A Drying-Storage Solar Hut: The Technical Aspects*

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ABSTRACT

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. The unit is easy to construct and operate, both for loading and unloading. It costs about ฿ 27,600 (฿27 = US$1) of which ฿21,600 is material cost, except for the engine, and the remainder is labour cost. The engine may be available from a walking tractor, or an electric motor may be used if electricity is available. In operation, air is sucked from a bare plate solar air heater modified from a roof by a centrifugal fan and delivered through an air plenum which is underneath a perforated steel sheet. It then passes through the paddy bed, in which heat and mass transfer take place. When an engine is used to drive the fan it requries about 1.13 and 2.08 L of diesel oil per ton of dry paddy per one percent wet basis of moisture reduced for the year crop and second crop respectively. The corresponding drying rate is 0.64% and 0.3% wet basis per ton of dry paddy per hour. The maximum storage capacity is 10 tons.

INTRODUCTION

Thailand is one of the major rice exporting countries of the world. The production of paddy is approximately 17.77M tons per year (1981)[1], and 14.97M tons of this amount is consumed within the country, with the remainder being exported.

Rice may be grown once or twice a year, depending on the water supply which is available. The year crop is grown during the rainy season and is harvested in the dry season. The second crop is grown during the summer and is harvested in the rainy season. Nowadays, the planting of the second crop has become more popular due to the expansion of the irrigation system. However, farmers have been faced with spoilage of the second crop when moisture cannot be reduced fast enough by field drying during the rainy season. To ameliorate the problem one must introduce proper methods of drying. A mechanical dryer is one attractive solution. It is composed of a drying chamber, a blower (which may be driven by an internal combustion engine or an electric motor), and a heat source (as an option), which may be electricity, gas, kerosene, fuel oil, agricultural waste, or solar energy, etc. An electrical heat source is quite simple, but operating costs are

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expensive. Also gas and fuel oils are less expensive than electricity, but the controls are more complicated. Agricultural wastes, such as rice husk, may be the most practical fuel if it is available on site and there are consequently no transportation costs involved. Solar energy is freely available, but a solar collector is always expensive. However, a solar collector can be designed for agricultural drying – in certain cases at least – so that it is not too expensive for the farmer.

Research and development on grain drying has been conducted in Thailand for several years. Most of the dryers which have been developed are of the batch type, with a drying capacity of 1-2 tons, and the drying time for each batch varies from a few hours to a few days.[2-5] All of them had been implemented in rural areas, but none of them has been accepted by Thai farmers. In the special case of the dryer discussed in reference 2 (a low-cost solar dryer in which the air flow is achieved by natural convection), Amyot and Sirisambhand[6] have pointed out that its ineffectiveness is due to the following socio-economic problems.

1. Paddy is harvested as fast as possible, and as a result, the dryer cannot finish the drying process in time. In order to use it effectively, the farmer would have to stagger his harvest over a longer period, but this is not possible because of the unavailability of irrigation water during the planting season and the difficulty of finding agricultural workers at harvest time.

2. Rice traders and millers are usually uninterested in buying paddy in small batches.

3. The price received by farmers for paddy dried by a solar dryer is no higher than that received for paddy dried in the field.

4. The dryer is too flimsy. The plastic sheeting is constantly being torn by village dogs and village children, or it simply disintegrates after a few months as a result of exposure to the sun, and it has to be replaced.

Lhoste and Louis[7] conducted a survey in Nakornpathom province in which they found that some farmers stagger their planting and harvesting. It was also found that the price of paddy depends on its quality and moisture content. The most serious problem was the lack of funds for investment in the dryer because most of the farmers were in debt.

To make the dryer more attractive for the farmers, drying and storage should be integrated so that paddy can be stored after drying, and be sold in large quantities when the price is reasonably high. Moreover, the unit should be durable even though this may increase the cost. In addition, it should be easy to construct and operate. The most important reason is that some farmers have storage huts and to make them into drying-storage huts do not need too many modifications.

An integrated paddy drying-storage solar hut was in fact designed and constructed at a farmer's house. The purpose of this report is to evaluate the suitability of this hut, with special reference to its technical features.

DESIGN AND CONSTRUCTION

The integrated paddy drying-storage solar hut is composed of a flat plate solar collector, two drying-storage rooms, a fan and an air duct system.

The 18.6 m^2 solar collector is constructed on the roof of the hut, and is made of corrugated galvanized steel sheets. In order to simplify the construction of the collector, there is no transparent cover. Air flows through a gap between the absorber and the insulation, which is placed under the absorber. The average spacing of these two sheets is 20 mm. The insulation is made of styrofoam, 25 mm thick, and is held in place by plywood, which is 4 mm thick (see Fig. 1).

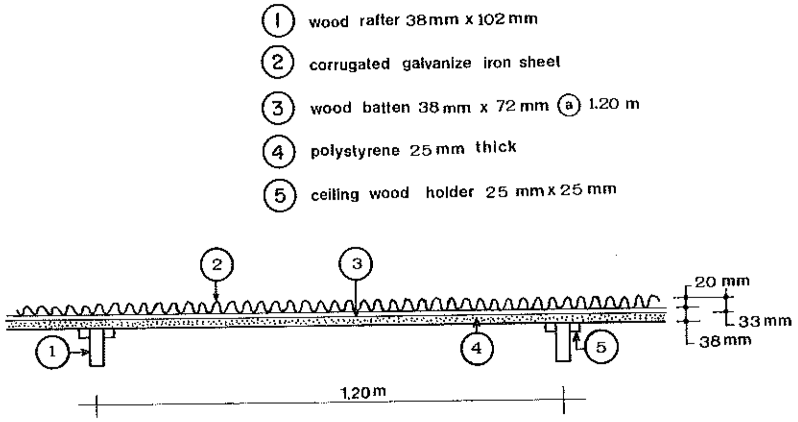

Fig. 1 Cross – section of the solar collector (perpendicular to the direction of air flow).

The space inside the hut is divided into two rooms, one of which has a floor area of 2.9 m^2 and the other of 5.8 m^2 (see Fig. 2). The floor is made of perforated steel sheet, 0.8 mm thick, and is placed over a wooden structure. About one ton of paddy is dried in the small room and is

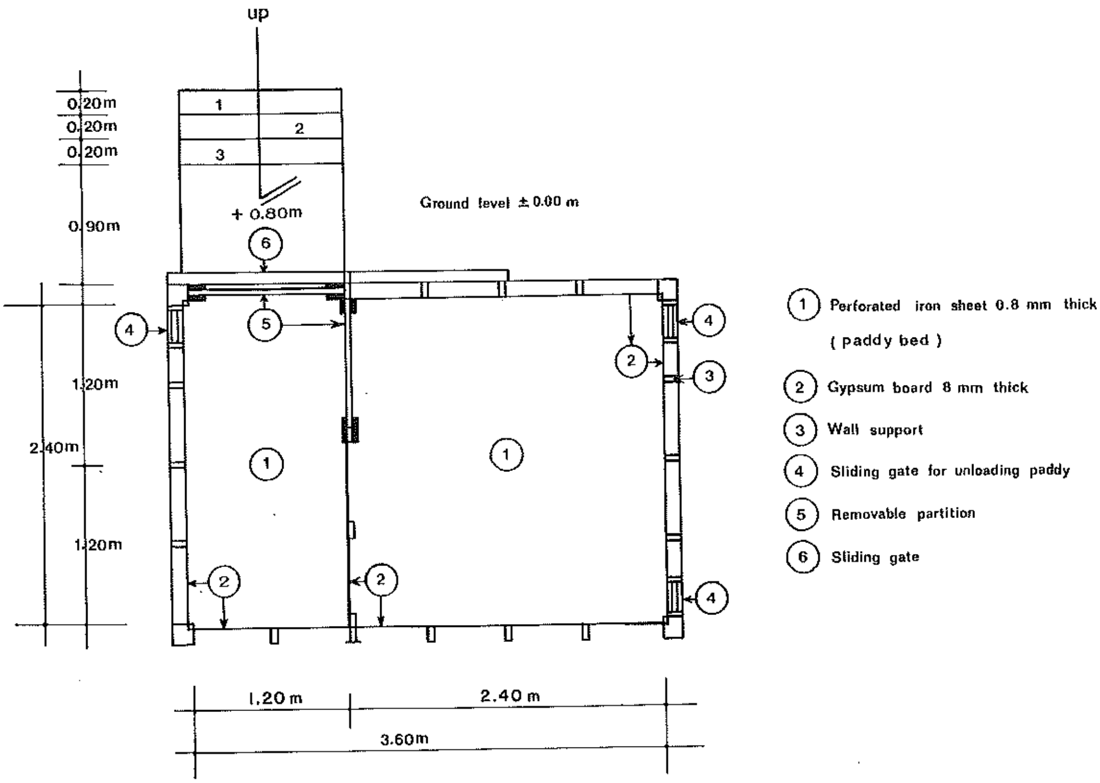

Fig. 2 Plan of the solar hut's floor.

then transferred to the big room after drying. However, both rooms can be used for either drying and/or storage. The maximum storage capacity is about 10 tons with a depth of 2 m.

A centrifugal fan, with a forward curved blade and driven by a 3.7 kW diesel engine is used to suck heated air from the solar collector and deliver it to the air plenum. The air then passes through the rice bed, in which the transfer of heat and moisture take place (see Fig. 3). The fan may be driven by an engine of a walking tractor or by an electric motor.

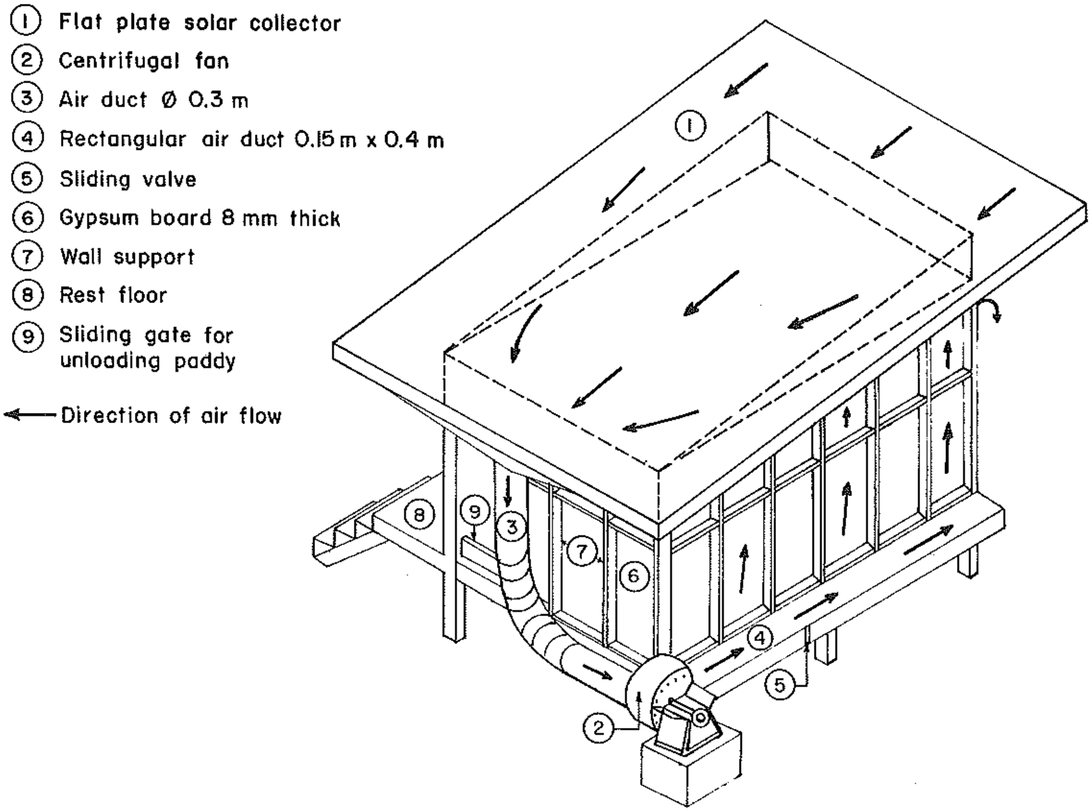

Fig. 3 Isometric 30° showing the solar hut.

Figs. 4-5 show the photographs of the integrated drying-storage solar hut dryer. The unit was constructed at a farmer's house, at Amphur Kampaengsaen, Nakornpathom Province, Thailand.

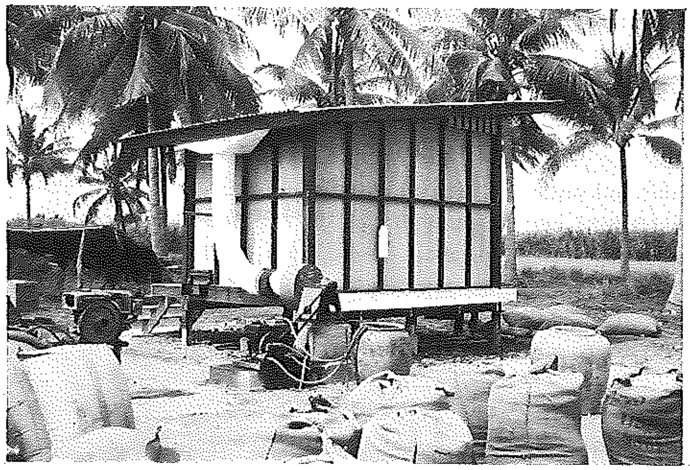

Fig. 4 Photograph showing the solar hut.

Fig. 5 Photograph showing another view of the solar hut.

METHODS OF CALCULATION

From the survey in Kampaengsaen, Nakornpathom, it was found that planting and harvesting were staggered by some farmers, with one or two tons of paddy being harvested each time. Consequently a drying capacity of one ton per day was selected for the design of the of dryer. To dry one ton of paddy from 20% to 15% wet basis, 59 kg of water has to be evaporated.

Soponronnarit,[8] and Soponronnarit and Tiansuwan,[9] tested a similar solar collector in accordance with the ASHRAE Standard 93-77, and found that the maximum efficiency (when the inlet temperature = the ambient temperature) was 29%, with an air flow rate of 0.018 kg/s m^2.

It can be calculated that when the average solar radiation is 15 MJ/m^2 day the air will be heated up 6.7 °C (average during 10 hours). It is assumed that the temperature will increase by another 1.1 °C if a fan is used. The total increase in temperature is thus 7.8 °C.

The ambient temperature and the relative humidity during the daytime are assumed to be 30°C and 65% respectively. By using the Psychrometric Chart, it will be found that the air temperatures at the inlet and outlet of the paddy bed are 37.8°C and 26.9°C respectively. The latter temperature is determined on the basis of the thermal and moisture equilibrium between the drying air and the grain at the top layer. In addition the enthalpy of the air is assumed to be constant during drying. The air flow rate required to dry one ton of paddy when the above conditions pertain is determined by the following equation:

$$\dot{m} = m_w h'_{f,g}/C_p (T_i - T_o) t,$$

where $\dot{m}$ = air flow rate, kg/h

m_w = evaporated moisture, kg

$h'_{f,g}$ = latent heat of vaporization of water, kJ/kg

C_p = specific heat of air at constant pressure, kJ/kg °C

T_i = inlet temperature, °C

T_o = outlet temperature, °C

t = drying time, h

therefore;

$$\begin{aligned}\dot{m} &= 59 \times 2500/(1 \times (37.8 - 26.9) \times 10) \\ &= 1353 \text{ kg/h} \\ &= 0.376 \text{ kg/s}\end{aligned}$$

The area for a suitable solar collector is thus 0.376/0.018 = 20.9 m^2 when the air flow rate is 0.018 kg/s m^2 of the collector.

The static paddy bed is usually 0.4-0.6 m thick for forced air circulation. This is because air and grain are nearly in a state of thermal equilibrium, and the maximum bed depth is thus limited by the moisture gradient which occurs in the grain bed.

MEASUREMENT

The ambient air temperature, the wet bulb temperature, the inlet and outlet air temperature of the solar collector, and the inlet and outlet air temperature of the blower were measured by mercury thermometers and recorded at one hour interval. The air velocity profile in the duct was measured by a Pitot tube and the air flow rate was the product of the average velocity and the duct cross-sectional area.

Due to limited instrumentation facilities at the farmer's house, the global solar radiation was measured by a bimetallic radiation recorder installed at Kasetsart University, Kampaengsaen Campus, about five kilometers from the site. The grain moisture content at the bottom, the middle, and the top layers (5-10 samples for each place and three places for each layer) was measured by a "Kett" moisture meter (riceter model D), and then calibrated with the moisture content measured by the oven method.

RESULTS AND DISCUSSION

Solar Collector and Air Duct

The efficiency of the solar collector as defined by the ratio of useful energy to incident global solar radiation, varies from 18% to 29% at the specific air flow rate of 0.029-0.041 kg/s m^2 of solar collector area. Useful energy is defined as the increasing sensible heat of air.

The difference between the outlet temperature of the solar collector and the inlet temperature of the blower is very small. These two points are connected by a round duct which, in practice, is not convenient or is expensive to insulate. It is thus recommended that in order to simplify the construction of the dryer, this duct should not be insulated.

Drying Test

Four batches of paddy were dried during December 1984 – January 1985. Each drying session took place during the daytime (except for the first test in which the paddy was partially ventilated at night) using heated air from the solar collector. No supplementary heat was used.

The tested paddy was of the RD 21 variety for the first, second, and fourth tests and RD 23 for the third test. Rice panicle was laid in the field for one night after harvesting and was threshed by a drum thresher on the following day, before being dried in the solar hut. Loading the wet paddy into the drying room via small buckets, and unloading dry paddy out of the drying room into sacks via sliding gates, was quite convenient.

For the first test paddy was dried in both rooms (a small room and a big room) and the thickness of the rice bed was 0.52 m. The small room was used to dry paddy during the second, third and fourth batches with a rice bed thickness of 0.47, 0.42 and 0.45 m respectively. The ratio of the fan speed to the engine speed was about 1:1 for the first test and was about 1.25:1 for the others. The experimental results are shown in Table 1.

From Table 1, it can be seen that the first test consumed more diesel oil than was consumed during the other tests. This may be attributed to the following reasons:

1. The high relative humidity of the drying air caused by the partial ventilation of the paddy at night.

2. The engine's power was too high, so the ratio of the fan speed to the engine speed increased from 1:1 to 1.25:1.

3. More energy was required to reduce the moisture content of 1% wet-basis from a high moisture content level.

After the first test, the ratio of the fan speed to the engine speed changed from 1:1 to 1.25:1, and ventilation was carried out only during the daytime. As a result, the diesel oil comsumption was less than it was for the other tests.

It was observed that each layer of paddy was uniformly dried, with the drying front starting from the bottom layer and then progressing to the top one. This meant that there was a uniform air flow distribution through the rice bed.

The relations between the average moisture content, the moisture content at various bed

Table 1 Results of drying tests

Items	Test No.			
	1	2	3	4
1. rice variety	RD 21	RD 21	RD 23	RD 21
2. mass of paddy after drying, kg	2386	750	669	722
3. average initial moisture content, wb.	21.6	18.6	17.7	18.8
4. average final moisture content, wb.	12.6	13.7	12	13.4
5. mean ambient temperature, °C	28.9	25.8	31.4	31.2
6. mean ambient relative humidity, decimal	0.66	0.55	0.46	0.50
7. mean inlet temperature, °C	32.7	31.3	36.3	35.3
8. mean inlet relative humidity, decimal	0.53	0.40	0.35	0.41
9. increasing temperature, °C	3.8	5.5	4.9	4.3
10. increasing temperature by solar energy, °C	1.8	4.4	3.5	3.2
11. increasing temperature by fan, °C	2	1.1	1.4	1.1
12. flow rate, m^3/min per ton of dry paddy	17.4	37.5	58.9	53.9
13. engine speed, rpm	1750-2060	1202	1290	1493
14. fan speed, rpm	1750-2060	1505	1595	1870
15. total useful energy from solar collector, MJ	198	68.2	46.1	26.5
16. total diesel oil consumption, L	37.8	4.2	4.4	3.5
17. diesel oil consumption, L per ton of dry paddy per 1 % wb. of moisture reduced	1.76	1.13	1.15	1.11
18. drying time, h	41.8	8	6	4

depths, and the drying time were plotted and are shown in Figs. 6-9. It was observed that stirring the paddy during drying in order to reduce the moisture gradient in the rice bed was not necessary because the moisture gradient at the end of the drying period was not too high (see Figs. 7,9). In addition, the dried paddy from different levels of the dryer was inevitably mixed together when it was transferred from the drying room to the storage room.

The average drying rate determined from the four runs is 0.64% wet-basis per ton of dry paddy per hour, and the average consumption of diesel oil for the engine as determined from runs 2-4, is 1.13 L per ton of dry paddy per 1% wet-basis of moisture reduced.

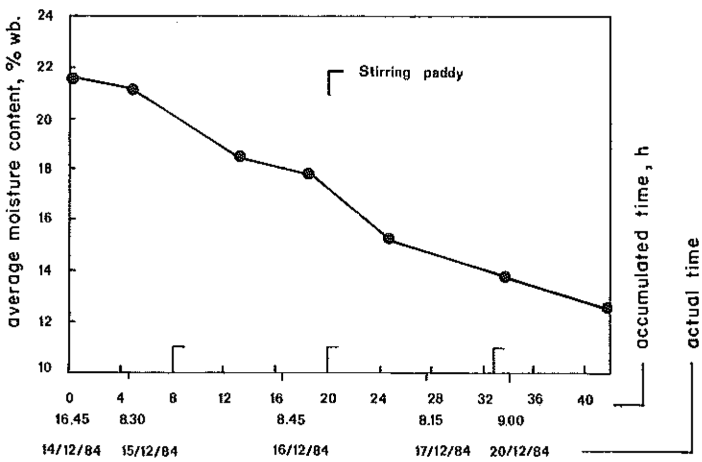

Fig. 6 Evolution of moisture content of paddy for the 1st test (14-20th December, 1984)

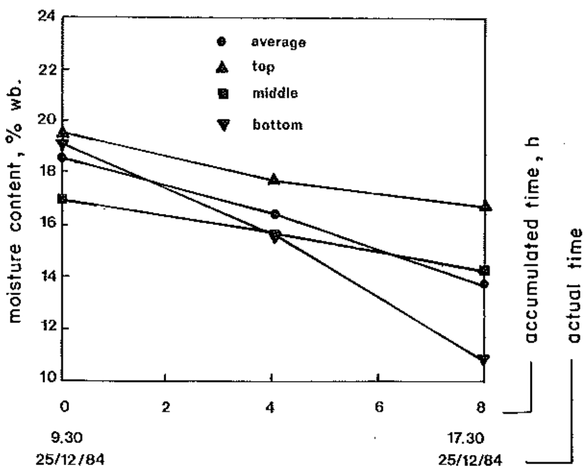

Fig. 7 Evolution of moisture content of paddy for the 2nd test (25th December, 1984)

An experiment in drying paddy during the wet season was also conducted by Mr. Yudthana Thirawanichkul in 1985. From 3 runs the average drying rate in this experiment was 0.3% wet-basis per ton of dry paddy per hour, and the average consumption of diesel oil for the engine was 2.08 L per ton of dry paddy per 1% wet-basis of moisture reduced.

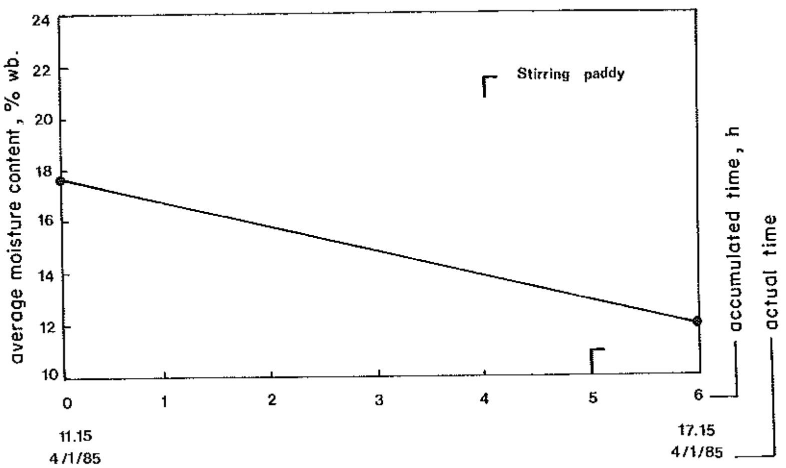

Fig. 8 Evolution of moisture content of paddy for the 3rd test (4th January 1985)

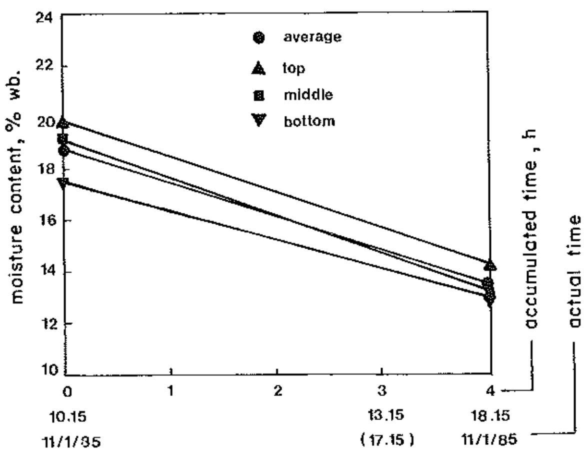

Fig. 9 Evolution of moisture content of paddy for the 4th test (11th January, 1985)

Quality Test

Milling and germination tests were conducted after drying, and the results are shown in Table 2.

According to Table 2, the germination of the seed was quite good, but the percent head yield after milling was not very high. However, the percent head yield of the paddy dried in the field during the dry season was usually less than 40%.[10]

Table 2. Results of quality tests

Items	Test Number			
	1	2	3	4
% head yield	49.7	46.3	48.2	47.5
% germination	97	93	96.5	92

Cost

Material costs for the solar hut (excluding the engine) can be divided as follows:

– main structure for storage	฿16 425
– additional styrofoam and plywood for solar collector	฿ 1 240
– additional styrofoam and air duct	฿ 1 760
– fan and transmission	฿ 2 250
total	฿21 675

Labour for the construction involves about 50 man-days and costs about ฿5325. This means that the total cost for materials and labour is about ฿27 600.

Farmers can derive considerable benefit from the use of the integrated paddy-drying-storage solar hut. For the year crop, the use of the solar hut allows the farmer to obtain a reduction in paddy losses, better milling quality, and a facility for the storage of paddy, which in turn enables it to be sold at a better price. For the second crop, it again allows the farmer to reduce paddy losses, gives him a better milling quality, a better quality of paddy (no yellowing grain and molds), and a better price for selling the dry paddy. The net benefits are estimated to be ฿500/ton for the year crop and ฿400/ton for the second crop.

The solar hut described here is capable of drying and storing 10 tons of paddy per season. Therefore the net benefit per year is ฿5000 + ฿4000 = ฿9000, and the break-even point would be ฿27 600/9000 = 3 years.

CONCLUSION

The integrated paddy-drying-storage solar hut (excluding the engine) costs ฿27 600 of which ฿21 675 is for the cost of materials, and the remainder is the cost of labour. The engine can be either a walking tractor or an electric motor.

The experiments described here indicate that the solar hut is technically suitable because it is easy to construct and operate, viable for use with several types of prime mover, and conforms to post-harvest practice of the farmer.

The drying rates are 0.64% and 0.3% wet-basis per ton of dry paddy per hour for the year crop and for the second crop respectivily. The consumption of diesel oil for the engine is 1.13 L and 2.08 L per ton of dry paddy per 1% wet-basis of moisture reduced for the year crop and the second crop respectively. The maximum storage capacity is 10 tons.

Results from the quality tests show that the head yield after milling and germination of the seed varies from 46-50% and 92-97% respectively.

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