per year were cultivated. The cultivation area should be 1.44 - 4.32 hectares. The pay back period was 2.3 - 14.8 years.

The second project was conducted by Thongprasert et al. [24]. A solar dryer was constructed and tested at a farmer's house in Pathumthani province. The schematic diagram of the system is shown in Figure 7. It was composed of 3.74 m wide x 4.48 m long solar air heater and a vertical fixed bed drying bin having a capacity of 1.2 tons of paddy. Drying tests 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 condition. Average electrical energy consumption for a blower was estimated to be 7 kWh per drying batch. Economic analysis showed that the solar dryer was economical when reduction of paddy loss was accounted but it was much less attractive when the benefit only came from better price of dry paddy.

Acceptance of forced convection solar grain drying is limited due to several reasons which will be discussed later. Solar drying of fruit seems to be more attractive due to its value added after appropriate drying. A forced convection solar banana dryer was investigated in Pitsanuloke province (Assayo [9]). The unit comprised a drying cabinet covered by 12 m^2 of clear glass and 32 m^2 of flate plate solar air heater (Figure 8). In operation, warm air was drawn by a fan from the solar collector and was blown through a heat exchanger before entering the drying cabinet where solar radiation was absorbed by drying product. Experimental results showed that the first law efficiency of the solar dryer was linearly proportional to moisture content and dry mass of banana per unit solar receiving area. The maximum efficiency was about 30 % and occured at an average moisture content of about 220 % dry-basis and a dry mass of banana of 3.7 kg/m^2 of solar receiving area. Simple financial analysis showed that pay back period varied from 1.5 - 5.4 years. An empirical equation linking a relationship among efficiency, moisture content and dry mass was developed. Drying time for each batch was 7 days (6 hours/day).

Solar-assisted curing of tobacco leaves was developed by Boonlong et al. [12]. 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. 9), an array of 38.5 m^2 flat-plate solar air heaters, 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. It was found that an average fuel saving of 28 % was possible. An average overall curing themal efficiency was found to be 40.5 %. The usefulness of a rock-bed thermal storage unit was still inconclusive.

The solar tobacco curing barn described in the previous section was converted into a dryer for other crops (Sitthiphong et al., [10]). 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. Thermal efficiencies of tobacco curing and longan drying were estimated to be 36-40 % 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. On the basis of the benefit received from LPG fuel saving, it was shown 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.

NATURAL CONVECTION SOLAR DRYING

Natural convection solar drying has advantages over forced convection solar drying that it requires lower investment though it is difficult to control drying temperature and drying rate may be limited. Due to low cost and simple operation and maintainance, natural convection seems to be more popular.

Wibulswas et al. [14] found that the drying rate of wet cloth in a natural convection solar cabinet dryer was about 4.2 kg/m^2-day. Watabutr [25] found that the maximum drying efficiency occured when the ratio of outlet area to solar receiving area was 11 % (The inlet area was much greater than the outlet area.) and the slope of glass cover was 14 degree yielding a drying rate of about 3.2 kg/m^2-day (Fig. 10). Drying of banana in a solar cabinet took three days and better quality of product was obtained as compared with direct sun drying [1].

Wibulswas and Thaina [15] tested a mixed mode natural convection solar dryer and found that the drying rate of wet cloth was 5 kg/m^2-day (Fig. 11). The maximum drying efficiency occured when the ratio of outlet area to absorbing area was 0.8 %. Patranon [16] conducted in-field solar drying using similar dryers compared to that of Wibulswas and Thaina [15]. Drying products were banana, fish, meat and coconut meat. Exell [17] developed a low cost mixed mode natural convection solar dryer for paddy drying. Paddy could be dried safely in 2-3 days (Fig. 12).

CONSTRAINT TO THE ACCEPTANCE OF SOLAR DRYING

China is a country which solar dryers have been successfully accepted. The total area of 11,800 m^2 were installed during 1975-1990 (Huang et al. [4]). Direct-type solar dryers were the most popular due to low cost and high efficiency. The largest mixed-mode forced-convection solar dryer, having an absorbing area of 620 m^2, was installed for drying sausage (Liu et al. [18]). Acceptance of solar dryers in Thailand has been very limited in numbers and places. According to the knowledge of the author, natural convection solar dryers have been used for drying local banana in Bangkratoom district, Phitsanuloke province. The acceptance was due to the benefit got from better price of banana dried in solar cabinet dryers. Amyot and Sirisambhand [6] 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 [3] are : high initial cost, lack of durability, misuse, lack of dependability and reliability during the wet season and finally due to other factors which are not necessarily of a technical or technological character. Also, suitable designs of solar dryers were indentified as follows [3]:

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, and fruit has proved technically feasible. However, there is limited acceptance of solar dryer among farmers in Thailand. The major constraint may come from a long pay back period and high initial investment.

RECOMMENDATIONS FOR FURTHER DEVELOPMENT

Research on solar air heater and solar dryer should be concentrated on cost reduction. A standard test of solar air heater should be developed [2].

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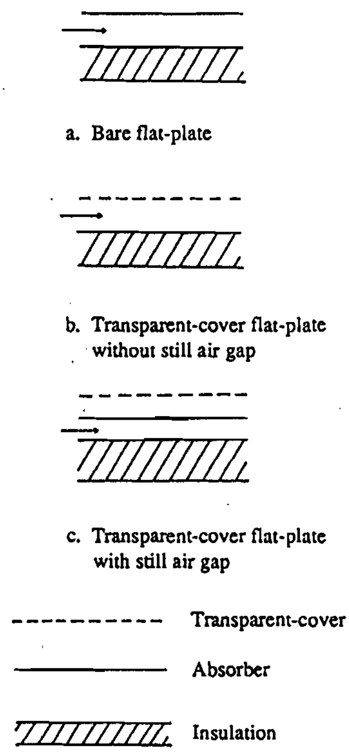


Fig. 1. Section in profile of typical flat-plate solar air heaters.

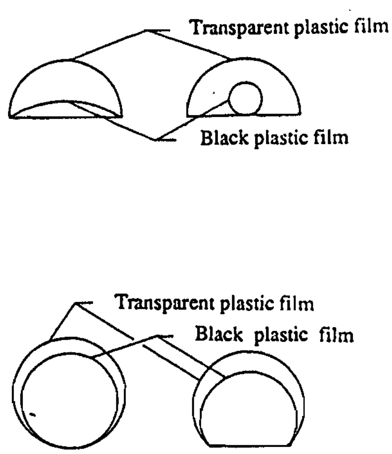


Fig. 2. Cross-section of typical inflated solar air heaters.

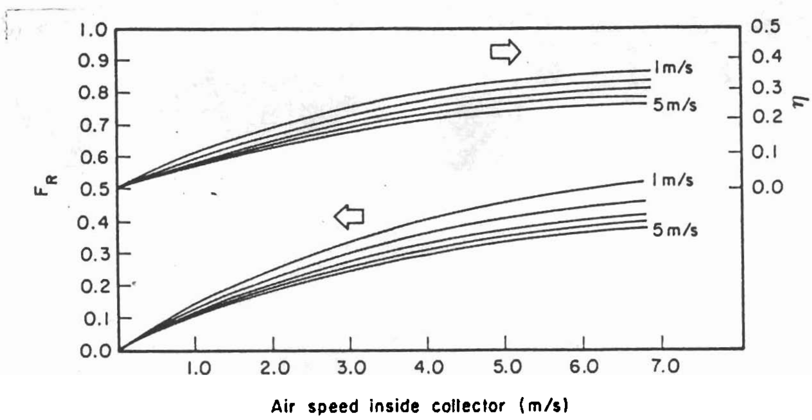


Fig. 3 Effect of air speed inside collector and wind speed above collector on F_R and thermal efficiency of bare flat-plate solar air heater. (Wind speed varies from 1 to 5 m/s from the top to bottom curves.)

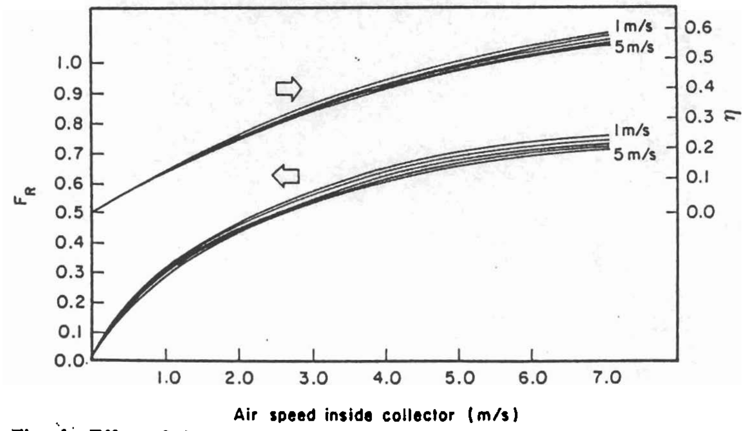


Fig. 4 Effect of air speed inside collector and wind speed above collector on F_R and thermal efficiency of glass-cover flat-plate solar air heater. (Wind speed varies from 1 to 5 m/s from the top to bottom curves.)

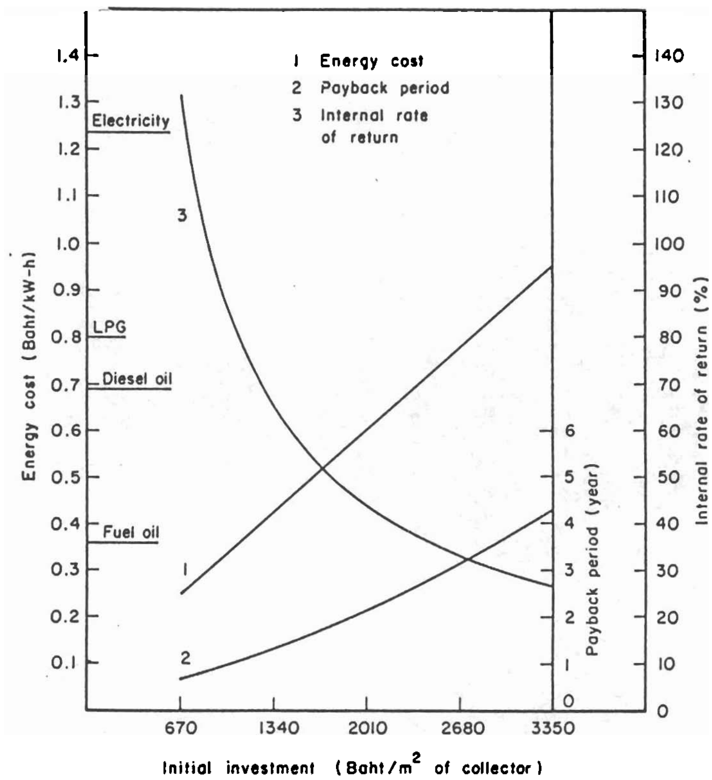


Fig. 5 Energy cost, payback period, and internal rate of return when compared to electricity, as a function of initial cost of glass-cover flat-plate solar air heater.

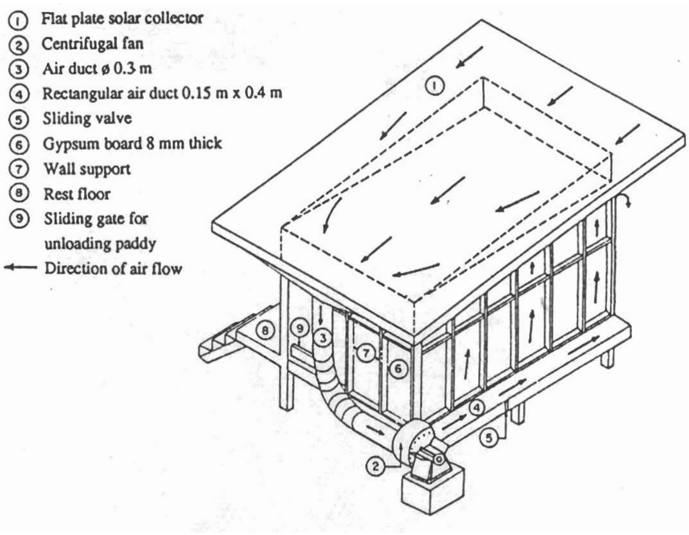
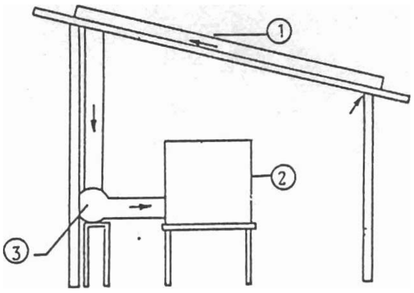
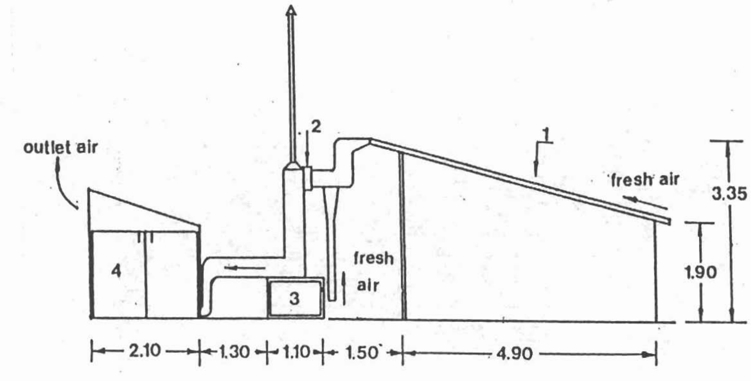


Fig. 6 Isometric 30° showing the solar hut, Soponronnarit *et al.* [22]



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

Fig. 7 Solar dryer developed by Thongprasert *et al.* [24]



1. SOLAR COLLECTOR
2. BLOWER
3. BURNER STOVE
4. GREEN HOUSE

Fig. 8 Solar banana dryer, Assayo [9]

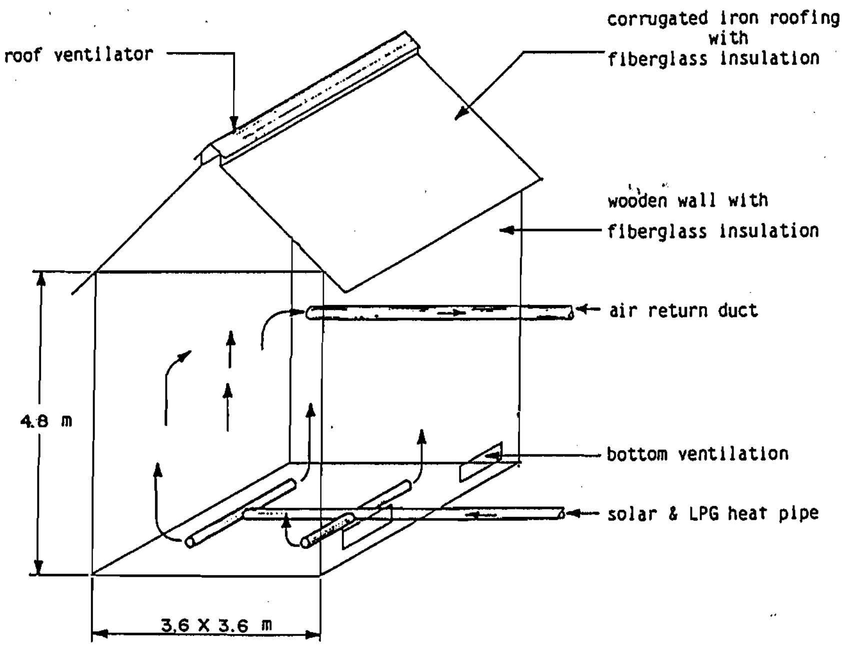


Fig. 9 The modified prototype tobacco curing barn, Boonlong *et al.* [12]

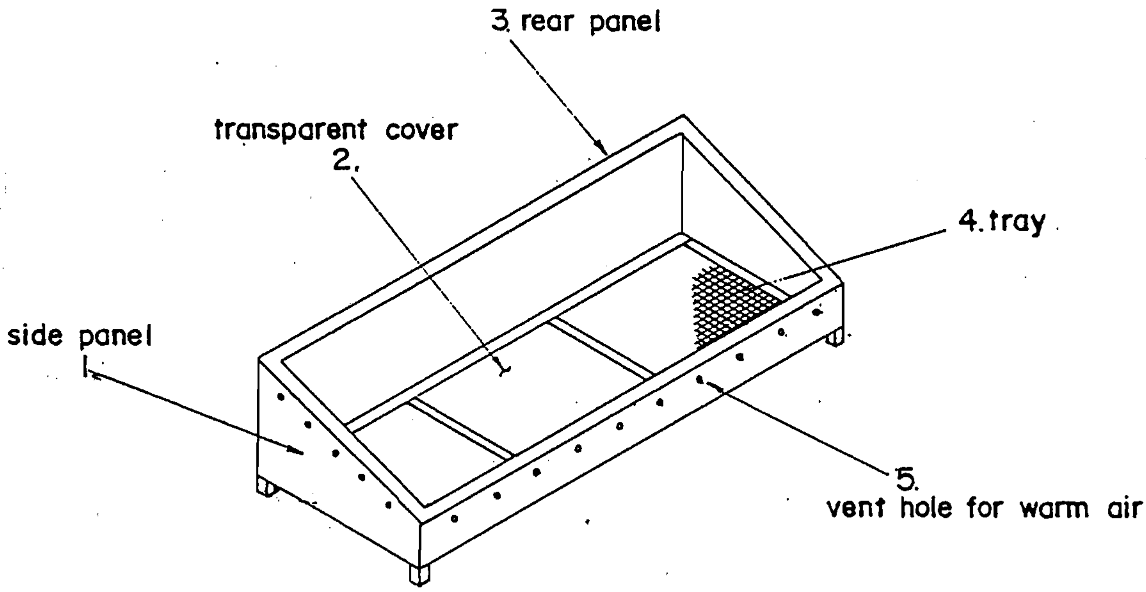


Figure 10 Box dryer, Patranon [16]

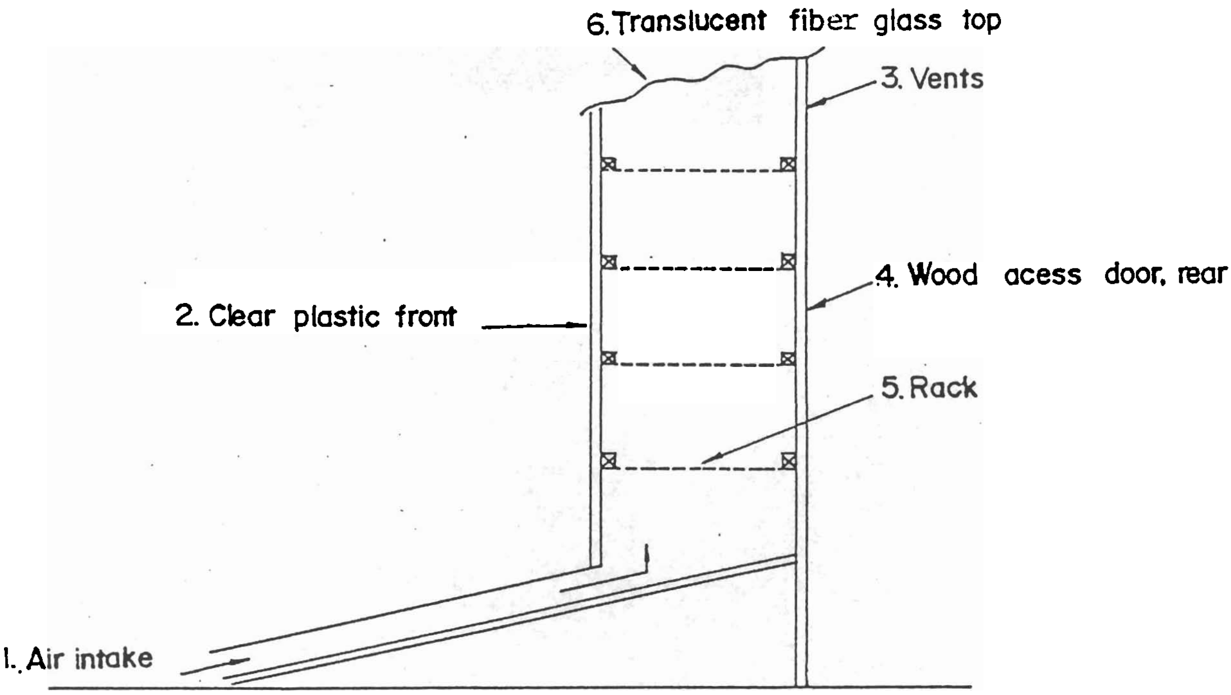


Figure 11 Section view of the fruit and vegetable dryer, Patranon [16]

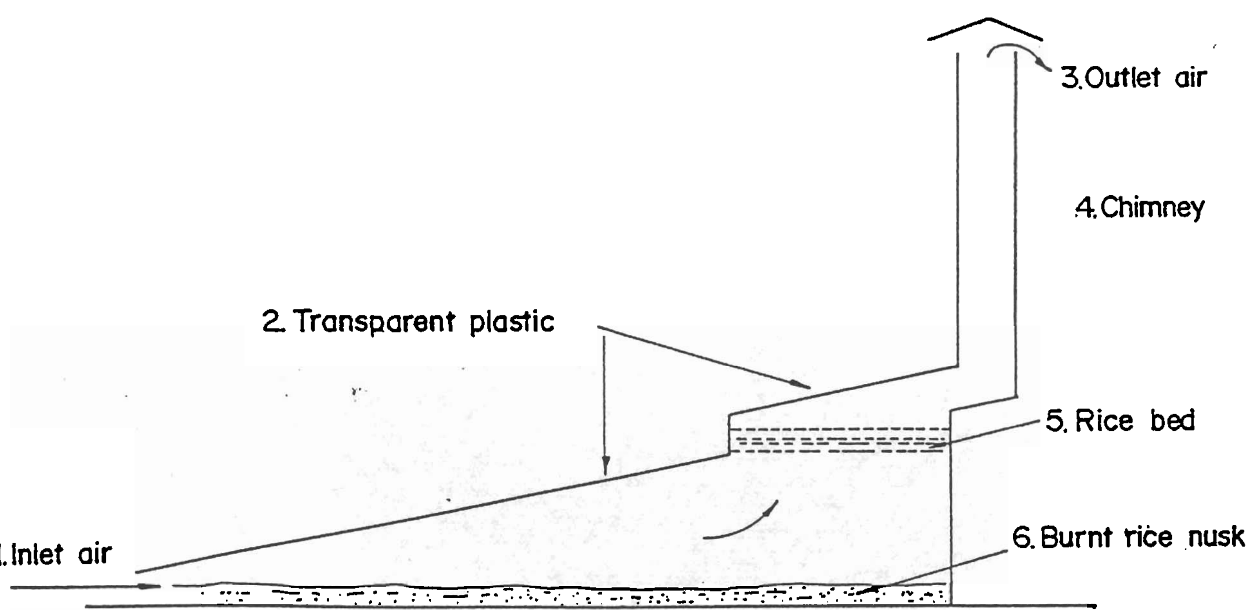


Figure 12 AIT rice dryer, Patranon [16]