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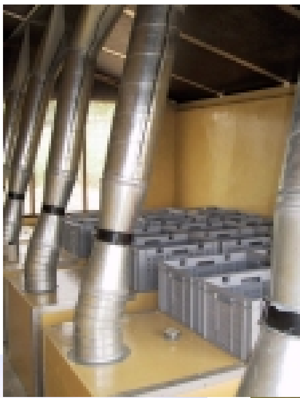
Test of solar dryers in Ghana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Preface

The report describes the tests carried out in Ghana on three solar dryers as part of the project "Test and Research Project into the Drying of Food and Wood Products with Solar Heat" financed by Danida (Danish International Development Assistance) via the Danish Embassy in Ghana. The project was established based on an initiative by the Energy Commission of Ghana.

The report describes the tests and the results from the tests carried out on three solar dryers: a solar crop dryer, a solar fish dryer and a solar wood dryer.

Contributors to the report

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Introduction

The main objective of the project "Test and Research Project into the Drying of Food and Wood Products with Solar Heat" was to develop and test solar dryers for crop, fish and wood in Ghana. Three dryers were erected:

- Solar crop dryer: The solar crop dryer was erected at Silwood Farms at Pokuase about 30 km north of Accra. Silwood Farms grows primarily maize for seed and pineapples.
- Solar fish dryer: The solar fish dryer was erected at Elite Enterprise Ltd. at Tema about 35 km east-north-east of Accra. Elite Enterprise Ltd. buys and dries fish.
- Solar wood dryers: The solar wood dryers were erected at Clipper Design Ltd. at Mankoadze about 65 km west-south-west of Accra. Clipper Design Ltd. produces mainly doors.

The locations of the solar dryers are indicated on the below map.

Figure 1.1. The location of the three solar dryers.

The present report contains the results from test performed on the above three solar dryers. The report is divided in three separate parts – one for each dryer. Each of the three parts contains the following section: brief description of the solar dryers, results from an inspection of the dryers in March 2002, description and results from the tests on the dryers, and an evaluation of the dryers and the performed tests. The following persons have contributed with the below-mentioned material:

Solar crop dryer

Description of the dryer and inspection report:	Søren Østergaard Jensen
Description of the tests and test results:	Erik Fløjgaard Kristensen
Evaluation of the dryer and tests:	Florence Agyei

Solar fish dryer

Description of the dryer and inspection report:	Søren Østergaard Jensen
Description of the tests and test results:	Florence Agyei
Evaluation of the dryer and tests:	Florence Agyei

Solar wood dryer

Description of the dryer and inspection report:	Søren Østergaard Jensen
Description of the tests and test results:	Tonny Larsen
Evaluation of the dryer and tests:	K.S Nketia

Solar crop dryer
Silwood Farms
Pokuase

Description of the dryer and inspection report

Søren Østergaard Jensen

4. Brief description of the solar crop dryer

Based on a survey in Ghana (Jensen, Frank and Kristensen, 1999) it was decided to develop a dryer for drying of maize for seed as the increase in value of the crop due to the drying here would be high – the dryer may, however, also be used to dry other crops or other items. The capacity of the dryer was defined to be 500 kg having a collector area of approx. 24 m². It was decided to let the dryer consist of 5 separate units each with a transparent collector area of 4.77 m² and a capacity of approx. 100 kg. The modulized concept has several benefits: If one drying bed is operated improperly this will not affect the total quantity of crops being dried at that time. It is possible to dry different crops (creating different pressure drop) side by side without risking that the crop with the highest pressure drop will be dried improperly. Small dc fans are often cheaper than larger dc fans. The system will be less complex, and an even air distribution over the solar air collector and the drying bed is easier obtainable. Finally it is possible to start with only one unit and then gradually increase the capacity of the solar dryer - this will make it easier to invest in a solar dryer.

It was further decided that the fans of the dryer should be powered directly by PV-panels in order to make the dryer independent of an often unreliable, missing or expensive grid.

Figure 1 shows the principle of the solar crop dryer.

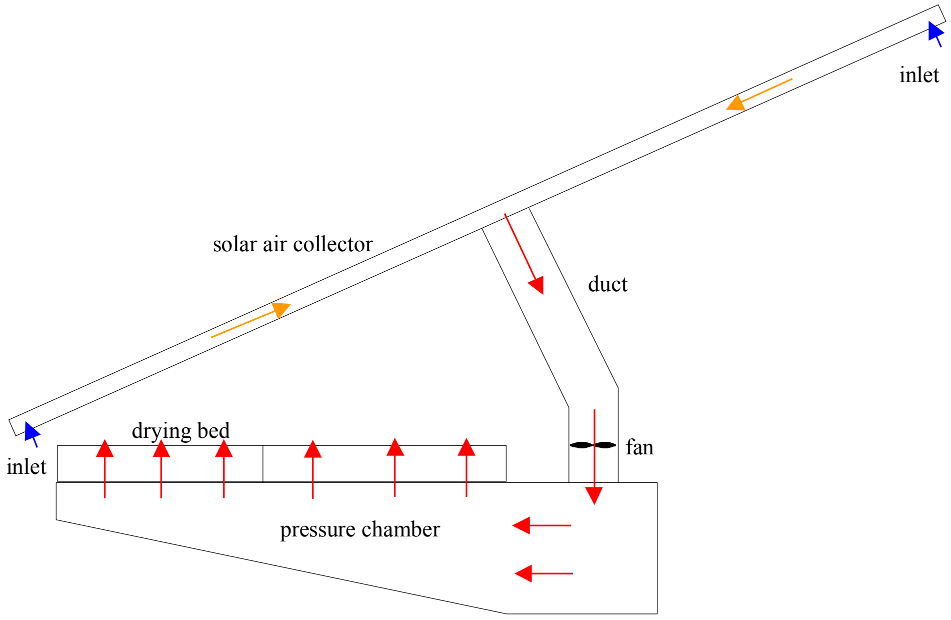

Figure 1. The principle of the concept in the solar crop dryer. The coloured arrows show the air stream through the system.

Based on tests the design was developed successively – please refer to (Jensen, Kristensen and Forman, 2001) for further details.

The main problem with a PV powered solar crop dryer is the fan: the fan should be inexpensive, durable and produce high flow rates at a high pressure while having a low power consumption in order to keep the prise of the solar crop dryer down and at the same time ensure an efficient drying process. A compromise is obviously necessary.

In order to limit the necessary size of the PV-panels the flow rate through the crop was decreased considerably compared to conventional dryers. With the air flow in the design case of 300 m³/h per unit the air speed through the drying bed was 0.06 m/s. This is very low compared to the 0.3-0.7 m/s in conventional cross flow dryers and also low compared to the 0.1 m/s in conventional platform dryers.

The final components of the solar crop dryer were:

- Collector: Outer dimensions: 4900 x 1070 mm². Transparent area: 4.77 m². Cover: 10 mm double walled ribbed UV-stabilized polycarbonate. Absorber: Black felt mat. Air intake at the back of the PV-panels at both ends and air outlet in the middle at the back.
- Fan: 300 m³/h at 40 Pa. 12 V dc motor. Power: 12 W at 12 V.
- PV: 2 panels of 12 V, 14 W_p.
- Duct between collector and drying bed: metal ducting with the smallest cross section of 0.031 m².
- Drying bed: 6 trays made of plastic: 600 x 400 x 278 mm³ (outer dimensions).

The description of the experiments carried out in Denmark with the solar crop dryer and the results are fully described in (Jensen, Kristensen and Forman, 2000).

The tests on the prototype dryers showed that under favourable conditions (rather low ambient humidity and high solar radiation) it was possible to dry 120 kg of maize from a water content of 20% down to 10% (which was the aim) in 1½ day in one unit of the solar crop dryer. It should, therefore, be possible to dry 100-120 kg in 2-3 days in Ghana per unit which early in the project was set as a goal.

Base on the investigations in Denmark it was decided to erect a solar crop dryer consisting of 5 modules in Ghana. The five modules for the solar crop dryer was manufactured in Denmark by Aidt Miljø A/S and shipped for Ghana by the beginning of August 2000 and erected in October 2000.

Figures 2 and 3 show the solar crop dryer at Silwood Farms.

An inspection in January 2001 of the co-ordinator of the project (Jensen, 2001) lead to the following conclusion: The building and drying units show good craftsmanship. Everything looks very nice as even small details have been taken care of. There is absolutely nothing to complain on about the look of the facility.

A check of the thermal performance of the solar crop dryer was also carried out in January 2001 and revealed that the dryer performed as could be expected with regards to efficiency of the solar air collector and air flow rates – for further details see (Jensen, 2001). As part of the inspection a detailed measuring system was designed and installed on one unit of the dryer – in January 2001. Figure 4 shows the measuring points. The measuring system was used for the tests on the solar crop dryer as described in the following section. The measurements were performed using small Tinytag data loggers – an example of such a data logger is shown in figure 5.

Figure 2. The solar crop dryer at Silwood Farms seen from the south.

Figure 3. The five drying units inside the building containing the solar crop dryer.

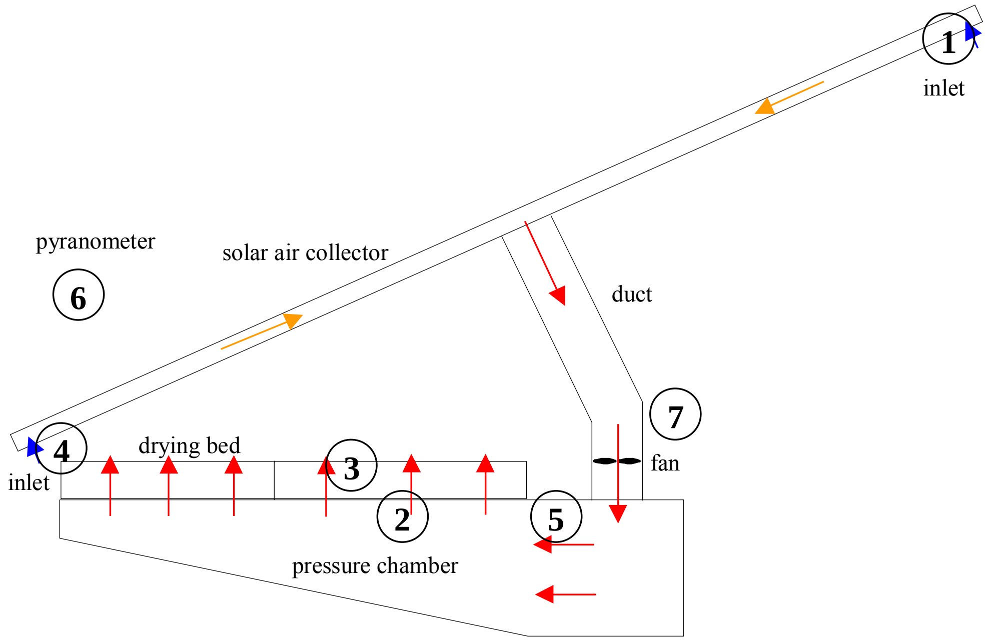

Figure 4. The location of the sensors of the measuring system in the solar crop dryer at Silwood Farms.

Description of the measuring points:

- 3 Tinytag Ultra – TGU-1500 for measurement of temperature and relative humidity (measuring range –30-50°C and 0-95% rh) – numbered 1-3 on figure 4.

- 2 Tinytag Ultra – TGU-0020 for measurement of temperature with an external temperature probe (measuring range –40-125°C) – numbered 4-5 on figure 4.

- 1 Tinytag Plus – TGPR-1001 for measurement of mV (measuring range 0-200 mV). The logger is via a cable connected a pyranometer. The logger is labelled 6 on figure 4.

- 1 Tinytag Plus – TGPR-0704 for measurement of V (measuring range set to 0-25 V). The logger is via a cable connected to the power supply to the fan. The logger is number 7 on figure 4.

The measuring system is fully described in (Jensen, 2001)

Figure 5. Picture of a Tinytag for combined measuring of the air temperature and the air relative humidity together with a Danish matchbox.

Inspection of the solar crop dryer at Silwood Farms - March 3 and 6, 2002

The dryer still looks nice and the appearance is expect for some dust and spider's web more ore less unchanged since the last inspection in January 2001 - please refer to the inspection report from January 2001 (Jensen, 2001). A more thorough inspection revealed some minor, however, easy fixable problems: leaking roof, some of the "floor" in the pressure chamber have fallen down, one fan is out of order, there is holes in some of the nets of the drying trays and the filters in the inlets to the solar air collectors are rather dirty.

<u>Leaking roof</u>

The solar air collectors are the roof of the house containing the drying beds of the solar crop dryer. The joints between the solar air collectors are sealed with silicone. However, holes in this sealing has started to appear – probably due to the expansion and contraction of the solar air collectors due to the rather large temperature span between day and night. The sealing should rather have been a rubber-sealing strip laying on top of the joints, however, with a appropriate profile for mechanical fixing in the joints between the solar air collectors.

The current sealing should be renovated.

<u>"Floors" in the pressure chambers</u>

The "floor" in the pressure chambers was made of 5 mm sheets of foam insulation, however, in two of the drying units the insulation foam was later replaced by plywood. Although bulky due to the heat and low humidity the plywood floors still serves their purpose as seen in figure 7. The insulation foam mats were all fallen down in one of the sites – see figure 8. This suggests that plywood is preferable for this purpose. However, as the air flow rate in the pressure chamber is very low the benefit of the tilted "floor" is not very high – but the floor has an insulating effect which is preferred.

It should be considered either to replace the floors made of insulation foam with plywood or make a more durable fastening of the insulation foam.

Figure 6. The solar crop dryer at Silwood Farms – March 2002.

Figure 7. Floor in a pressure chamber made of plywood.

Figure 8. Floor in a pressure chamber made of sheets of 5 mm insulation foam.

Fan out of order

The fan of the middle solar air dryer was not running. It has not yet been investigated why it isn't running. The fans are by the manufacture promised to be able to run for between 80,000 and 37,500 h when continuously run at respectively 40 or 72°C. At the conditions in the solar crop dryer the fans should thus be able to run without problems for 20 years when running for 8 hours a day.

The fan should be taken out of the system and examined closely in order to find the reason for the malfunction. If possible the fans should be repaired and put in operation again – or re-placed by another fan.

Holes in the drying trays

Figure 9 shows two of the drying trays where there was a hole in the net in the bottom of the trays at one of the corners. Several of the drying trays have these holes in the net. The holes in the nets were caused by rats. Maize will fall out and be wasted when handling the trays. A more durable solution should be found.

Figure 9. Two drying trays with a hole in the corner of the net in the bottom of the trays.

Dirty inlet filters to the solar air collectors

The filters in the inlets (see figure 10) of the solar air collectors were very dirty most probably due to the dust from the Hamatan. The farmer was made aware of this fact and asked to wash the filters.

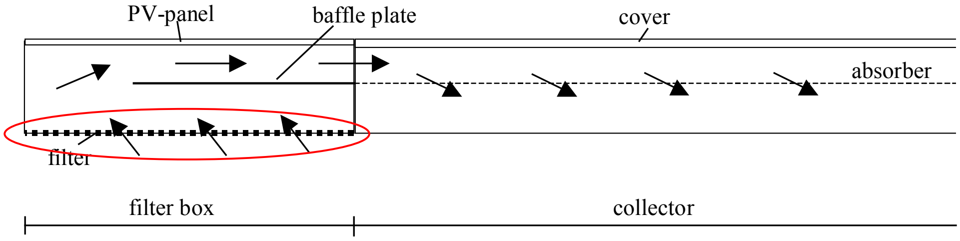

Figure 10. The filters at the inlets of the solar air collectors

Air flow rate

Just after noon on March 3 and in the afternoon of March 6 combined measurements of voltage to the fan and air speed in the ducting of one of the dryers (all dryers expect the dryer with the not running fan showed the same voltage to the fan) were carried out. The measurements on March 6 were performed around 16:00 where the solar radiation was very low – leading to a low voltage to the fan: the point at approx. 4.5 V in figure 11. In order to obtain a higher volume flow rate the fan was connected to the battery of a car: the point at 12 V.

The result of the measurements is shown in figure 11. Figure 11 also shows the relationship between voltage to the fan and the air flow rate measured at the first inspection of the solar crop dryer in January 2001 (Jensen, 2001). From figure 11 it is seen that the air flow rate at low voltage is almost identical to the flow rate measured in January 2001. However, the measured flow rate at high voltage is either far higher or far lower than the flow rates measured in January 2001. This is believed to be due to a larger temperature dependency of the fan than expected. The air temperature to the fan on March 3 was about 52°C due to high ambient temperature and high solar radiation while it on March 6 was bout 34°C due to the lower angle of the sun and thereby lower radiation level – see figure 12.

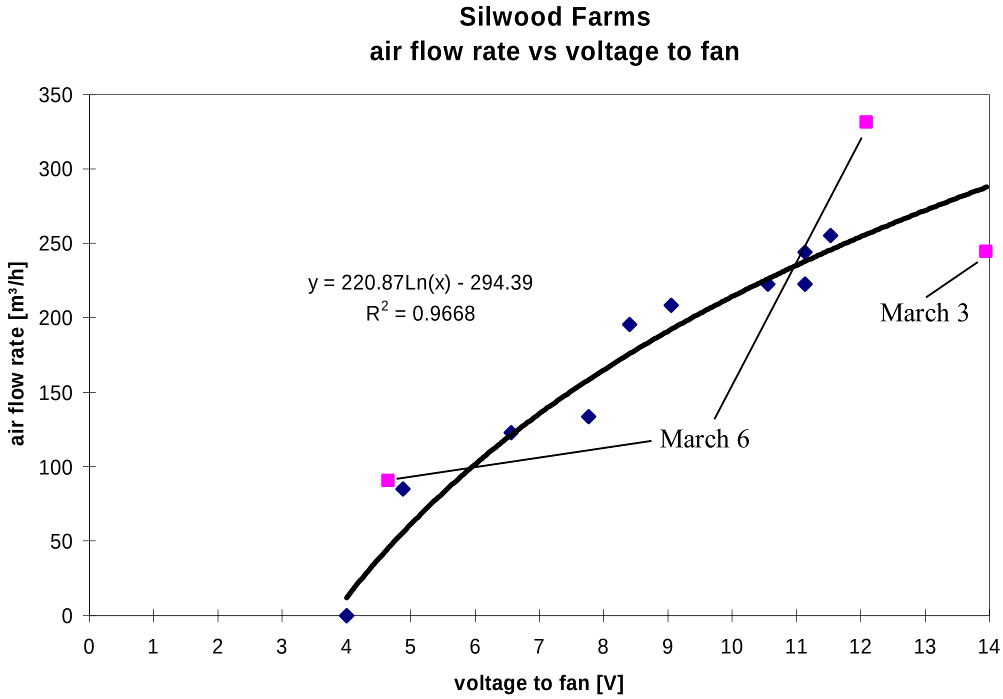

Figure 11. Flow rates measured in January 2001 (Jensen, 2001) together with a flow rate measured on March 3 and 6, 2002.

Although different from the measurements in January 2001 it is based on the measurements in March 2002 concluded that the fan performs as when installed and that the flow rate through the solar air dryers has not changed significantly.

However, if further developed it should be considered to find a less temperature dependent fan for the solar crop dryers in order to maintain a high flow rate at high temperature levels for keeping the temperature of the air to the drying bed below 45°C.

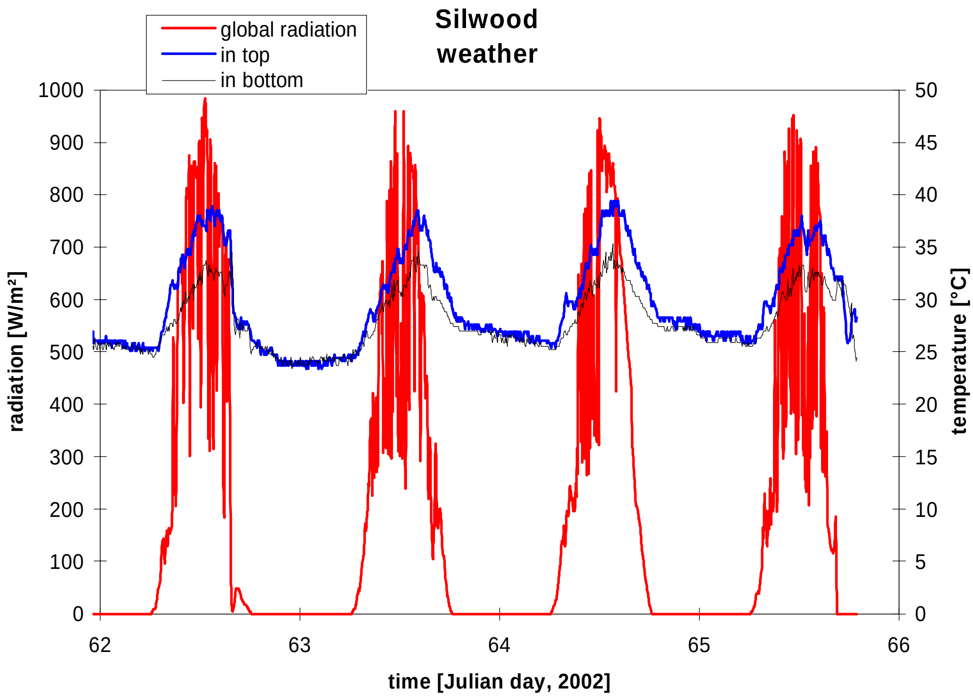

Figure 12. The weather conditions at Solwood Farms in the period March 3-6 (both inclusive).

From figure 11 it is also seen that the voltage to the fan seems higher than found during the inspection in January 2001. This is, however, not the case as seen when comparing figure 13 and 14 showing the voltage to the fan as a function of the total solar radiation on the PV-panels for January 22-24, 2001 and March 3-6, 2002 (the shown solar radiation is the total solar radiation not corrected for reflection at the cover of the PV-panels at non zero incidence angles of the solar radiation). The mean voltage at identical irradiation levels is very similar. The high voltage shown in figure 11 is due to the higher radiation level on March 3 – close to 1000 W/m² as seen in figure 12. The performance of the PV-panels has thus not changed during the year between the two inspections.

Brief interview with the manager of the farm

The manager of the farm estimates that since the installation of the solar crop dryer they have harvested 40 tones of maize of which 10 tones have been dried in the solar crop dryer. As the solar crop dryer are able to dry 500-600 kg at a time and the drying time at good weather conditions is 3 days this means that the dryer have been in operation at least 2 months. However, based on the visits to the farm by DENG and the consultants it doesn't seem likely that the dried amount of maize in the solar crop dryer is as high as 10 tones.

The manager of the farm is happy for the solar crop dryer as it has turned out that the conventional kerosene dryer – see figure 15 - is not suited for drying of seed due to the manual control of the dryer. The temperature of the air to the drying bed has to be adjusted by a manual valve on the inlet of kerosene based on a mechanical thermometer in the drying bed. The dryer tents to blow in too hot air which will decrease the germination capacity of the seed. All the seed from Silwood Farms is, therefore, now dried in the solar crop dryer.

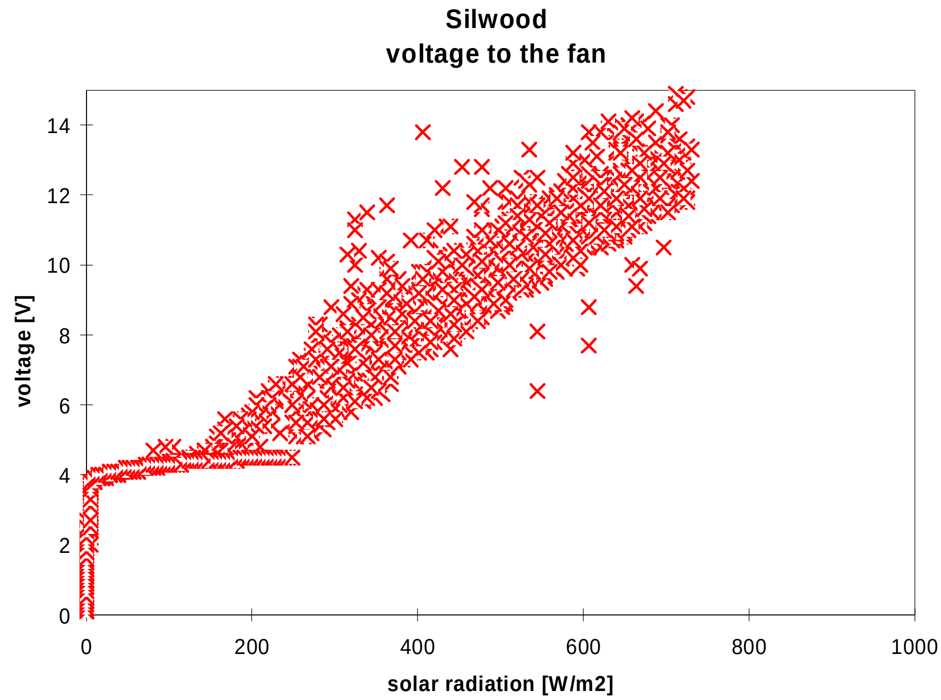

Figure 13. The voltage to the fan dependent on the total radiation on the PV-panels on January 22-24, 2001.

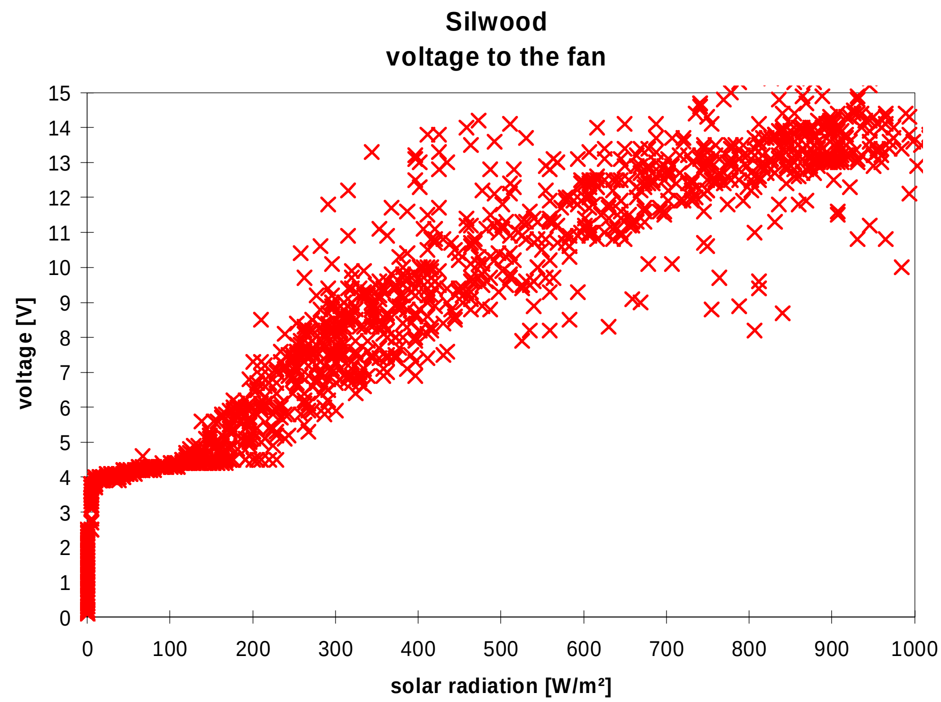

Figure 14. The voltage to the fan dependent on the total radiation on the PV-panels on March 3-6, 2002.

Figure 15. The traditional kerosene dryer at Silwood Farms.

The manager of the farm would like to have a constant air flow through the dryer when drying other crops e.g. pineapples. A constant air flow through the dryer day and night is obtainable if the fans also are connected to batteries. But in order to charge the batteries a far larger area of PV-panels is required, which will increase the price of the dryer considerably. Further the dependency of the flow rate on the solar radiation is ideal when only the sun is used as heat source in the dryer. The low air flow rate at low radiation levels maintain a higher temperature increase across the solar air collector than a constant high flow rate. The higher the temperature increase is, the lower is the relative humidity of the air to the drying bed and thereby the drying capacity of the air. A constant high air flow rate will thus reduce the drying capacity of the solar crop dryer in the morning and afternoon. During the night with no heating of the air in the solar air collectors no drying will occur if no other heat source is applied. This could be an electrical resistance heater or a furnace fired with the waste from the corncobs. A thermostat should control the heat source in order to maintain a certain air temperature to the drying bed. The initial cost of an electrical resistance heater is low but the running cost is high. A furnace is expensive if it can be run automatically and man power demanding if run manually.

The above should, however, be considered in a further development of the solar crop dryer.

Economics

Based on the experience with the solar crop dryer at Silwood Farms DENG Ltd. has estimated the following cost of one unit of the solar crop dryer based on a crop dryer of minimum five units:

One unit

Solar air collectors	1280 US$
2 PV-Panels	180 "
Ductworks	700 "
Fan	50 "
Wiring	120 "
Sealant	25 "
Pressure chamber	120 "
Drying trays	50 "
Total without VAT	2525 US$

Five Units

Crop dryer consisting of five units	12625 US$
Civil works (housing for the dryer)	1000 "
Total for a five unit dryer without VAT	13625 US$

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Jensen, S.Ø., Kristensen, E.F. and Forman, T., 2001. Test of a solar crop dryer. Solar Energy Centre Denmark, Danish Technological Institute and Department of Agricultural Engineering, Danish Institute of Agricultural Sciences and Aidt Miljø A/S. ISBN 87-7756-583-5.

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Description of the tests and test results

Erik Fløjgaard Kristensen

Contents

Test of solar crop dryer in Ghana

This chapter contains test results for the solar crop dryer at Silwood Farms in Ghana. For documentation of the solar crop dryer's applicability and performance data on drying capacity and important operating characteristics, data on e.g. drying air temperatures, air humidity and airflow rates were collected.

For the carrying through of the drying tests, the Danish Institute of Agricultural Sciences developed a simple test method. The method is described in details in Appendix A. The necessary tables and test forms are all shown in Appendix A. The method is based on determination of the moisture content prior to the drying and weighing of the crops at regular intervals during the drying. The actual moisture content can be calculated on the basis of the initial moisture content and weight loss, which will occur due to the evaporation of water.

The maize drying process may be divided into two steps. On the first day of drying, the whole maize ears are filled into the drying trays, and the day is used for drying. After this, the ears are threshed, and the maize grain is filled back into the drying trays, after which the drying is finished.

For the drying of other crops, e.g. pepper, the drying process may be performed in one step. The fresh material is filled into the drying trays and remains in the trays until the drying is finished. Cassava and similar large vegetables or fruits must be sliced or cut into small pieces prior to drying.

Before the drying process is started, the moisture content of the crop must be determined. An electric moisture meter may be used to determine the moisture content of the grain or of the crop. In most cases, a reliable moisture meter will not be available. Then the moisture content can be determined by drying a test portion of the grain or crop in a heating oven. A test portion of milled or crushed grain should be dried at an oven temperature of 130°C. For wheat, barley, rice and sorghum, the drying time should be 2 hours. For maize, the drying time should be 4 hours, according to international standard, but for oriented or instructive moisture determination, a drying time of 2 hours will be sufficient. The formula for calculation of moisture content is:

$$W = \{1 - (m_2/m_1)\} \; \% \; 100$$

where

W = moisture content in per cent
m_1 = mass in g of the test portion before drying
m_2 = mass in g of the test portion after drying.

For a good documentation of the drying progress, regular weighing is needed. As a minimum, 1 tray per drying section must be weighed 3 times a day – morning, midday and evening. The weighing results were noted down on a form. Also, the weather conditions, the temperature and the air humidity were registered and noted down.

In order to determine when sufficient drying of the crop was reached, one of three drying tables in Appendix A should be used.

Step-by-step outline for a drying test

Before drying:

1. Determination of moisture content
2. Weighing of test tray
3. Filling up trays
4. Weighing of test tray incl. crop
5. Calculation of required weight loss

During drying:

1. Registration of ambient air temperature and humidity 3 times a day
2. Weighing of test tray incl. crop 3 times a day
3. Emptying of trays when required weight loss is reached and the drying is finished.

Test of the solar crop dryer, January – February 2001

The solar crop dryer was used for drying of maize in the period from 22 January to 2 February 2001.

During the drying process the manager at Silwood farms filled out information sheets with some basic data describing the progress of the drying and the actual weather conditions. Two tests were made.

Test No. 1 was started on 22 January and ended on 26 January. The maize ears were threshed before the drying, and the drying process was performed in one step. The goal was to dry the maize to an end moisture content of about 10%. The quantity of maize was the same, 14.5 kg, for all six trays in each drying section. The drying process was registered by weighing one tray with the crop before the drying was started and again several times during the drying process. An electric moisture meter was used for measuring the moisture content of the maize before, during and after drying. The registered data are shown in the below Table 1.

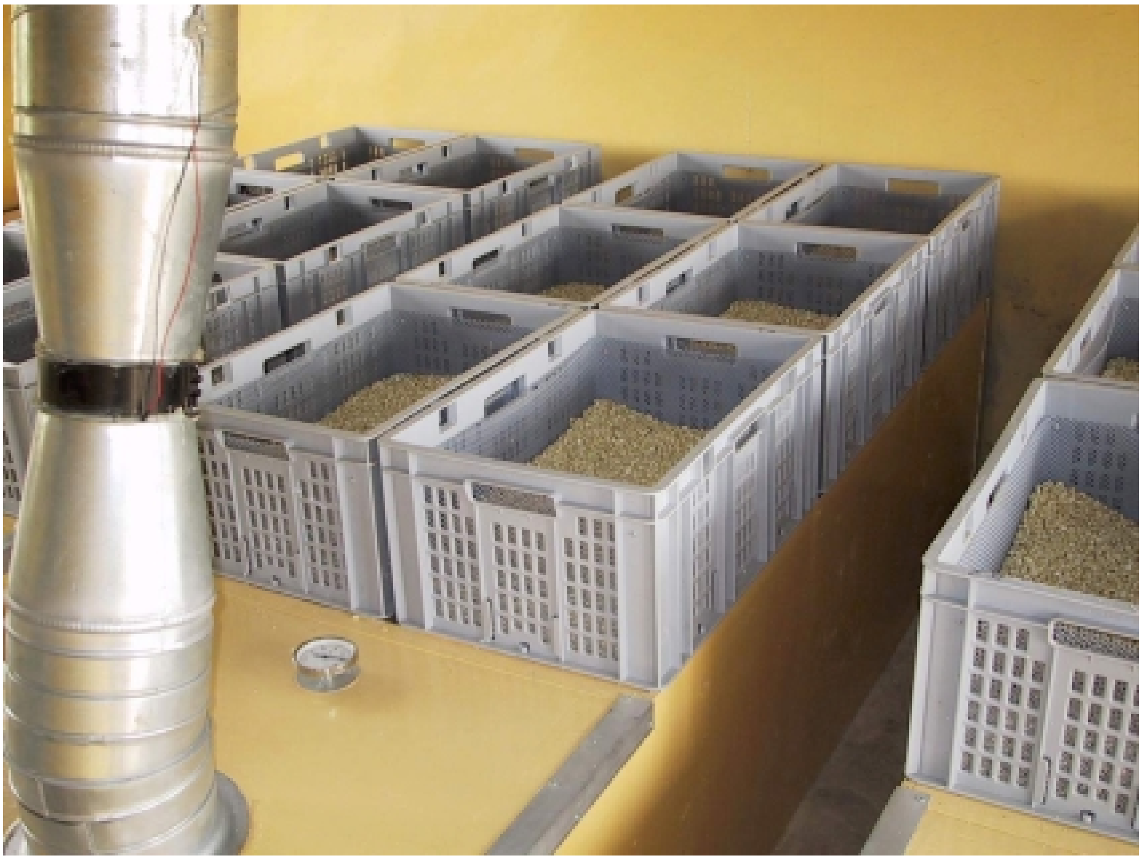

Figure 1. Drying test performed at Silwood Farms. The drying trays in the crop dryer are filled with maize.

Date	Hour	Weight Maize kg	Total weight loss Maize, kg	Moisture content, %		Ambient air	
				Moisture meter	Calculated (1)	Temperature °C	Humidity RH, %
22 Jan	14:30	14.5	0	16.3	16,3[1)]	35	44
-	17:03			11.4		31	62
23 Jan	8:35			12.0		25.5	88
-	14:24	13.5	1.0	10.4	10.1	35.5	36
-	17:20	13.6	0.9		10.75	29.5	69
24 Jan	7:40	13.5	1.0	11.1	10.1	23	92
-	12:06	13.4	1.1	10.6	9.43	24	
-	17:05	13.4	1.1		9.43	29	66
25 Jan	8:05	13.5	1.0	11.1	10.1	25	77
-	13:40	13.5	1.0	10.2	10.1	35	48
-	17:00	13.5	1.0	10.3	10.1	29.5	69
26 Jan	8:20	13.5	1.0	10.8	10.1	25	85
-	13:07			9.9		34.5	44
-	16:14					32	57

[1)] Moisture content calculated on the base of moisture meter measurement at start (16.3 %) and weight loss measurements.

Table 1. Drying test No.1 at Silwood Farms. Drying progress and weather conditions.

As it will appear from Table 1, the drying was in fact finished after only one day. Already on 23 January at 14:24 the moisture content was very close to 10%. From start of the drying on to that time about 8-9 hours of effective running of the drying fan was available. If the average air flow rate is set at 250 m^3 per hour, the average temperature and air humidity during the running period are set at 35°C and 40% RH, respectively, and the air heating in the solar collector set at 10°C, the moisture content can be calculated at 13% on the basis of the theoretical equations concerning drying of maize in the solar crop dryer. This test thus shows a higher drying capacity than expected, but it must be mentioned that there are some uncertainties concerning the measurements, especially as regards the moisture content of the maize. In general, the performance of the crop dryer was satisfactory.

Test No. 2 was started on 27 January and ended on 1 February. The maize ears were threshed before drying, and the drying process was performed in one step. As for test No. 1 the aim was to dry the maize to a final moisture content of about 10%. The quantity of maize was the same for all six trays in each drying section. For this test, the drying process was registered by weighing one tray with maize in three different drying sections before the drying was started and again several times during the drying process. As for test No. 1, an electric moisture meter was used for measuring the moisture content of the maize before, during and after drying. In two of the sections there were 16.5 kg of maize in each tray, while there were 14.5 kg per tray in the third section. The registered data are shown in Tables 2-4.

Date	Hour	Weight Maize kg	Total weight loss Maize, kg	Moisture content, %		Ambient air	
				Moisture meter	Calculated (1)	Temperature °C	Humidity RH, %
27 Jan	8:34	16.5	0	16.3	19.45	26	82
-	16:15			11.3		34	34
28 Jan	7:45			11.7		24	82
-	17:30			10.4		30	58
29 Jan	7:45			11.2		24	81
-	12:30			10.6		34	34
30 Jan	7:30			11.0		25	90
-	12:10	14.8	1.7	10.2	10.2[1)]	36	36
-	17:30	14.7	1.8	10.3	9.6	29	60
31 Jan	7:15	14.9	1.6	10.7	10.8	25	90
-	15:10	14.7	1.8	9.9	9.6	33	63
1 Feb	7:13	14.8	1.7	10.7	10.2	25	90

1) Moisture content calculated on the basis of moisture meter measurements after drying on 30 January at 12:10 (10.2%) and weight loss measurements.

Table 2. Drying test No. 2 at Silwood Farms, solar crop dryer section E. Drying progress and weather conditions.

Date	Hour	Weight Maize kg	Total weight loss Maize, kg	Moisture content, %		Ambient air	
				Moisture meter	Calculated (1)	Temperature °C	Humidity RH, %
27 Jan	8:34	16.5	0	16.3	20.0	26	82
-	16:15			11.4		34	34
28 Jan	7:45			12.0		24	82
-	17:30			10.4		30	58
29 Jan	7:45			11.1		24	81
-	12:30			10.6		34	34
30 Jan	7:30			11.1		25	90
-	12:10	14.7	1.8	10.2	10.2[1)]	36	36
-	17:30	14.6	1.9	10.3	9.6	29	60
31 Jan	7:15	14.8	1.7	10.8	10.8	25	90
-	15:10	14.5	2.0	9.9	9.0	33	63
1 Feb	7:13	14.7	1.8	10.7	10.2	25	90

1) Moisture content calculated on the basis of moisture meter measurement after drying 30 January 12:10 (10.2%) and weight loss.

Table 3. Drying test No. 2 at Silwood Farms, solar crop dryer section D. Drying progress and weather conditions.

Date	Hour	Weight Maize kg	Total weight loss Maize, kg	Moisture content, %		Ambient air	
				Moisture meter	Calculated (1)	Temperature °C	Humidity RH, %
27 Jan	8:34	14.5	0	16.3	19.5	26	82
-	16:15			11.4		34	34
28 Jan	7:45			12.0		24	82
-	17:30			10.4		30	58
29 Jan	7:45			11.1		24	81
-	12:30			10.6		34	34
30 Jan	7:30			11.1		25	90
-	12:10	13.0	1.5	10.2	10.2[1)]	36	36
-	17:30	12.6	1.9	10.3	7.3	29	60
31 Jan	7:15	12,9	1.6	10.8	9.5	25	90
-	15:10	12,5	2.0	9.9	6.6	33	63
1 Feb	7:13	11.8	2.7	10.7	1.1	25	90

[1)] Moisture content calculated on the basis of moisture meter measurement after drying 30 January 12:10 (10.2%) and weight loss.

Table 4. Drying test No. 2 at Silwood Farms, solar crop dryer section C. Drying progress and weather conditions.

As it will appear from Tables 2-4, the drying at test No. 2 was finished after three days. Maybe the drying was finished even before that. This cannot be decided due to the lack of weighing data from the period from the start of the test on 27 January and until the 30 January 12:10. The drying progress cannot be described on the basis of the moisture meter measurements of the moisture content, only, because obviously, these data are somewhat inaccurate. According to the weight loss, which will only occur due to water evaporation, the reduction in moisture content in the period was about 10 and not 6 percentage units, as shown by the moisture meter data. Due to the drying conditions and the fact that the following days the moisture content measurements showed constant values of about 10%, it is assumed that the determination of moisture content on 30 January at 12:10 was correct. Therefore, the initial moisture content must have been about 20% (see the calculated moisture contents in the tables).

During the drying tests the ambient air temperature and humidity, the temperatures within the crop dryer and the air flow rate was measured and recorded by means of Tinytags data logger. For more details on the Tinytag measuring system please refer to the former chapter and to (Jensen, 2001). The latter contains a thorough evaluation of the measurements obtained with the data logger system during January 22-27, 2001.

Figure 2 shows results from Test No.2 in combination with the drying progress in crop dryer section E.

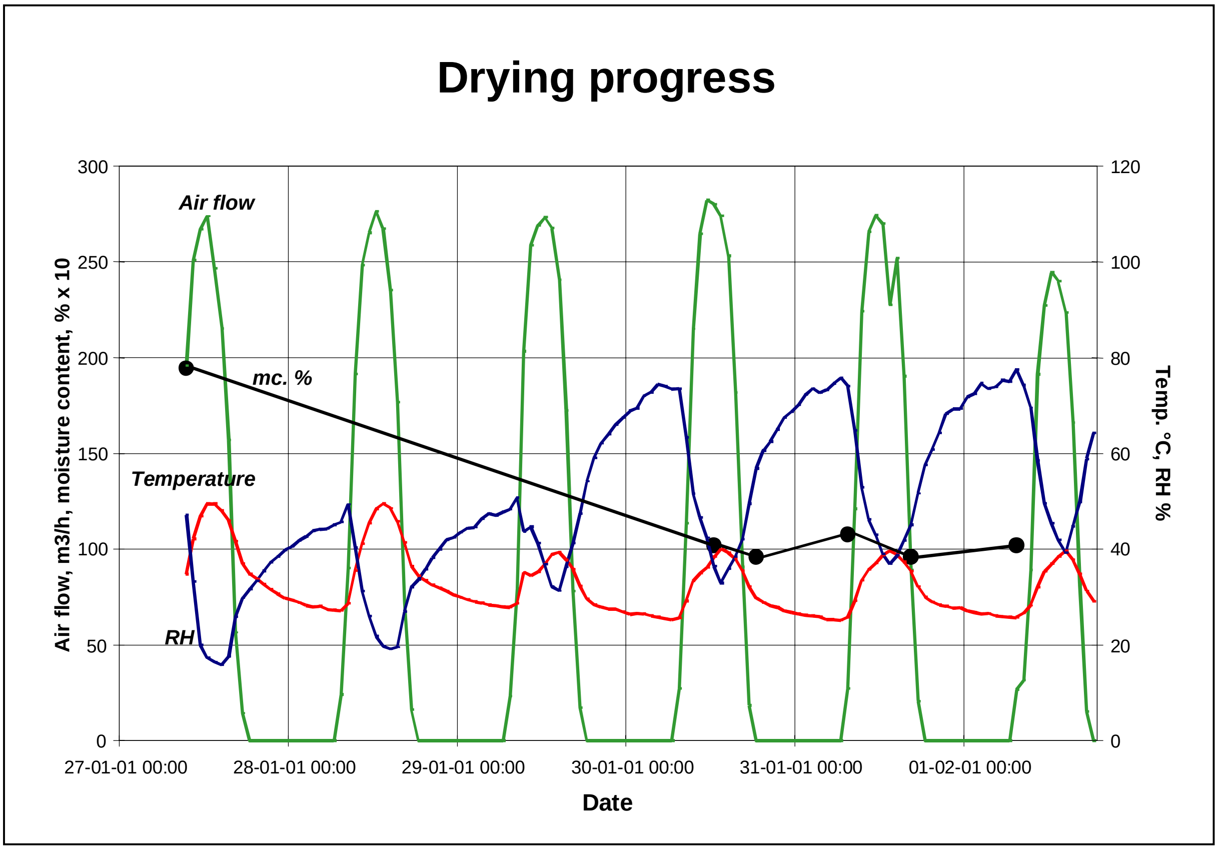

Figure 2. The drying progress in the solar crop dryer. The correlation for reduction in maize moisture content, air flow rate, temperature of the drying air and relative humidity of the drying air.

The effective drying period per day corresponds to the running time of the drying fan. This time was about 8-9 hours per day. Figure 2 shows that the air flow rate was about 250 m^3/h during the drying. On 27 and 28 January the average temperature and the relative humidity of the drying air were about 44°C and 21% RH, respectively. On 29 and 30 January, the temperature was a little lower. For this period the average temperature and the relative humidity of the drying air were about 36°C and 40% RH, respectively. At these conditions and at drying until 30 January at 12:10, the moisture content can be calculated to be 10.0% on the basis of the theoretical equations concerning drying of maize in the solar crop dryer. The measured moisture content was 10.2%. This test thus shows a drying capacity very close to the expected level. The capacity is a bit lower than what was estimated theoretically, but considering the uncertainty involved with the measurements, especially the moisture meter measurements and weighing of the test trays, the results are in good accordance with what had been the expected as well as with the tests made in Denmark. Please refer to (Jensen, Kristensen and Forman, 2001) for details on the tests carried out in Denmark.

The germination ability of the maize may be damaged if the temperature of the drying air is higher than 45°C for a longer period. This will mean that the maize cannot be used for seed. Figure 2 shows, that the drying air temperature was higher than 45°C for a very short period of time, only. Such short and small exceeding will not damage the crop quality and the germination ability. In other cases with different weather conditions and higher temperatures, it may be necessary to stir or mix the maize in the drying trays to avoid that the maize kernels in the bottom of the trays will be exposed to temperatures higher than 45°C over long periods.

As it will appear from the Tables 1-4 and Figure 2 the relative air humidity is high in the nights. Therefore, there is a risk of moistening of the maize during the nights. However, the tests indicate as expected that the increase in moisture content during the nights is relative small as long as the moisture content in the maize is higher or about 10%. If the maize have to be dried to a lower moisture content, moistening during the nights might be a problem.

Conclusion

In general, the preliminary tests at Silwood Farms were very satisfactory. The drying performance of the crop dryer was as expected. The drying progress when drying maize was in good accordance with the previous tests made in Denmark. However, it must be mentioned that there are some great uncertainties concerning the measurements, especially as regards the moisture content of the maize. Furthermore, the measurements only included two single tests, and moreover, the initial moisture contents of the maize were relatively low in both tests. Therefore, further trials were needed.

Test of the solar crop dryer, September – October 2001

Just like during the minor harvest season of January/February, tests for the documentation of the solar crop dryer's applicability and capacity etc. were made during the main harvest season of September/October 2001. During the drying tests, the manager at Silwood farms filled out information sheets with some basic data describing the progress of the drying and the actual weather conditions. Temperatures, air humidity, sun radiation and airflow through the dryer were recorded by means of sensors connected up with a data logger.

The solar crop dryer was used for drying of maize in a period from 6 September to12 of October 2001. The drying process was divided into two steps. First, the de-husked corncobs were dried to a medium moisture content. Then, the maize was threshed, filled back in the dryer and the second part of the drying process was performed.

The maize was harvested on 6 September and de-husked on the same day. The corncobs were filled into the solar crop dryer. All five sections of the dryer (below called dryer A, B, C, D and E) were used. The quantity of maize was the same, 11.5 kg, for all six trays per drying section.

The registration of temperatures etc. recorded by means of data logger were only made for Dryer A, but as the five drying sections are of the same construction and the operating characteristics were identical the logged data are used for all five drying sections.

An electric moisture meter was used for the determination of the moisture content of the maize before drying. In maize from four of the sections, the moisture meter reading showed 22.2% of water, and for one of the sections – section A - the moisture meter reading showed 27.5% of water. As the maize was from the same lot, it is assumed that the initial moisture content of all the maize was 22.2%, and that the 27.5% is due to an incorrect reading or error in measurement. Unfortunately, no determination of moisture content by the standard method (drying out of a test portion in an oven) was made. Thus, there is a great uncertainty connected with the statement of moisture content.

Figures 3 to 7 show results from first part of the drying test, where the corncobs were dried. The figures show the drying progress in combination with the ambient air temperature and humidity and the air output of the drying fan. The graph named "moisture content" is the moisture content calculated on the basis of the weight loss and an initial moisture content of 22.2%.

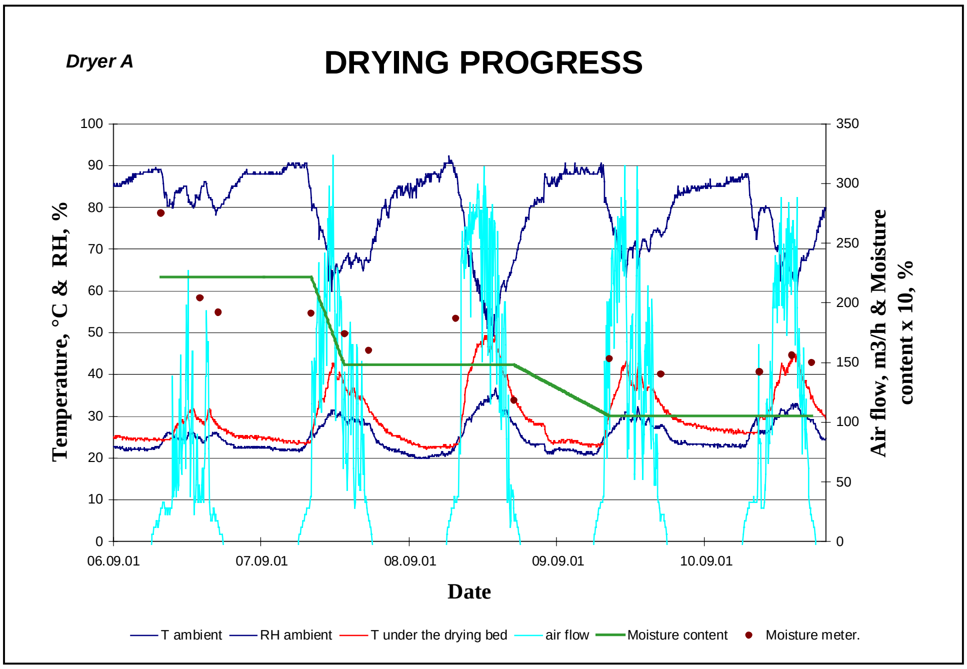

Figure 3 Drying progress in the solar crop dryer section A. Moisture content, airflow rate, temperature of ambient air and drying air, and relative humidity of the ambient air when drying corncobs.

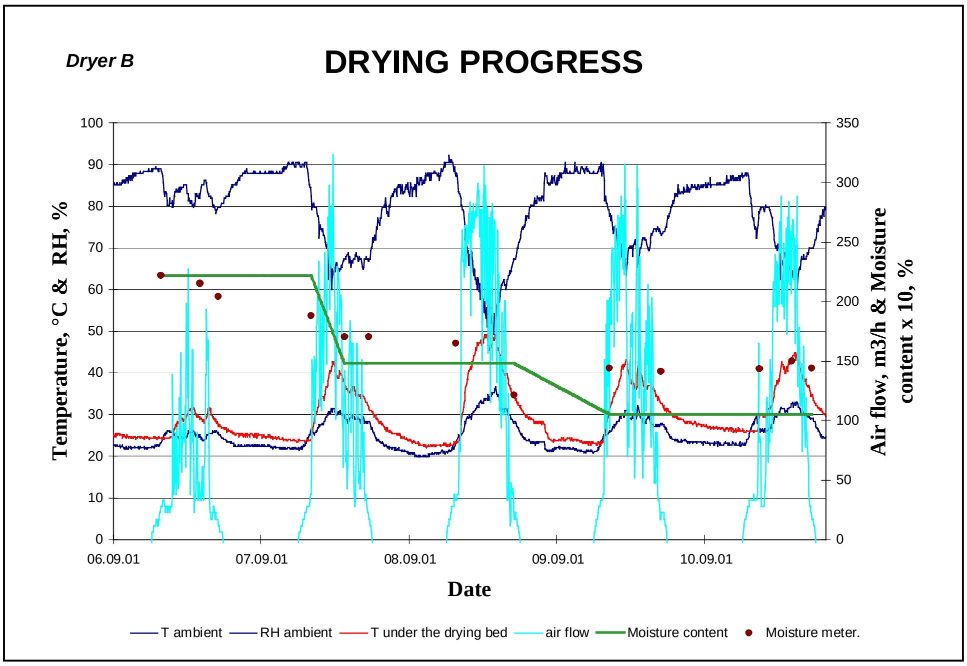

Figure 4 Drying progress in the solar crop dryer section B. Moisture content, airflow rate, temperature of ambient air and drying air, and relative humidity of the ambient air when drying corncobs.

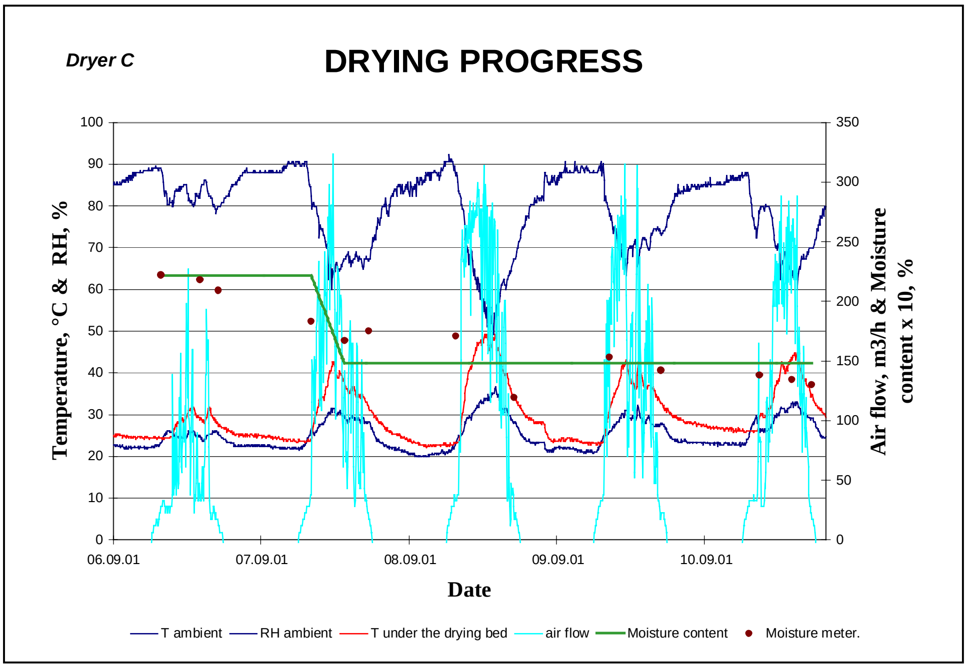

Figure 5 Drying progress in the solar crop dryer section C. Moisture content, airflow rate, temperature of ambient air and drying air, and relative humidity of the ambient air when drying corncobs.

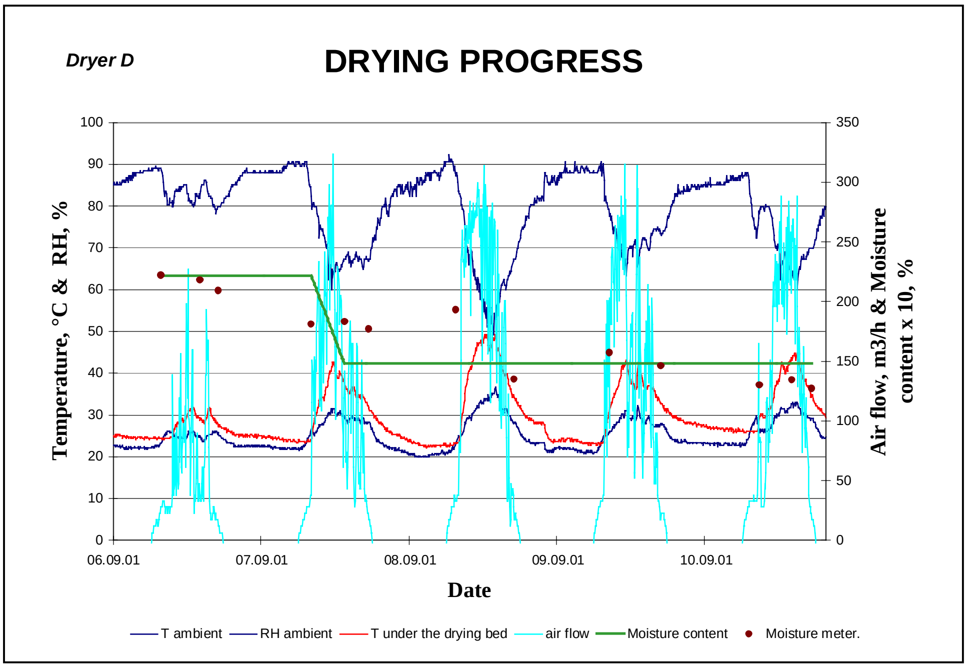

Figure 6 Drying progress in the solar crop dryer section D. Moisture content, airflow rate, temperature of ambient air, and drying air and relative humidity of the ambient air when drying corncobs.

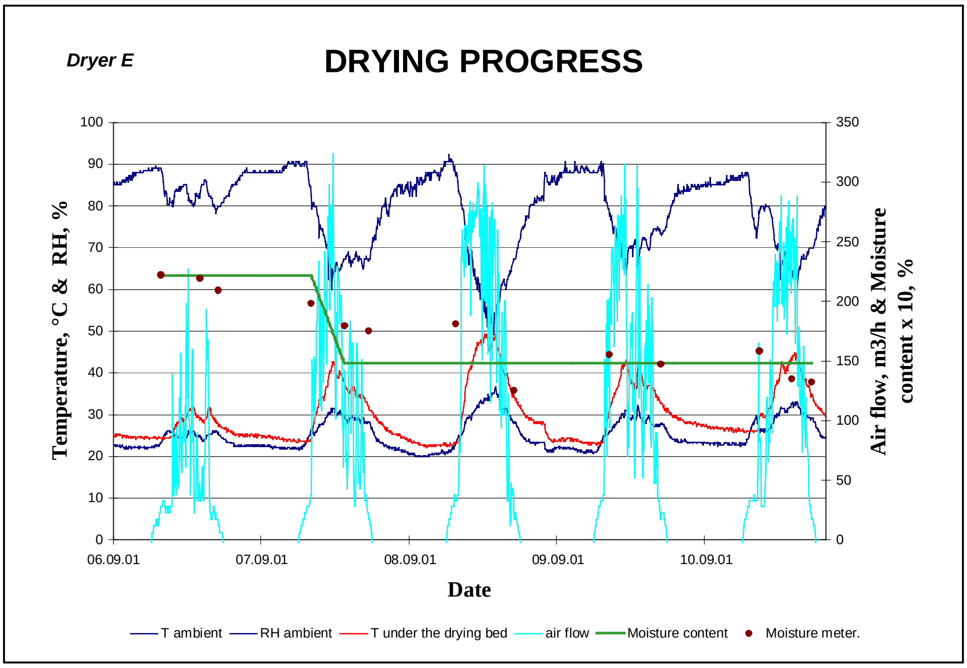

Figure 7 Drying progress in the solar crop dryer section E. Moisture content, airflow rate, temperature of ambient air and drying air, and relative humidity of the ambient air when drying corncobs.

As it will appear from the Figures 3 to 7 the drying conditions were pour on 6 September due to very high air humidity (80-90% RH), low warming of drying air and low airflow. In the period of 7-10 September the drying conditions were better even though the humidity of the ambient air was relative high and only below 60% for a short time of period on 8 September. Except for the 6 September the effective drying time -corresponding to a fan output higher than 100 m³ per hour- was about seven hours per day. During the drying period the warming up of the air - the difference between the ambient air temperature and temperature of the air under the drying bed - was about 10°C. At these conditions the moisture content by the end of 10 September can be calculated to be about 13.4% on the basis of the theoretical equations concerning drying of maize in the solar crop dryer.

The drying air temperature was higher than 45°C only for a very short period of time. Such a short and low exceeding of the maximum temperature in respect to damaging the germination ability of the maize will probably be without any significance.

As for the first drying tests performed January 2001, the drying progress can not be described only on the basis of the moisture meter measurements of moisture content, because there obviously are some inaccuracy in this data. By way of example, it can be seen that the moisture meter readings of 9 September for Dryer E dropped from 18.1 to 12.5% without any changes in weight. Such a drop in moisture content would cause a weight loss of 0.7 kg due to the occurring water evaporation. However, the statement of moisture content based on the weight loss, which occur only due to water evaporation, is also imperfect due to the much too low weighing accuracy. Apparently, the weight used had a graduation of only 500-gram. A weight graduation of 500 gram when weighing this amount of material leads to graduations in the calculated moisture content of 4-5 %-units. This is an insufficient accuracy for carrying through a satisfactory evaluation of the drying capacity.

The first part of the drying – drying of the whole corncobs - was finished on 10 September. The maize was threshed on 11 September, filled back into the solar crop dryer, and the second part of the drying process started on the same day. Based on the measured weight loss and a moisture content of 22.2% at start, the moisture content after the first part of the drying can be calculated at 13.1% on average. The moisture meter readings showed an average of 13.7% for all five sections, and a moisture content of 13.5% of the threshed maize that was filled back into the drying trays. On average, there was thus a satisfactory similarity between the calculated moisture content based on weight loss and the moisture meter readings after the first part and at the start of the second part of the drying test, in spite of all the mentioned uncertainties involved. Also, the theoretical estimations of drying rate were in good accordance with the measured data for the first part of the drying test.

It is assumed that the moisture content of all the maize was 13.5% at the start of second part of the drying test. Only two sections of the dryer – Dryer D and Dryer E - were used for this part of the drying test. The quantity of maize was the same, 15.5 kg, for all six trays per drying section. Part 2 of the drying test continued until 12 October.

Figures 8 and 9 show results from the second part of the drying test where the threshed maize was dried. The figures show the drying progress in combination with the ambient air temperature and humidity and the air output of the drying fan. As for the first part of the test, the graph named "moisture content" is the moisture content calculated on the basis of weight loss, and for this part of the test on the basis of an initial moisture content of 13.5%.

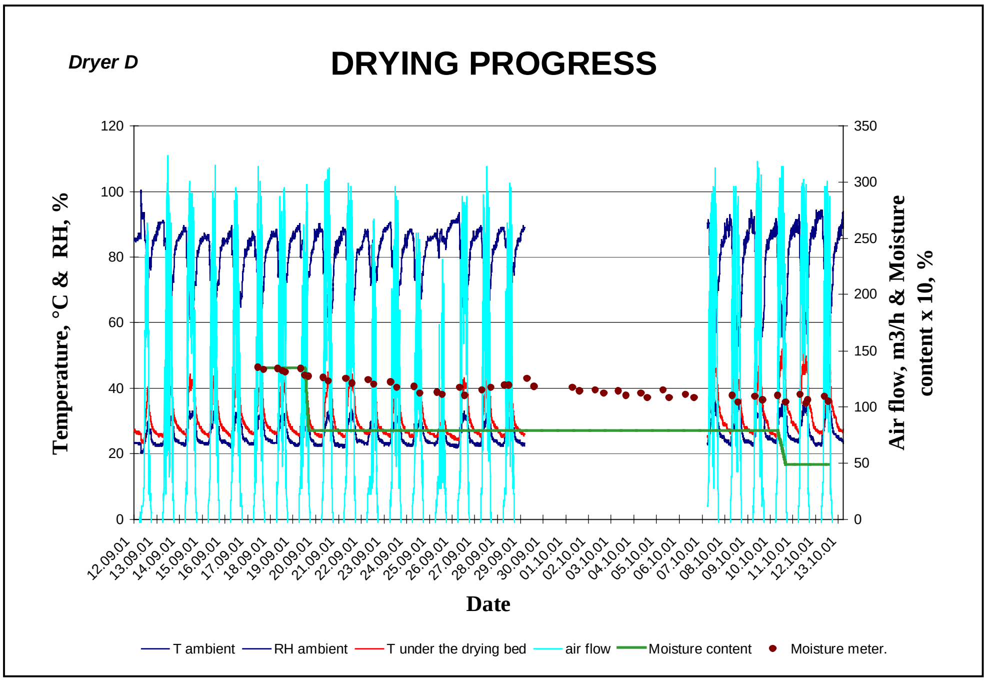

Figure 8 Final drying of threshed maize. Drying progress in the solar crop dryer section D. Moisture content, airflow rate, temperature of ambient air, and drying air and relative humidity of the ambient air.

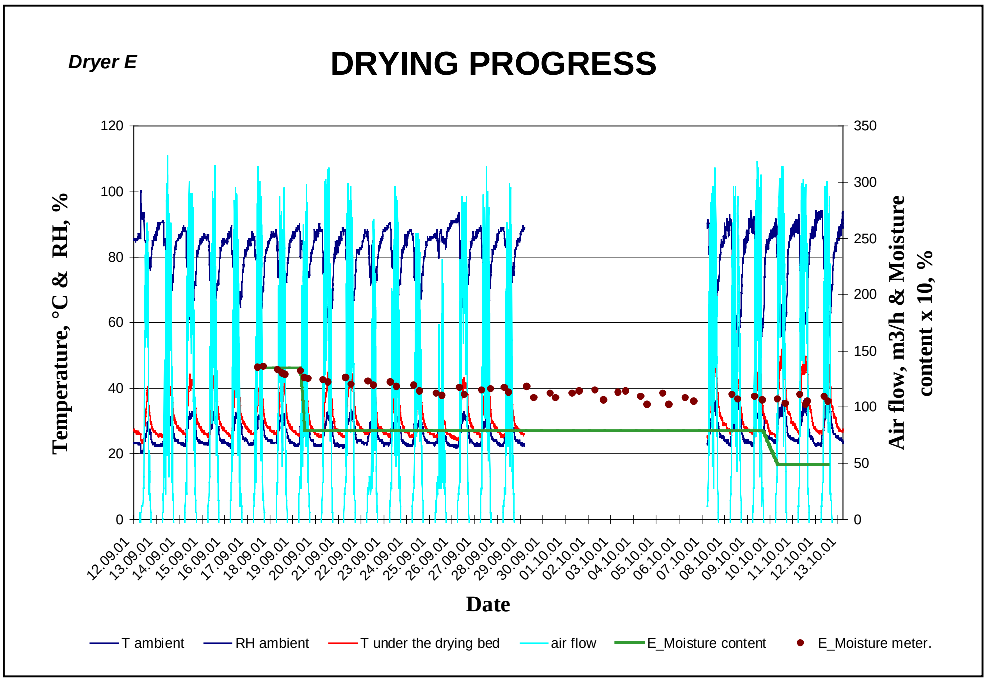

Figure 9 Final drying of threshed maize. Drying progress in the solar crop dryer section E. Moisture content, airflow rate, temperature of ambient air, and drying air and relative humidity of the ambient air.

As it will appear from Figures 8 and 9, data is missing for some periods. Although the maize was filled into the dryer already on 11 September, no registrations of weight loss or moisture meter readings were made before 17 September. The manager at Silwood Farms probably considered that registrations were unnecessary, due to relatively poor drying conditions within this period. From 29 September and until 7 October, the data logger system was out of function, and therefore, no data on temperatures, humidity and airflow have been recorded.

This second part of the drying test was running over a very long period of time. The goal was to dry the maize to a final moisture content of about 10%. If one look at the moisture content determined on the basis of the measured weight loss, the maize in fact was sufficient dry already on 19 September. At that time the moisture content can be calculated at about 8% or when the current applied weighing accuracy is taken in consideration between 9.4 and 6.4%.

However the drying was continued until 12 October, because the moisture meter readings still showed values higher than 10%. Either are the moisture metre readings not useful because the accuracy of the moisture meter used is insufficient for this purpose (the accuracy of measurement for the metre not high enough), or the weighing results are wrong. Weighing is a simple method and must be considered to be the most reliable, but the weighing accuracy has been too low.

On the other hand the moisture content at the end of the test - the 12 October - calculated on the basis of weight loss is unlikely to be correct. The moisture content can here be calculated at 4.9%. This is a very low moisture content, and in fact lower than the theoretical equilibrium moister content for maize and the current drying air. Either the weightings are incorrect or material has been removed from the drying trays during the test.

In general, the weather conditions during the second part of the drying were not optimal for solar drying. The humidity of the ambient air was relatively high and only for very short periods from 12 September to 29 September it was below 70%. This can explain the relatively low drying capacity for this period. In the last part of the period the weather conditions were more suited for solar drying.

From 11 September to 19 September the effective drying time -corresponding to a fan output higher than 100 m³ per hour- was 4-7 hours per day. During the drying, the warming up of the air was 7-10°C and the relative humidity of the drying air was about 38%. At these conditions the moisture content by the end of 19 September can be calculated at 9.95% on the basis of the theoretical equations concerning drying of maize in the solar crop dryer. This supports the assumption that the moisture meter readings are wrong.

As for the first part of the drying test, the drying air temperature was higher than 45°C only for very short periods of time. Such short and low exceeding of maximum temperature in respect to damaging of the germination ability of the maize will probably be without any influence.

Conclusion

The tests performed at Silwood Farms during the main maize harvest season of 2001 from September to October show varying results. When drying corncobs the drying performance of the crop dryer was as expected. When drying corncobs from a moisture content of about 22 to about 13%, the effective drying time during non-optimal weather conditions was four days.

The drying progress when drying threshed maize is very difficult to evaluate on the basis of the test, due to the lake of accurate measurements and inconsistent data. The moisture content calculations based on the recorded weight loss shows a results which is in acceptable accordance with the drying capacity based on the theoretical equations during the first week of the drying. The moisture meter readings have shown substantially different values than that calculated, and it is obvious that the accuracy of the used moisture meter is insufficient for this purpose.

The measurements only include drying of one single batch of maize, and some great uncertainties are involved on the determination of the moisture content of the maize. Therefore further trials were needed. The moisture content before and after the drying process must be determined accurately and the weight loss during the drying progress must be recorded with an accuracy of at least +/- 100-gram.

The germination ability of the maize may be damaged if the temperature of the drying air is higher than 45°C for a longer period. This will mean that the maize can not be used for seed. The tests have shown, that the drying air temperature only will be higher than 45°C for very short periods of time. Such short and small exceedings will probably not cause reductions in the quality and the germination ability, but it has to be verified by means of germination tests on the processed maize. In cases with drying air temperatures higher than 45°C, it may be necessary to stir or mix the maize in the drying trays to avoid that maize kernels in the bottom of the trays are exposed for temperatures higher than 45°C for an long period of time.

The drying capacity of the dryer seems to be lower than what has been the goal for the project. The aim of the project has been to reduce the initial moisture content of about 600 kg of maize from 22 to 10-12% within 2-3 days. The results from the test of January 2001 showed results as expected and apparently in good accordance with the theoretical estimation and the goal for the project. The test of September-October 2001 showed a longer drying period and a lower drying capacity. The capacity was not quite satisfactory in this test. The reason why the drying capacity was low may be due to that the weather conditions during the test were not optimal; for instance was the humidity of the ambient air high. Still, the weather conditions were not extreme for this time of the year in Ghana, and therefore, the solar crop dryer should also be applicable for that kind of conditions.

Test of the solar crop dryer, November 2001

As a result of the problems in the evaluation of the drying capacity for the plant an extra test was made in the period from 9 November till 11 November. The problem is that calculations based on the measured weight loss (= the evaporation of water due to the drying) at the previous tests have shown results that are substantially different to the moisture metre readings.

Either are the moisture metre readings from test made during the drying process not useful for this purpose (the accuracy of measurement for the metre not high enough) or the weighing results are wrong.

Figure 10. Dole Grain Moisture Tester, the moisture meter used at Silwood Farms.

At the previous tests the determination of the moisture content at start and by the end of the drying only have been done by means of the farmer's moisture metre. In order to achieve more reliable data on the determination of moisture content in the crop, a sample of the maize before and again after drying in the solar crop dryer was sent to the *Food Research Institute* of the Council for Scientific and Industrial Research (CSIR).

The results of the test are shown in table 5.

	Before drying	After Drying
Weight of maize, kg	71.7	65.31
Moisture meter, %	13.6	12.8
Moisture content, % [1)]	11.8	11.3

[1)] Standard method. Moisture content determination performed by the Food Research Institute.

Table 5. Results of drying test November 2001, including moisture meter reading in comparison with moisture content determined by standard method.

As it will appear from the table hardly any reduction in moisture content did occur during the test. This is primarily because the maize was almost dry before it was filled in the dryer; the moisture content at start was only 11.8%. There weren't made any registrations on weather conditions, temperatures and air humidity or solar radiation. For these reasons it is not possible to make any good or reliable evaluation of the drying capacity at this test.

However, an evident result from the test is the differences between the moisture meter readings and the moisture content determined by the standard method at Food Research Institute. The results from the analysis performed at Food Research Institute should be considered as the correct values. It appears clearly that the farmer's moisture meter have shown to high values for moisture content, thus 1.5 – 1.8 percent point to high moisture content.

Conclusion

This test performed at Silwood Farm from 9 November till 11 November 2001 give no significant information on the drying ability of the solar crop dryer. However, the test gives some important knowledge concerning the determination of moisture content of maize dried in the plant.

The farmer's electric moisture meter may show incorrect results when measuring in rather dry maize. The results may be 1.5 – 1.8 percent point to high compared to the real moisture content of the crop. Therefor the measured weight loss (= the evaporation of water due to the drying) must be used for making out when the drying process is finished. The method is described in Appendix A "Simple test method". If a good and reliable moisture meter is available, it of cause may be used instead, or the moisture content can be determined by drying a test portion of the maize in a heating oven as described in Appendix A.

Test of the solar crop dryer, January 2002

During the minor harvest season of January/February 2002, a test was started on 8 January and ended on 15 January. The maize ears were threshed before the drying, and the drying process was performed in one step. The goal was to dry the maize to an end moisture content of about 10%.

Only one of the five section of the dryer was used at this test. The quantity of maize was the same, 11.7kg, for all six trays in the drying section used for the test. The drying process was registered by weighing the trays with the crop before the drying was started and again several times during the drying process. Furthermore the farmer's electric moisture meter was used for measuring the moisture content of the maize before, during and after drying. During the drying test, the works manager at Silwood farms filled out information sheets with some basic data describing the progress of the drying. By each weighing of the maize one moisture meter measurement was made on maize from al six drying trays, tray A-F. The registered data are shown in the below Table 6.

Date	Hour	Weight Maize[1], kg	Weight loss Maize[1], kg	Moisture content, %						
				Moisture meter reading						Calculated[2]
				A	B	C	D	E	F	
8 January	8:30	11.7	0.00	14.8	14.8	14.8	14.8	14.8	14.8	14.8
-	13:20	11.4	0.27	11.1	11.3	11.3	11.4	11.6	11.7	12.8
9 January	7:30	11.4	0.28	11.2	14.4	11.4	11.5	11.5	11.3	12.7
-	13:30	11.3	0.42	11	10.9	10.9	10.8	11	11	11.7
10 January	7:00	11.3	0.38	11	11	11	11	11.1	1	11.9
-	14:50	11.2	0.55	10.8	10.6	10.5	10.6	10.5	10.2	10.6
11 January	6:50	11.2	0.52	10.8	10.9	10.9	10.7	10.8	10.8	10.9
-	14:30	11.0	0.67	10.6	10.4	10.3	10.7	10.6	10.3	9.6
12 January	7:00	11.0	0.68	10.6	10.7	10.8	10.6	10.7	10.5	9.5
-	14:10	10.9	0.78	10.3	10.3	10.6	10.6	10.3	10.2	8.7
14 January	7:00	11.1	0.62	10.8	10.8	10.7	10.6	10.8	10.6	10
-	13:50	10.9	0.78	10.3	10.2	9.9	9.9	9.8	9.2	8.7
15 January	6:50	10.9	0.85	10.2	10.8	10.6	10.8	10.3	10.5	8.1
-	14:30	10.8	0.93	10.1	10.3	10.2	10.1	10.1	10.1	7.4

1) Average for the six drying trays (tray A-F).

2) Moisture content calculated on the base of the moisture content at start (14.8 %) and weight loss

Table 6. Drying test at Silwood Farms 8-15 January. Water evaporation and moisture content during the drying progress.

Figure 11 show results from the drying test graphically. The figure shows the drying progress and the airflow. The graph named "moisture content" is the moisture content calculated on the basis of the weight loss, which takes place due to the evaporation of water, and the initial moisture content of 14.8%.

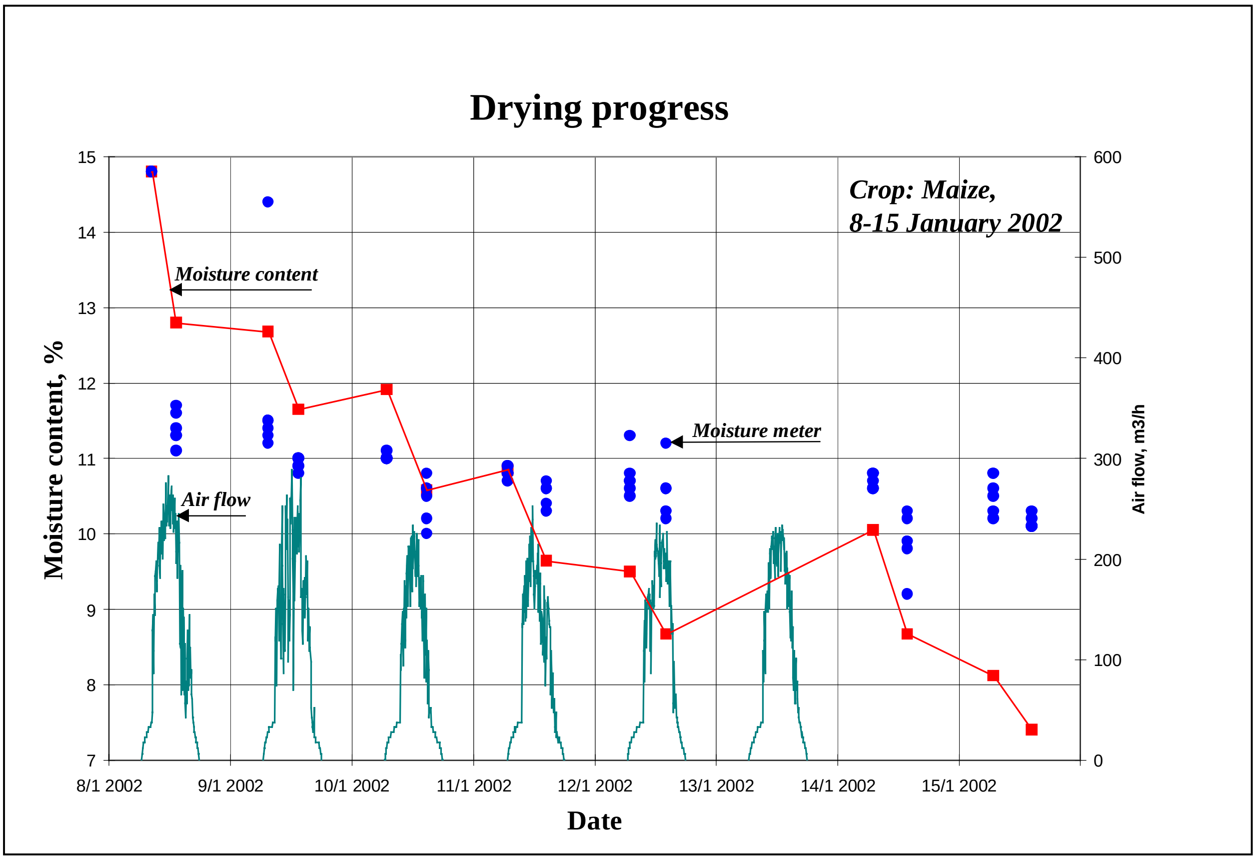

Figure 11 Drying progress in the solar crop dryer. Moisture content and airflow rate when drying maize.

As it will appear from Table 6 and Figure 11, the drying was in fact finished on the12 January. After 1 day the moisture content was reduced to about 12% and after 4 days drying the moisture content was below the 10%. As for the previous tests the moisture meter readings show very varying results. The meter show a tendency to give to low values at the first part of the drying, and to high values at the last part of the drying. The to high moisture meter values at the end of the drying is as expected, and in accordance with the results obtained from the test in November where samples were send to the Food Research Institute and moisture content were determined by the standard method.

During this test there were no registrations of solar radiation, air temperature and air humidity. These parameters have decisive influence on the drying process, and since these data is missing it is not possible to make a complete evaluation of the drying process. Also there are some uncertainties on the determination of the moisture content at the start of the test. The moisture content at start of the test is only determent by means of the farmer's moisture meter.

Conclusion

This test performed at Silwood Farms during the minor maize harvest season of 2002 from 8 January to 15 January show acceptable results. The drying capacity seems to be a little lower than expected. The moisture content was reduced from 15% to about 12% after 1 day, and to below 10% after 4 days.

After drying, the variation in moisture content between maize from the 6 different trays was low, and without practically importance.

Test of the solar crop dryer, March 2002

By the end of the minor harvest season of January/February, a final test for documentation of the solar crop dryer's applicability and capacity was made. At the previous tests, the determination of exact moisture content has been a problem. At the actual test the determination of the moisture content of the maize before the drying, and that of the maize after completion of the drying test were made at the Danish Institute of Agricultural Sciences, Research Centre Bygholm, according to the International Standard ISO 6540.

The test was performed during the Danish project participants' visit to Ghana on 2 to 8 March, 2002. The Danish experts assisted the manager at Silwood Farms in the measurements involved with the test. During the drying test, the manager at Silwood farms filled out information sheets with some basic data describing the drying progress. Temperatures, air humidity, sun radiation and airflow through the dryer were recorded by means of sensors connected with data loggers. Only one of the five drying sections in the solar crop dryer was used for this test.

The test was started on 3 March and finished on 6 March. The maize ears were threshed before drying, and the drying process was performed in one step. The goal was to dry the maize to a final moisture content of about 10%. The quantity of maize was the same, about 12 kg, for all six trays in the drying section used.

The drying process was registered by weighing the trays with the crop before the drying and again several times during the drying process. A precision scale was used for the weighing at the start of the drying test and again at the end of the test on 6 March. On the basis of the weighing, the weight of the maize and the weight loss during the process were calculated. The recorded weight loss was due to water evaporation from the maize concurrently with the drying.

An electric moisture meter was used for measuring the moisture content of the maize before, during and after drying. The moisture meter readings were only used as guidelines and with the purpose of controlling the accuracy of the meter. For each weighing, one moisture meter measurement was made of the maize from all six drying trays, A-F. The registered data are shown in the below Table 7.

Figure 12 shows graphical results from the drying test. The drying progress and some of the essential drying parameters, the ambient air temperature and humidity, the temperature of the drying air and the airflow are shown. The graph named "moisture content" shows the moisture content that has been calculated on the basis of the weight loss that takes place due to the evaporation of water. The calculations are based on the initial moisture content of 15.4%.

Date	Hour	Weight Maize[1], kg	Weight loss Maize[1], kg	Moisture content, %							
				Moisture meter reading						Standard method, ISO 6540	Calcu-lated[2]
				A	B	C	D	E	F		
3 March	12:30	11.95	0.00	14.4	14.4	14.4	14.4	14.4	14.4	15.4	15.4
-	16:00	11.81	0.14	12.7	12.7	12.5	12.8	12.7	12.6		14.4
4 March	7:30	11.15	0.80	12.2	12.0	12.4	12.4	12.6	13.3		9.4
-	12:40	11.07	0.88	11.9	11.8	12.0	12.0	12.2	12.6		8.7
-	17:20	11.03	0.92	10.8	10.6	10.4	10.5	10.7	10.8		8.3
5 March	7:00	11.03	0.92	12.7	10.9	11.3	11.3	11.1	11.3		8.3
-	13:00	11.00	0.95	11.4	11.0	11.2	11.1	11.0	11.1		8.1
-	16:10	11.03	0.92	9.9	9.6	9.8	9.8	9.9	10.0		8.4
6 March	7:05	10.96	0.99	11.0	11.1	10.6	10.9	11.2	10.9		7.8
-	16:20	11.04	0.91	10.3	9.9	10.3	10.3	10.3	10.0	8.8	8.5

[1] Average for the six drying trays (A-F).

[2] Moisture content calculated on the basis of the initial moisture content (15.4%) and weight loss measurements.

Table 7. Drying test at Silwood Farms 3-6 March. Water evaporation and moisture content during the drying progress.

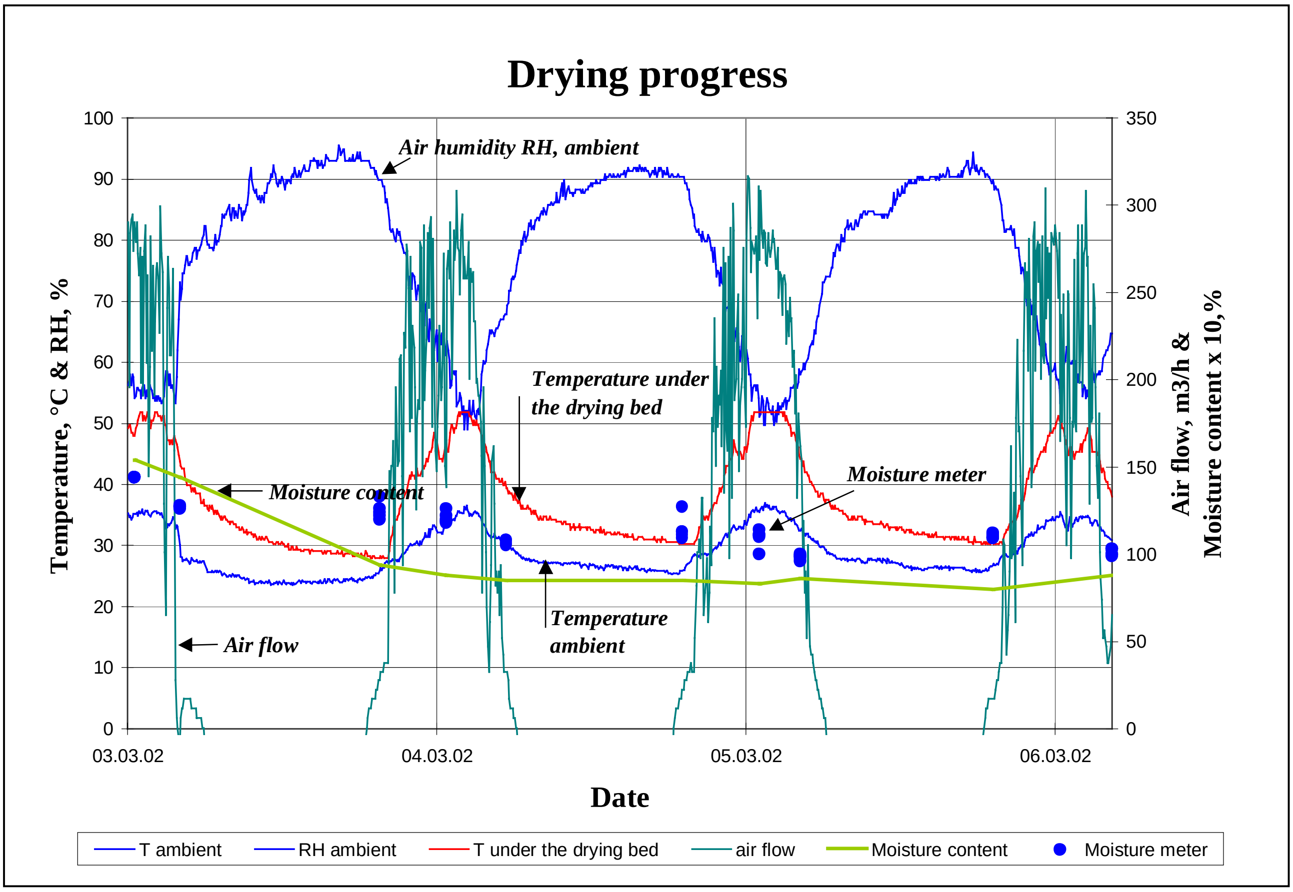

Figure 12. Drying progress in the solar crop dryer. Moisture content, airflow rate, temperatures of ambient and drying air, and relative humidity of ambient air when drying maize.

As it will appear from Table 7 and Figure 12, the drying was finished after one day, only. Already on 4 March, the moisture content was below 10%. From the start of the drying and until then, the effective operating time of the drying fan was only 4 to 5 hours. If the average air flow rate is set at 250 m^3 per hour, the average temperature and the average air humidity (ambient air) during the running period are set at 35°C and 55% RH, respectively, and the air heating in the solar collector is set at 15°C, then the moisture content can be calculated at 11% on the basis of the theoretical equations for drying of maize in the solar crop dryer. This test thus shows a higher drying capacity than expected, but it must be mentioned that there are some uncertainties concerning the weighing performed on 4 and 5 March. A precision scale was used for the weighing at the start of the drying test on 3 March and again at the end of the test on 6 March.

The air temperature measurement indicates that some drying was still taking place on 4 March. Thus, the temperature was reduced as the air passed through the maize. As an example, the air temperatures at 2:00 p.m. were reduced by about 14°C on the 3 March, by about 6°C on 4 March, and by less than 1°C on 5 March, and on 6 March no reduction occurred at all. As conclusion, the temperature measurements confirm that no drying took place after 4 March.

During the drying period, the heating up of the air – i.e. the difference between the ambient air temperature and temperature of the air under the drying bed – was about 15°C. At the actual conditions with an ambient air temperature of about 35°C in the afternoon, the drying air temperature will be very high. The drying air temperature was higher than 50°C for a short period of time. In respect to damaging the germination ability of the maize, such high maximum temperatures might be critical for maize for seeding.

Water will evaporate from the maize seeds as long as the drying process takes place. The water evaporation will cause cooling of the maize, and the temperature of the seeds will therefore become lower than the temperature of the drying air. During the drying process, drying air temperatures higher than 45°C will therefore not necessarily damage the germination of the seeds. When the drying is completed, the maize temperature will reach the same level as the drying air. If the temperature is about 50°C, as was the case for this drying test, the germination ability of the seeds will be damaged if the maize stays in the dryer after the finalization of the drying.

The works manager had previously made germination tests on maize dried in the solar crop dryer, and he had not observed any reduction in the germination percentage. The germination tests had shown germination percentages about 96%, which is a high germination rate.

At weather conditions with high temperatures as for this period, it is thus very important that the maize is removed from the dryer immediately after the drying is completed. By weighing the maize, the works manager will always be able to see when the drying is finished. Once the weight loss has been measured, the moisture content can be calculated on the basis of the initial weight and initial moisture content. This can be done by means of the table shown in Appendix A "Simple test method", or the current moisture content can be calculated according to the below formula:

$$M = ((A * (M_1 / 100) – B) * 100) / (A – B)$$

M	=	Current moisture content, %
M_1	=	Initial moisture content, %
A	=	Initial weight, kg
B	=	Weight loss due to drying, kg

In general, the weather conditions during the drying period were good for solar drying. The temperature was high, and the humidity of the ambient air was sufficiently low.

Conclusion

The test performed at Silwood Farms during the minor maize harvest season from 3 to 6 March 2002 showed very good results. When threshed maize was dried, the drying performance of the crop dryer was at least as high as expected, or even higher. When maize was dried from a moisture content of 15.4 to about 10%, the drying time was about one day.

As for the previous drying tests, the drying progress cannot be described only on the basis of the moisture meter measurements of the moisture content, because obviously, there are some inaccuracy in these data. The accuracy of the farmer's moisture meter is insufficient for this purpose. The farmer or the works manager will be able to see the drying progress simply by weighing one drying tray during the drying process.

The germination ability of the maize may be damaged, if the temperature of the drying air is higher than 45°C for a longer period. If the maize seed temperature exceeds 45°C, the maize cannot be used for seed. The test has shown that the drying air temperature may be about 50°C for short periods of time. Such short-term excess temperatures will probably not cause reductions in the quality and the germination ability, as long as the maize drying takes place, because the water evaporation will cause cooling of the maize. Germination tests on maize dried in the solar crop dryer have thus shown high germination percentages. But in cases with drying air temperatures higher than 45°C, it may be necessary to stir or mix the maize in the drying trays to avoid that maize kernels in the bottom of the trays be exposed for temperatures higher than 45°C for a long period of time. Furthermore it is very important that the maize be removed from the dryer immediately after the drying is completed.

Conclusive evaluation of the tests

In general, the results from the drying tests at Silwood farms have been satisfactory. It is thus possible to dry maize for seed in the solar crop dryer.

Germination tests on maize dried in the solar crop dryer have shown high germination percentages. The manager at Silwood Farms stated that the germination percentage was 96%.

The drying performance of the dryer has been as expected during the tests performed during the minor maize season of January-February. It was thus possible to dry 100-120 kg maize per drying section within 1-4 days. The initial moisture content of the maize was 15-20% and after drying, the moisture content did not exceeded 10%.

The test performed in September-October 2001 showed a longer drying period and a lower drying capacity. The capacity at this test was not quite satisfactory. However, it must be mentioned that there were some great uncertainties concerning the measurements at the test. The reason why the drying capacity was low may be due to the weather conditions during the test. The weather was not optimal. For instance was the humidity of the ambient air high. The goal was to dry the maize to a final moisture content of about 10%. The drying test ran over a very long period, because the moisture meter readings showed values higher than 10% allow the moisture content was below 10%.

The accuracy of the moisture meter (Dole Grain Moisture Tester) used at Silwood Farms was insufficient to determine when the drying was finished. The moisture meter showed incorrect results. When measuring in rather dry maize, the moisture meter readings were 1.5-1.8 pct. points too high compared to the real moisture content of the maize. Therefore, the measured weight loss (= the evaporation of water due to the drying) must be used for determining when the drying process is finished, or the moisture content must be determined by drying a test portion of the maize in a heating oven, as described in Appendix A. If a good and reliable moisture meter is available, it can, of course, be used instead.

It is very important that the maize is removed from the dryer immediately after the drying is finished. If dry maize remains in the dryer, and the temperature of the drying air is higher than 45°C for a long period, the germination ability may be damaged. If the maize seed temperature exceeds 45°C, the maize cannot be used for seed. The tests have shown that the drying air temperature can be about 50°C for short periods. As long as the drying takes place, the water evaporation will cause cooling of the maize, and thereby keeping the maize temperature below 45°C. When the maize is dry, no water evaporation will take place, and the cooling will stop. Thereby, there will be a risk of too high temperatures in the maize. In cases with drying air temperatures higher than 45°C, it may be necessary to stir or mix the maize in the drying trays to avoid exposure of the maize kernels in the bottom of the trays to temperatures higher than 45°C for a long period.

After the drying process, the variation in moisture content between the 6 trays per section is acceptably low and without any practical importance.

The operation and maintenance of the dryer went without any essential problems. The solar collector panels were cleaned only when it rained. At the inspection in March 2002, the filters at the inlets turned out to be dirty and had to be washed. Dirty inlets filters will cause reduction in the airflow. After the 1-year running period of the dryer, some minor repair work had to be done, e.g. mending a leaking roof, straightening and tightening of the bottom of a pressure chamber and problems with a fan and the Kreiberg psycrometer.

Some non-technical conclusions of the test and on the introduction of this new solar drying technique may also be made. Firstly it is important to appoint someone on the site to be responsible for quality. This person must be responsible for implementing and monitoring the system. All personnel involved should be given some training concerning the drying technique and the fundamental drying process. The training should provide each individual with enough information to be able to carry out their duties in a professional manner.

Improvements and further development of the dryer

On the basis of the tests and the acquired experience, some improvements can be made on the solar crop dryer. Due to uncertainties involved with the performed tests it is difficult to make an exact determination of the potential for improvements. However, it is obvious that the use of the plant will involve some problems. Reduced drying abilities during poor weather conditions will for instance have to be taken into consideration, but it is likely to be expected that improvements can be made within reasonable costs.

The solar crop dryer may also be used for drying of other crops. That will enlarge the total number of operational days per year and thereby improve the economy of the dryer (Jensen; Kristensen and Forman, 2001). A preliminary test at Silwood Farms has shown that the dryer could dry cassava, pepper and okro very well within 3 days. For drying of pawpaw and pineapple there were problems with the quality of the dried crops. Thus, there are good possibilities for drying of other crops, but the drying methods and perhaps also the construction of the drying bed have to be developed for these alternative crops. As regards the test of the solar crop dryer for drying of other crops, please see the next chapter by Florence Agyei.

The aim of the project has been to reduce the initial moisture content of about 600 kg of maize from 22 to 10-12% within 2-3 days. The results from the tests during the minor maize season of January to February were as expected and apparently in good accordance with the theoretical estimation and the goal of the project. Under weather conditions that are not optimal for sun drying, the drying capacity of the dryer seems to be lower than what has been the goal of the project. The test of September-October 2001 showed a longer drying period and a lower drying capacity due to high humidity of the ambient air was high. Still, the weather conditions were not extreme for this time of the year in Ghana, and therefore, the dryer should also be applicable for that kind of conditions.

Improvements in the capacity may be obtained, either by increasing the drying air temperature, by increasing the airflow or extending the running time of the dryer.

Higher drying air temperatures will be critical in respect to the germination abilities of seeds. If higher temperatures are used for drying maize for seeding, it will be necessary to stir the maize or keep it in continuous motion during the drying process. A technique to prevent heating up the single seeds to temperatures higher than 45°C must be developed. That is, of course, possible, but a more complicated and more expensive technique will be required. Different methods of construction should be evaluated both from a technical and from an economical point of view.

An increase in the air volume is a factor which might speed up the drying process and at the same time reduce the risk of too high temperatures in periods with high ambient air temperatures. The mechanical efficiency of the chosen fan is good as well as the fan characteristic is suitable for the current purpose. Therefore, an increased air volume will require a higher electric input, and as PV-panels are expensive, it will be expensive to increase the air volume. An increase in flow rate demands further an increase in the area of the solar air collectors.

The third possibility will be to increase the running time of the plant. The present situation of the existing solar crop dryer is that maximum 1/3 or the daily number of hours is used for drying. If there is none or a very low solar radiation, the fan will not run, and no heating of the drying air will take place. If the energy is stored from the middle of the day for later use, the drying periods per day might become longer. A battery back-up system to supply the fan with electricity could be a possibility. However, such a technique would demand development of a control system for the fan, in respect to storage of electricity, balance between airflow and temperature and the available stored heat energy. Use of extra solar collectors to provide more energy for the heating of air might be necessary or beneficial. The issue needs to be thoroughly examined both by means of theoretical estimations of energy balances and drying time, etc., and from an economical point of view. Finally, in order to evaluate the system, some particle trials will be necessary.

References

Jensen, S.Ø., Kristensen, E.F. and Forman, T., 2001. Test of a solar crop dryer. Solar Energy Centre Denmark, Danish Technological Institute and Department of Agricultural Engineering, Danish Institute of Agricultural Sciences and Aidt Miljø A/S. ISBN 87-7756-583-5.

Jensen, S.Ø., 2001. Inspection of solar dryers in Ghana. Solar Energy Centre Denmark, Danish Technological Institute. ISBN 87-7756-615-7.

Appendix A

Simple test method

For the drying of maize the drying process may be divided into two steps. On the first drying day the whole ears of maize are filled into the drying trays, and the day is used for drying. After this, the ears are threshed, and the maize grain is filled back into the drying trays, after which the drying is finished. The quantity of maize <u>must</u> be the same for all six trays per drying section.

For the drying of other crops, e.g. pepper, the drying process may be performed in one step. The fresh material is filled into the drying trays, and remains into the trays until the drying is finished. Cassava and similar large vegetables or fruits must be sliced or cut into small pieces prior to drying. The quantity of crop <u>must</u> be the same for all six trays per drying section.

The drying process may be registered by weighing the trays with the crop before the drying is started and several times during the drying process. As a minimum 1 tray per drying section must be weighed 3 times a day – morning, midday and evening. The location of the tray to be weighed is shown in Figure 1. For the drying of maize the weighing procedure should only be performed when drying the threshed crop, and not at step one when the whole ears of maize are dried.

The results are noted down in the enclosed form. Also, the weather conditions, the temperature and the air humidity are registered and noted down.

For the determination of when sufficient drying of the crop is reached one of the 3 enclosed drying tables can be used. Use the table for the current type of crop. Before the drying process is started, the moisture content of the crop must be determined. In the tables the loss in weight per kg of crop to reach the required moisture content can be found. The total required loss in weight for the crop in the tray can be calculated by multiplying the number of kg filled into the tray at the start of the drying process and the value found in the table. The drying process will be finished when the weight of the crop in the tray has been reduced by the calculated value.

Before drying:

1. Determination of moisture content
2. Weighing of test tray
3. Filling up the trays
4. Weighing of test tray incl. crop
5. Calculation of required weight loss

During drying:

1. Registration of ambient air temperature and humidity 3 times a day
2. Weighing of test tray incl. crop 3 times a day
3. Emptying the trays when required weight loss is reached and the drying is finished.

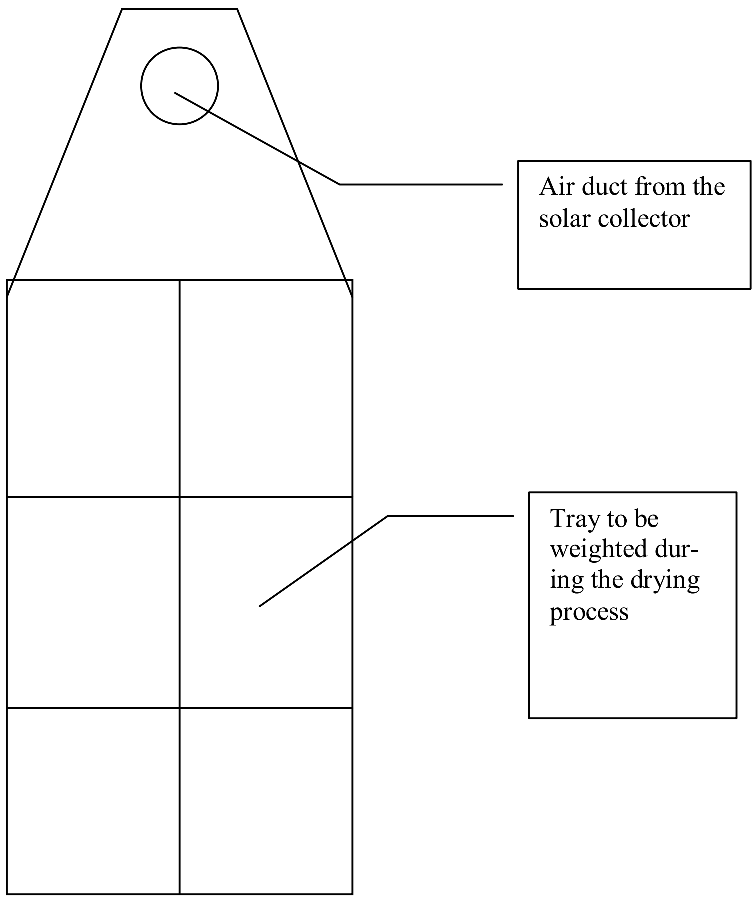

Figure 1: Sketch plan of one section of the crop dryer

Step by step test instruction

1. Use 100–120 kg moist maize per section for the test. The moisture content of the threshed maize must be between 15 and 20%. If no moist maize is available moistening of dry maze might be used. For each percentage the moisture content has to be raised add 1.2 kg of water per 100 kg maize. After admixture of the water the maize must be mixed careful and stored for a period of minimum 24 hours before it can be used for the drying test.

2. Determination of moisture content in the maize. This is done by the standard method[1)] or a representative sample is sent to the Food Reach Institute for analyse. The sample for the determination of moisture content must be stored airtight in a plastic bag in the period from collection until the analyse is performed. The result is stated in the test form.

3. Weighing of test tray. Weighing accuracy minimum 100 gram. The result is written in the test form[3)].

4. Filling up the trays with maize. The quantity of maize must be the same for all 6 trays.

5. Weighing of test tray incl. maize. Weighing accuracy minimum 100 gram. The result is written in the test form[3)].

6. Start the Tinytag data logger system for the registration for drying temperatures, air humidity, solar radiation, etc. Performed by DENG.

7. Weighing of test tray incl. maize 3 times a day. Weighing accuracy minimum 100 gram. The result is written in the test form[3)].

8. Emptying the trays when required weight loss is reached[2)]. Mix the maize from the test tray careful and take out a representative sample for determination of moisture content.

9. Determination of moisture content in the dry maize. This is done by the standard method[1)] or the representative sample is sent to the Food Reach Institute for analyse. The sample for the determination of moisture content must be stored airtight in a plastic bag in the period from collection until the analyse is performed. The result is written in the test form[3)].

10. The registrations made by the Tinytag data loggers are collected by DENG.

11. The drying test is finished.

[1)] Determination of moisture content by standard method

A test portion of milled or crushed maize is dried in an oven at a temperature of 130°C. The drying time must be 2 hours. The test portion is weighed before and again after the drying. The test portion of maize must be about 50 gram. The weighing accuracy must be minimum 0.1 gram.

Calculation of moisture content:

$W = \{1 - (m_2/m_1)\} \times 100\%$

where

W = content in %
m_1 = in g of the test portion before drying
m_2 = mass in g of the test portion after drying.

[2] Determination of required weight loss

<u>Drying shrinkage when drying grain or similar products in the crop dryer.</u>
<u>(E.g. maize and wheat).</u>

Loss in weight when drying 1 kilogram of crop, Gram /kg										
Moisture content before drying, %	**Moisture content after drying, %**									
	14	13	12	11	10	9	8	7	6	5
20	70	80	91	101	111	121	130	140	149	158
19	58	69	80	90	100	110	120	129	138	147
18	47	57	68	79	89	99	109	118	128	137
17	35	46	57	67	78	88	98	108	117	126
16	23	34	45	**56**	67	77	87	97	106	116
15	12	23	34	45	56	66	76	86	96	105
14	0	11	23	34	44	55	65	75	85	95
13		0	11	22	33	44	54	65	74	84
12			0	11	22	33	43	54	64	74
11				0	11	22	33	43	53	63
10					0	11	22	32	43	53
9						0	11	22	32	42
8							0	11	21	32
7								0	11	21
6									0	11

Example
When drying 15kg maize with 16 % moisture content to 11 % moisture content the loss in weight will be:
Weight loss = 15kg × 56g/kg = 840 gram = 0.840kg

Drying shrinkage when drying products with high moisture content
(E.g. vegetables and fruit).

Loss in weight when drying 1 kilogram of crop, Gram /kg											
Moisture content before drying, %	Moisture content after drying, %										
	30	28	26	24	22	20	18	16	14	12	10
80	714	722	730	737	744	750	756	762	767	773	778
75	643	653	662	671	679	688	695	702	709	716	722
70	571	583	595	605	615	**625**	634	643	651	659	667
65	500	514	527	539	551	563	573	583	593	602	611
60	429	444	459	474	487	500	512	524	535	545	556
55	357	375	392	408	423	438	451	464	477	489	500
50	286	306	324	342	359	375	390	405	419	432	444
45	214	236	257	276	295	313	329	345	360	375	389
40	143	167	189	211	231	250	268	286	302	318	333
35	71	97	122	145	167	188	207	226	244	261	278
30	0	28	54	79	103	125	146	167	186	205	222
25	-	-	-	13	38	63	85	107	128	148	167

Example
When drying 8kg fruit with 70 % moisture content to 20 % moisture content the loss in weight will be:
Weight loss = 8kg $\times$ 625g/kg = 5000 gram = 5kg

Drying shrinkage when drying products with low moisture content
<u>(E.g. millet seeds and nuts).</u>

Loss in weight when drying 1 kilogram of crop, Gram /kg										
Moisture content before drying, %	**Moisture content after drying, %**									
	14	13	12	11	10	9	8	7	6	5
20	70	80	91	101	111	121	130	140	149	158
19	58	69	80	90	100	110	120	129	138	147
18	47	57	68	79	89	99	109	118	128	137
17	35	46	57	67	78	88	98	108	117	126
16	23	34	45	56	67	77	87	97	106	116
15	12	23	34	45	56	66	76	86	96	105
14	0	11	23	34	44	55	65	75	85	95
13		0	11	22	33	44	54	**65**	74	84
12			0	11	22	33	43	54	64	74
11				0	11	22	33	43	53	63
10					0	11	22	32	43	53
9						0	11	22	32	42
8							0	11	21	32
7								0	11	21
6									0	11

Example
When drying 15kg millet seeds with 13 % moisture content to 7 % moisture content the loss in weight will be:
Weight loss = 15kg × 65g/kg = 975 gram = 0.975kg

3) Test form

Test No.:
Crop:
Date of harvest:
Date of start of drying:
Moisture content at start of drying:

Date	Hour	Weight, kg				Comments [B)]
		Tray (1)	Tray+crop (2)	Crop (3) = (2)-(1)	Weight loss[A)]	

A) Weight loss calculated as weight of the crop at the start of the drying process minus the actual weight of the crop noted in column (3)

B) Example on comments could be: Cloudy weather with rain. Crop with high content of impurities. Moisture meter readings.

Evaluation of the dryer and tests

Florence Agyei

LIST OF CONTESTS

CHAPTER 1

VISIT TO SILWOOD FARMS - 1ST REPORT 2/10/2001

1. Introduction

A visit was made to Silwood Farms on 28/09/2001. The main objective of the visit was to asses and evaluate the operational performance of the test solar crop dryer. The solar crop dryer is intended to dry different crops, e.g. vegetables, fruits, cereals etc.

Open sun drying is a very simple ancient skill, however this method exposes the food to contaminants such as dust, pest and bacteria.

The solar crop dryer is an improved solar trapping technology, which protects the food crops in the process of drying from the hazards of the open environment. Based on this advantage among others, the systematic monitoring evaluation of the test solar crop dryer is a project worth pursuing in Ghana. The success of the project could contribute towards the reduction of post harvest loss of crops in the country. At the moment the solar crop dryer is being used to dry harvested maize, to be stored as seed maize.

2. Activity with the solar crop dryer

Maize was harvested on 6/9/2001, and dedusked on the same day. The moisture content of the whole maize on cob was determined to be 22%. Each test tray on the five (5) dryers was filled with whole maize to a weight of 15 kg (weight of maize + tray) and then left on the dryers. The weight of the empty tray is 3.5 kg. Moisture content was being monitored on daily basis.

On 11/09/2001, the moisture content of the maize had reduced to 13.0%. In effect it took six (6) days for the dryer to reduce the moisture content of 345 kg of whole maize from 22% to 13%.

3. The weight loss and moisture content of whole maize on the different drying beds (A-E) from 6th to 10th September, 2001.

The formular for calculating weight loss is as follows:
Weight loss = x-y
Where:
X: Actual wt of crop at the start of drying
Y: wt of crop at the end of drying

(i) Drying bed A
Weight loss = 11.5 kg – 10.0 kg = 1.5 kg

(ii) Drying bed B
Weight loss = 11.5 kg – 10.0 kg = 1.5 kg
The moisture content dropped from 22% to 14.4%

(iii) Drying bed C
Weight loss = 11.5 kg – 10.5 kg = 1.0 kg

The moisture content dropped from 22% to 13.0%

(iv) Drying bed D
Weight loss = 11.5 kg – 10.0 kg = 1.5 kg
The moisture content dropped from 22% to 13.2%

4. Drying of threshed maize

The maize was threshed on 11/09/2001 and put back on the dryers the same day. The quantity obtained was then put in the test trays. Twelve (12) test trays were filled with maize to a weight of 20 kg each (tray inclusive). The recorded moisture content was 13%. The trays filled with threshed maize were placed on drying beds C and E. The moisture content was recorded three times in a day i.e. morning, mid-day and evening

The weight loss and moisture content (moisture content based on readings from the farmers moisture meter) of threshed maize on the different dryers (C & E), from 11th to 28th September is as follows:

The weight of the crop at the start of drying was 16.5 kg.

(i) Dryer C
Weight loss = 16.5-15.5 kg = 1.0 kg.
The moisture content dropped from 13.5% to 11.5%

(ii) Dryer E
Weight loss = 16.5-15.5 kg = 1.0 kg.
The moisture content dropped from 13.5% to 11.5%

5. Observation

It was noted that

- The instrument for measuring ambient R.H (Psykrometer) was not functioning.
- Temperature readings varied in the different dryers. The readings at the time of visit is as follows:

Drying bed	**Temperature**
A	35°C
B	35°C
C	28°C
D	35°C
E	38°C

Drying bed C had a rather low temperature reading. No reason could be attributed to the low temperature reading, probably it needs to be serviced.

- There was no rain gauge at the site

6. Comments

Intermittent rainfall and cloudy weather. The highest recorded R.H is 90%, and the lowest recorded R.H is 60%. The recorded weight loss that occurs only due to evaporation of water, showed that the moisture content was sufficient low the 19 September. Thus, it is clear that the use of the farmer's moisture meter for the determination of the moisture content is problematic, and may lead to wrong conclusions. Another drying test performed by Erik Kristensen at the silwood farms from the 3rd – 6th of March 2002, however gave promising results. Threshed maize of weight 71.7 kg at a moisture content of 15.4% had the moisture content reduced to 8.8% within 3 days. The results obtained are as follows:

Before drying	After drying
Weight - 71.7 kg	Weight – 66.26 kg
Moisture content(%)	Moisture content (%)
*standard method-15.4	* standard method – 8.8
moisture meter – 14.5	moisture meter – 10.1
	weight loss – 5.44 kg

NB.* test was performed at the food research institute using the standard method.

The theoretical water evaporation calculated gave the value as 5.19 kg and the actual weight loss measured is 5.44 kg.

7. Conclusion/Recommendation

Using the standard method for analyzing the moisture content, it was realized that the actual weight loss was 5.44 kg as compared to the calculated weight of 5.19 kg. Since the difference is small, the standard method confirms the efficiency of the dryer and the inaccuracy of the moisture meter.

Germination test will be carried out on the seed maize after the required moisture content of 9% has been obtained, to ensure that the quality of seed maize being produced is acceptable to the farmer.

CHAPTER 2

VISIT TO SILWOOD FARM, 2ND REPORT

As a result of your comments received through the Managing Director of Deng Ltd. another drying experiment was performed on a rather short period (4 days). It was detected that the scale on Silwood Farm was unreliable, and this could have affected the weighing process.

In order to achieve a more reliable data in the determination of maize moisture content or drying capacity of the solar crop dryer, some maize of weight (m1) 70.21 kg, was put in the dryer in addition with some crops, thus pepper and cassava on 9/11/2001. The moisture content as recorded by the moisture meter was 13.6%.

On 13/11/2001, thus after drying for 4 days, the moisture content recorded by the moisture meter was 12.8%. The weight (m2) of the maize was 65.31 kg.

Some of the maize before and after was sent to the Food Research Institute (FRI) of the council for Scientific and Industrial Research (CSIR) for the moisture content to be determined through a standard method. The results are attached.
Sample A is maize moisture content before drying
Sample B is maize moisture content after drying, thus from 9th Nov.-13th Nov. 2001.

It is envisaged that the attached results may provide some information for documentation on the drying capacity of the solar crop dryer, since this should be the most reliable analysis.

From the laboratory tests at FRI it can be concluded that the used moisture meter is not sufficient reliable, as the readings are essentially different to the results obtained at the laboratory. This is confirmed by the results obtained by our test and that obtained by Erik Fløjgaard Kristensen as discussed in the previous contribution.

FOOD RESEARCH INSTITUTE
LABORATORY REPORT

Source of Sample:	Florence Agyei	Chemistry Division
Address:	Fadagod Company Limited	P. O. Box M20
Description of Sample	Maize Samples A & B	Accra-Ghana
Date Received:	13-11-01	
Date Examined:	14-11-01	
FRI Ref. Lab. No:	Lab/CID Ref. No 01/297-298	

	Sample A	**Sample B**
% Moisture	11.8	11.3

Supervised BY: W. K AMEVOR
(Princ. Tech. Officer)

Signature:………………..
Signed: …………………
E. K ANKRAH
HD/CHEMISTRY DIV…

TO: FLORENCE AGYEI

CHAPTER 3

TEST OF SOLAR CROP DRYER WITH OTHER CROPS-5/11/2001

Introduction:

The solar crop dryer was used to dry other food crop items apart from maize. The drying period was from 30th Oct. to 2nd Nov. 2001.

The selected crop items were:

- *Carica papaya* (pawpaw)
- *Capsicum frutescens* (red hot peper)
- *Ananas comosus* (pineaplle)
- *Hibiscus esculentus* (okro)
- *Manihot utlillissima* (cassava)

Method:

The outer covering of whole pawpaw, pineapple and cassava were removed and the edible portion sliced into reasonable pieces.

The pawpaw and pineapple has to be partially ripe to prevent crushing during the drying of the fruits. The sliced pieces of pineapple were placed in the test tray outside the dryer for excess liquid to trickle out. The peeled cassava tubers were sliced into slightly bigger pieces than the pawpaw and pineapple. The sliced cassava pieces were washed in clean water before drying.

The red pepper was dried whole but the okro was sliced into small pieces. It was dried together with the seeds. The moisture content of the various crops was measured by using the grain moisture meter before and after drying.

The result is indicated below:

Crop type	Wt before drying (kg)	Wt after drying (kg)	Moisture content before	Moisture content after
Pawpaw	5.0	4.10	24	13
Pepper	10.0	9.20	18.8	14
Pineapple	5.0	3.80	30	12
Okro	5.0	4.3	22	10.4
Cassava	20.0	16.5	28.2	10.5

Results/Observations

The pawpaw dried quite well but discoloured. The pepper dried well and maintained its reddish colour.

The pineapple dried well, maintained its sweetness but turned brownish in colour. The dried pieces stuck together, and were gummy to chew.

The okro dried very well. Some quantity was boiled later for verification of its “sliminess”, the drying had no effect on this trait of the okro.

The cassava dried very well without colouring.

Conclusion –Test Solar Crop Dryer with Other Crops – 5/11/2001

The solar dryer could dry the cassava, pepper and okro very well within the 3 days. The quantity of the dried pawpaw and pineapple were however daunting even though the sliced pieces were thinly spaced in the test trays. The pawpaw assumed black colouration whereas the pineapple became brownish. The parboiled pieces of pine apple however maintained the original the original colour, flavour and sweetness. They however got stuck to the trays and were scraped with a metal object.

It suggested that the 6 test trays per dryer be removed and replaced with a long continuous shallow test tray to fit on the drying bed. This will be convenient for easy spreading of the food item and also increase the surface area for the drying process.

In conclusion, the solar dryer was found to be most effective for the drying of cassava, pepper and okro in that order and will be recommended for the drying of these crops especially for the drying of cassava.

CHAPTER 4

THIRD REPORT ON MAIZE DRYING WITH SOLAR CROP DRYER SILWOOD FARMS. 16/01/2002

1. Duration of experiment – 8/01/2002 – 15/01/2002

2. All 6 trays of drying bed A were filled with maize. The quantity was the same for all trays. The recorded Time, Temperature readings and comments is applicable to all 6 trays

3. Weighing of test tray incl. maize, was done two times daily.

4. Weighing of test tray incl. maize varied on the different days. Time of weighing was determine by the time the farm manager arrived on the farm in the mornings afternoons.

5. The available moisture meter was used in measuring the moisture content of the maize throughout the experiment, and the available scale was used in weighing

6. Measurements were taken on each test tray and reported in the test forms. Fluctuations in weight loss and moisture content as observed during the mornings and the previous afternoon may be due to increased R.H during the night.

7. Numbering of test trays were as follows: 1&4 in the front row, 2&5 in the middle and 3&6 in the last position.

8. The instrument for measuring R.H (Psykrometer) is not functioning, and so ambient R.H could not be recorded.

9. Even though there are variations in the final moisture content (based on moisture meter readings) of the maize in the different trays, an estimated average of 10.2 % may be acceptable. In effect the experiment has shown that the moisture content was reduced from 14.8% to an estimated average of 10.2% over a period of 7 days. However results based on the moisture meter cannot be reliable, since results based of weight loss gave a shorter period .

10. Total crop weight before drying is calculated as 70.2 kg. The cumulative crop weight of the 6 different test trays after drying is calculated as 64.6 kg. the weight loss is therefore 5.6 kg. The weight loss (evaporation of water) showed that the moisture content was below 10% after 4 days. Results based on weight loss are the most reliable, as the moisture meter readings according the test decried in Chapter 2 are incorrect and too high.

Conclusion

Even though the drying capacity may seem to be below the expectation, improvement upon the system may yield the desired results. There seems to be poor maintenance of the system. Panels are cleaned only when it rains. The room leaks when it rains and some of the fixed thermometers register ridiculous reading. The system design may need to be upgraded in order to improve upon it drying performance.

CHAPTER 5

ECONOMIC EVALUATION OF THE SOLAR DRYER – A PROJECT FINDING IN GHANA

a. Introduction

In Ghana, the economy and its development programmes depend principally on hydropower, petroleum products and fuel wood to meet the energy requirements.
To ensure the availability and equitable distribution of energy to all socio-economic sectors and geographical regions, the country and for that matter the Ministry of Energy has added to its objectives strategies to accelerate the development and use of solar energy in the country.

In line with this objective, the Energy Commission is promoting and supporting solar energy projects in the country.

The utilization of solar dryers on pilot basis is a laudable and timely project. However in the process of adopting and utilizing the solar dryer on a commercial scale, an economic evaluation of the project is imperative.

The solar crop dryer is located on Silwood Farms as Pokuase. Some studies have already been conducted into the drying of maize and some fruits. The dryer was able to dry 450 kg of maize at 19-20% moisture content to 9% in approximately six days, at a temperature of about 35-38°C. At 9% moisture content, the maize is suitable for storage as seeds. The germination rate of the dried seeds was high. During another test the moisture content was reduced from 15.4% to 8.8% in three days.

In order to appropriately evaluate the economic viability of the solar dryers, certain pertinent factors will need to be critically analyzed. These may include among others the following:

- Initial capital investment/capital cost
- Installation cost
- Operational /maintenance cost
- Sufficient technology demonstration
- Technology transfer strategy
- Acceptability of the technology

These factors are very necessary to consider and analyze since there is the tendency for people to compare the system with open sun drying which needs very little or no capital, installation, operational and maintenance cost. In the practice of open sun drying, skilled labour is of no relevance and it is available to be utilized.

The system has also been able to dry parboiled pineapples chips from 60% moisture to about 8% moisture in four days. All the aesthetic and consumption characteristics of the pineapple were retained after the drying process.

As much as the system may be appropriate for the functions required, high capital cost investment could be a limiting factor for a potential investor. Additionally, the fear of failure of the system, longevity and efficiency of panels could also be limiting factors. The promotion of credit schemes and import tax elimination may help potential investors meet the high investment cost of the solar dryers. If the capital cost is high, investors may opt for other available choices.

Initial capital investment

The initial capital cost should be compared or related to the purpose for which the system would be utilized. The pricing of components parts has been quoted as

ITEM	PRICE ($)
• Thermal Collector	1,280
• Aluminium Duct	700
• PV Panels (2)	180
• Fan	50
• Wiring	120
• Sealant	25
• Presuure chamber	120
• Drying trays	50
Total without VAT	2,525
Crop dryer consisting of five units	12,625
Civil woks (installation and housing)	1,000
Total for five units without VAT	13,625

Installation cost

Local contractors and technicians should be trained to do the assembling and installation of imported solar panel parts, in order to reduce the installation cost. The building of capacity is paramount. Correct installation is vital for optimal performance of the solar dryers.

Operational/maintenance cost

A credible commitment to the operation and maintenance of the system is very necessary for its sustainability. A properly operated and maintained solar dryer will achieve optimal performance (high efficiency), which will reduce cost.
If the system is reliable and appropriate, then potential investors will be attracted to invest in it. The impact of weather conditions/variations on the performance of the solar dryer could increase cost of operation since the system would be virtually non-performing during the wet and cloudy periods. Inappropriate handling of component parts and accidental damage to panels may increase operational and maintenance cost.

b. Performance of the crop dryer

The efficiency of the Solar Crop Dryer (based on experiments in Silwood) was realised to be determined by a number of factors, which included changes in the weather conditions, and the air speed/flow through the drying bed.

During the period of the test drying, the air speed through the drying bed was found to be 0.06 m/s. This is very low compared to the 0.3-0.7 m/s in conventional cross flow dryers and also compared to the 0.1 m/s in conventional platform dryers. The low flow rate, together with the drying during daytime only, could have increased the drying time for the maize and other crops. The dryer was expected to dry maize and other crops within one day, but this was altered as a result of the above factors stated.

As much as the solar crop dryer may be appropriate for the drying of maize and other selected crops, certain pertinent factors will need to be critically analysed before promoting the technology for commercial operations. These may include the following:

1. **The Development Benefits of the Solar Crop Dryer**

   Some issues to be considered under the factor include

   - Job Creation (will the solar crop dryer create jobs)?
   - Wealth Creation (will it increase the quality of produce, hence increase the price of produce)?
   - Capacity building (build capacity to reduce the involvement of foreign technicians)?
   - Health Improvement
   - Social Acceptance of the technology
   - Use of local resources (Human and Material).

2. **Market Potential of the Solar Crop Dryer**

   Issues to be considered include:

   - Finance (initial capital investment)
   - Affordability (installation cost)
   - Investment sustainability (operation/maintenance cost)
   - Commercial available (sufficient technology demonstration)
   - Replicability (Technology transfer strategy).

3. **Climate Change/Environment Protection**

The contribution of the Technology to Greenhouse Gas Emissions. In terms of green-house gas emissions the solar crop dryer is environmentally friendly.

c. Challenges of the solar crop dryer

The major limiting factors of the solar crop dryer include:

(i) low output per drying process as compared to the open sun drying. A multiple of the system may have to be built to dry maize on commercial basis. This measure will however increase the capital investment cost, which may not be affordable or eco-nomically viable to the investor. A recent investigation revealed that 198 kg of threshed maize at 13% moisture content was place on the dryers to be dried. After 17 days of drying the moisture content had reduced to 11%. However, it must be

men-tioned that a great uncertainty on the determination of moisture content was involved. The precision of the used moisture meter was to low. Calculations based on evapora-tion of water from the crop showed an essential shorter drying time. Unfavourable conditions such as cloudy weather and intermittent rain were men-tioned as some fac-tors which could have affected the performance of the solar crop dryer, (Farm Man-ager, Silwood).
Other results obtained indicates that 71.7 kg of threshed maize at 15.5% moisture content was dried using the crop dryer. After 3 days, the weight of the threshed maize was 66.26 kg at 8.8% moisture content.

(ii) High initial capital cost i.e. cost of solar panels. The cost of solar panels makes it comparatively more expensive operating system.

The solar crop dryer however has the potential to dry other fruit crops such as pineapple, pawpaw, apart from the grains. Even though this has been on experimental basis, it could be viable on the small and medium scale level. There would have to be a fruit quality test to as-certain its nutritional properties and further research on the packaging and storage. The sys-tem could reduce moisture content of pawpaw from 24% to 13% and cassava from 28.8% to 10.5% (ref. Chapter 3). These results were however obtained using the moisture meter on the farm which is concluded to have very low accuracy. A more credible analysis will have to be done in future by using the standard method.

Maize dried by the solar drier has been found to be of higher quality and of higher germina-tion percentage. A recent germination test (17/10/2001) performed by the overseer of the farm on the maize dried with the solar dryer, confirmed 96% germination. This achievement is highly commendable for maize production. It has been observed that maize seeds dried by solar crop dryers are generally clean and of higher quality, (Tropical agric. CTA, 1987). Contamination is insignificant, as the seeds are not exposed to the open environment. The seeds do not discolour or wrinkle as experienced with seeds dried in the open environment. Seed breaking is also insignificant.

d. Conclusion

In analyzing the economic viability of the solar dryers, the focus should be on the return on investment (profit) and the quality of the product as a result of utilizing the system.

These are critical points to consider since open sun drying is favourable competitor, which has proven efficient in the drying of food items both on subsistence and commercial scale. How-ever an improvement on the solar crop dryer will give it an advantage, since it is a cleaner technology.

A consumer preference survey (to ascertain the social acceptability) effective marketing cam-paign (through demonstrations) and the active involvement of the private sector are some im-portant factors to consider in the economic evaluation process.

Unfortunately a credible decision on the economic viability of the solar dryers cannot be de-duced based on the findings of the project sited on Silwood Farms at Pokuase in Accra, be-cause information gathered is insufficient. In addition to that, information on solar dryers in Ghana is rather scanty/lacking. More demonstration farms may have to be sited on selected farms throughout the country in order to provide a credible statistical evaluation on its economical viability.

It may be concluded that the technology is still at its teething stage in the country and such promotional programmes/projects should be consistent and intensified.

Reference:

1. The storage of food grains and seeds. The Tropical Agriculturist. CTA Macmillan Education Ltd. 1987.

2. Kerr, Barbara. The Sustainable Living Center.
3310 Paper Mill Road, Taylor, Arizona 85939, USA

Solar fish dryer
Elite Enterprise Ltd./DENG Ltd.
Tema/Accra

Description of the dryer and inspection report

Søren Østergaard Jensen

Brief description of the solar fish dryer

The dryer is basically identical to the solar crop dryer, but consists of one drying unit where the crop dryer consists of five units. The unit has as the solar crop dryer a solar air panel of 4.77 m² and a PV-area of 0.64 m² (28 W_p). The principle of the dryer is shown in figure 1 in the brief description of the solar crop dryer. For further details please refer to (Jensen, Kristensen and Forman, 2001). The solar air collector, PV-panels, connection from the solar collector to the ducts and the fan were delivered by the Danish company Aidt Miljø A/S. The remaining ductworks and the drying bed were delivered/manufactured by DENG Ltd. DENG also build the movable hut in which the solar fish dryer is installed. The solar air collector serves as in the solar crop dryer as roof of the hut. The drying bed is different from the drying bed in the solar crop dryer: in the solar crop dryer the drying bed consists of two rows of three drying trays – each with the internal dimensions: 0.56 x 0.36 x 26 (l x w x h) m³, while the drying bed of the fish dryer consists of one row of four drying trays with the dimensions: 0.56 x 0.36 x 0.13 (l x w x h) m³.

Figures 1-2 show the solar fish dryer from the south and the east respectively, while figure 3 shows the inside of the hut and the drying bed. Figure 4 shows the drying trays while figure 5 shows the extension box to be located on top of the drying trays – also seen in figure 3. The extension box has a top hatch with a net. The hatch may be opened. The aim of the extension box is twofold: To protect the fish from insects and to make it possible to hang op larger fish.

Figure 1. The solar fish dryer seen from the south.

Figure 2. The solar fish dryer seen from the east. The dryer has two hatches in the east wall with insect net and an entrance door.

Figure 3. The interior of the hut containing the drying bed of the solar fish dryer.

Figure 4.   The trays of the drying bed.

Figure 5.   The extension box of the drying bed.

The solar fish dryer incl. hut is a bit more primitive than the solar crop dryer.

An inspection in January 2001 of the co-ordinator of the project (Jensen, 2001) lead to the following conclusion: the craftsmanship of the solar fish dryer does not show the same high standard as for the solar crop dryer. However, the quality of the solar fish dryer is still good. The benefit of the chosen design is that the dryer is movable.

Inspection of the solar fish dryer at DENG Ltd - March 4, 2002

The solar fish dryer was originally located at Elite Enterprise Ltd. at Tema – please refer to (Jensen, 2001). However, the company showed after all no interest in using the dryer. The dryer was, therefore, moved to the premises of DENG Ltd., which had been in charge of the construction of the dryer. At DENG Ltd. a test series on the dryer was conducted as described in the next section. Figure 6 shows the dryer at the premises of DENG Ltd.

Figure 6. The solar fish dryer at the premises of DENG Ltd.

The inspection of the solar fish dryer revealed only one fault compared to the inspection in January 2001 (Jensen, 2001): the thermometer situated on the drying bed was out of function - this is also reported by Ms Florence Agyei in next section of the present report.

Figure 7 shows that the cover of the solar air collector and the PV-panels were very dirty, which is no surprise as the premises of DENG is situated in a very dusty area. Before the test the solar air collector and the PV-panels were cleaned. Also the interior of the solar fish dryer was at the time of inspection very dirty

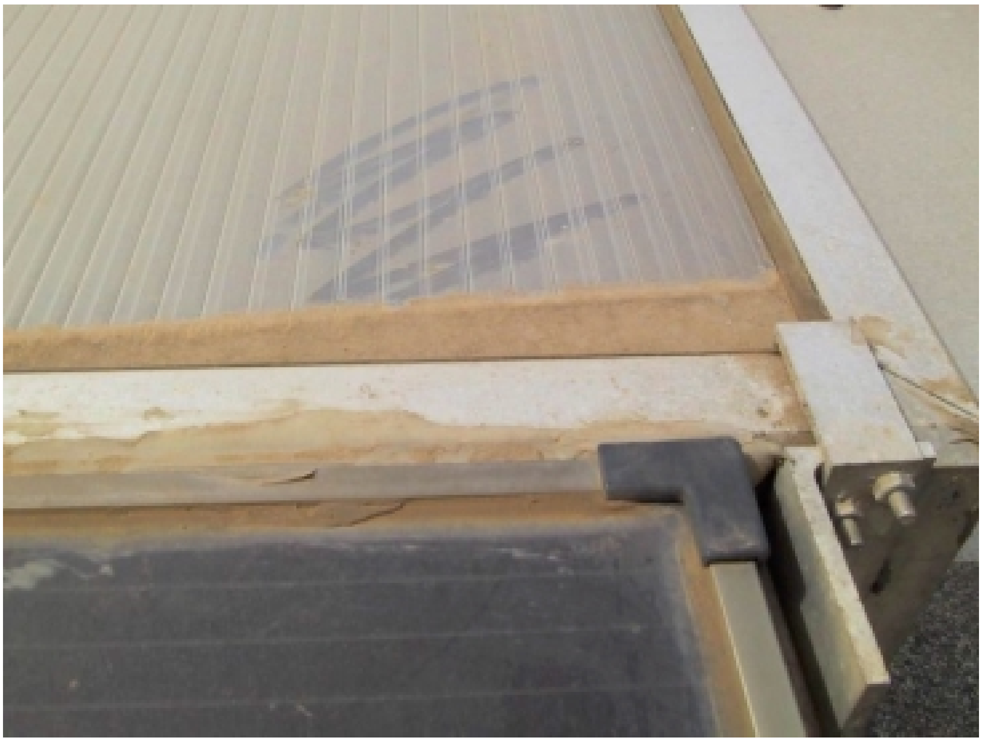

Figure 7. The photo clearly shows the dust deposit on the solar air collector and PV-panel.

References

Jensen, S.Ø., Kristensen, E.F. and Forman, T., 2001. Test of a solar crop dryer. Solar Energy Centre Denmark, Danish Technological Institute and Department of Agricultural Engineering, Danish Institute of Agricultural Sciences and Aidt Miljø A/S. ISBN 87-7756-583-5.

Jensen, S.Ø., 2001. Inspection of solar dryers in Ghana. Solar Energy Centre Denmark, Danish Technological Institute. ISBN 87-7756-615-7.

Description of the tests and test results
and
Evaluation of the dryer and tests

Florence Agyei

Chapter 1

REPORT ON INVESTIGATION INTO THE SOLAR FISH DRYER PROJECT WITH ELITE ENTERPRISE, TEMA.

1. Introduction

Elite Enterprise, a local enterprise engaged mainly in open sun drying of fish waste was chosen by DENG Ltd. to experiment on a solar fish dryer on pilot basis. The system was therefore placed within the premises of Elite Enterprise on 19/12/2000. The office and compound of the enterprise is located at Tema fishing harbour in a community popularly known as “U”.

The main objective of the experiment was:

- to test the effectiveness and efficiency of the solar fish dryer in drying different types/size of fish.

Unfortunately, Elite Enterprise failed to achieve the objective of the experiment and abandoned the project. The present investigation therefore intends to identify the problems that were encountered or could have contributed towards the failure of the experiment by Elite enterprise.

2. Problem Identification Methodology

i. interview of workers who experimented with the solar fish dryer;
ii. Assessment of the outcome of the experiment, taking into consideration the type/size of fish dried, quantity at a time, moisture content of fish before and after drying, quality of fish (hardness, colour, taste, flavour etc.), duration of drying, pre-drying precautions/measures.

2.1 Problems Identified

- *User-related issues*

It was evident that even though the owner of Elite Enterprise agreed to allow the system to be sited on the compound of the company, the user was not interested in the project implementation. The reason could have been that she was not well informed or did not appreciate the relevance of the technology. She was not enthused about the system and declined to perform any experiment on her own. The technology was not acceptable or wanted by the user. She was quite resistant to accepting or adopting the new technology.

- *Size of the solar fish dryer*

The user was discouraged by the size of the solar fish dryer, even though it was explicitly explained to her that the project was on pilot basis. During the assessment, she indicated that as a business woman, she was expecting some large structure that could conveniently dry her fish waste faster than the open sun drying. She was not prepared for any experiment and commented that the size of the solar dryer was not appropriate for a brisk and progressive business, and did not want to waste her time. She indicated that the return on investment/profit could not be economically viable, even if the wooden structure was expanded and modified, hence her indifferent attitude towards its usage.

- *Lack of knowledge*

The workers who were involved in the experiment had no background information/education on the functioning and operation of the solar dryer neither were they taught by Deng Ltd, prior to the commencement of work. Consequently they found the system to be complex and cumbersome especially as compared to the traditional open sun drying. Even though they accepted the fact that the open sun drying exposes the fish to the hazards of the environment, they did not trust the operational performance of the dryer and commented that the system could not be reliable for a large business or when fish was in abundance.

- *Time taken for the drying process (duration)*

The workers observed that the process of drying took more days (about 5 days for Engraulis encrasicolus and more than one week for the fish waste) as compared to the open sun drying which is 3 days for Engraulis encrasicolus, and about 5 days for the fish waste. Open sun drying is regulated by factors such as air temperature, relative humidity and wind temperature (uncontrolled ventilation). However, the user realized that ventilation within the structure was poor. According to the workers, some fish wastes put in the solar dryer got rotten, instead of drying.

- *Convenience of utilization*

It was observed that the structure was too compact for easy movement, especially for the tall and fat people. It was not convenient shifting the extension box to remove trays and placing back the trays for the fish to be dried.

- *Output per drying time*

The outcome of the experiment according to the workers showed that on a favourable sunny weather, the solar dryer (4 trays) could dry just about half a crate (weight not known) of Engraulis encrasicolus (keta school boys).
The output per drying time from the user's perception could be uneconomical. She was skeptical about the output or quantity of fish that could be dried per day if the system is commercialized. In her opinion the output per day cannot be compared to the open sun drying.

- *Quality of fish*

The quality of dried fish from the solar dryer was not too good, and according to the user the colour of the fish appeared brownish like smoked fish. The flavour and taste were slightly different as compared to the open sun dried fish. The odour from the fish was bad. The dried fish was slightly soft. Even though the moisture content of the fish was not measured, it could be deduced by the user that the fish was not dried to an acceptable moisture level.

- *Risk level*

The user commented that the risk involved in using the solar dryer could be high especially when the dryer did not function during the night, and exposes the fish to high humidity levels. She also commented on the impact of unfavourable weather on the utilization of the system.

- *Marketing of produce*

Comments were raised on the pricing of the dried fish from the system. She was doubtful if the dried fish could command higher price to justify the investment cost. The technology according to the user may not be able to produce quality fish to compete with the existing produce on the market. She also had doubts as to the acceptability of the dried fish by local fish traders

- *Affordability, Maintenance and Repairs*

Concerns were expressed about the probable affordability and maintenance of the system. In the opinion of the user, the availability, affordability, maintenance and repairs of the system could not be guaranteed. She was not willing to work with a technology for which she could not afford to purchase or maintain in the near future.

3. Recommendations

- Education and training programmes for potential PV (food-dryers) system users is very necessary to ensure that they operate the system appropriately to achieve the desired results. Users must be well informed to accept and adopt the technology since this may facilitate its transfer and dissemination.
- The experiment may be repeated to involve a more interested and enthusiastic user in order to gather enough relevant information for cost/ benefit analysis.
- The need for research into the marketing strategy of the produce is an essential facet of the project, futhermore the acceptability of the dried fish on local and foreign market should be investigated.
- Pre-treatment of the fresh fish may be necessary before placement into the solar dryer.

4. Conclusion

It is pertinent to note that even though the technology may be appropriate for the drying of fish, monitoring of the experiment was unsatisfactory.

The user was not committed to the entire activities in the drying process of the experiment, consequently the desired results could not be realized.

In effect the system was not operated and maintained appropriately by the user.

Chapter 2

REPORT ON THE RESULTS OF TEST SOLAR FISH DRYER

1. Introduction

Deng Ltd. has constructed a prototype solar fish dryer, which is being tested on demonstration basis. The system is presently located on the premises of Deng Ltd.,Alajo, Accra.

The solar fish dryer consist of the following parts:

i. solar air panel
ii. dry wooden bed with one row of four trays
iii. extension box with a hatch which may be opened
iv. fan
v. solar air collector
vi. ducts
vii. pressure chamber

Extensive research (ILO, 1982) has proven that the use of solar dryers could be an appropriate alternative to traditional sun drying.

Solar dryers employ means of collecting or concentrating solar radiation with the result that elevated temperatures and lower relative humidities are achieved for drying. When using solar dryers, the drying rate can be increased, lower moisture content can be attained and product quality is generally higher. The solar dryer can attain much higher temperatures ideal for drying tropical fish than the ambient temperature. They also provide shelter from the rain.

In sunny weather conditions, fish can be dried within three (3) days using solar dryers compared with five (5) days for open sun drying (CSIR/FRI, pers. Comm.). Solar drying also reduces the effects of insect infestation on fish. The quality of solar dried fish is comparatively higher. Literature on fish dryers is limited, however, a solar tent dryer was experimented by the Food Research Institute (FRI) of the Council for Scientific and Industrial Research (CSIR) in the late 70's to 80's. Literature revealed that, with an ambient temperature of 30oC, temperatures of around 45oC could be attained inside the tent dryer. This temperature could kill insects or larvae present on the fish thereby presenting a means of disinfestation.

Another tent drier made from a bamboo frame covered with clear and black polythene was evaluated in Bangladesh (Doe et al; 1972). This dryer also attained a maximum temperature of 48oC, which is suitable for drying fish. The ambient temperature was 27oC. Dried fish were produced within a marginally shorter period than in the case of natural drying and were superior in quality.

A fish drying experiment was performed on the premises of Deng Ltd., using the solar fish dryer, from 6th – 8th October, 2001. Five different types of small pelagic fishes were used, namely:

A. Ilisha sp.
B. Pseudotholithus sp. (cassava fish)
C. Sardinella maderensis
D. Ethmalosa fimbriata (shad)
E. Engraulis encrasicolus

The objective of the study was:

- to monitor and evaluate the efficiency of the solar fish dryer in the drying of different types/size of fish.

Since the technology will have no absolute value if the people for whom it is developed refuse to use it, it was part of the study to find out how receptive the technology will be to a user.

2. Some Important Factors which Affect the Suitability of Fish for Drying

2.1 Size

Small fish may be dried whole, large ones must always be cut so as to increase the surface area available for moisture loss. Small fish may therefore be preserved with gut content intact, while this is always removed in large fishes.

2.2 Oil content

Fish oils oxidize readily and become rancid, giving a bitter flavour to the product. Fish containing much oil do not generally make good dried products, since the oil acts as barrier to moisture loss. Cooking the fish before drying may produce satisfactory products.

2.3 Flesh texture

Fish with firm or moderately firm flesh are relatively easy to handle. They can be cut without falling apart and dried product can be transported without breaking up. Fish with soft flesh tend to tear when attempts are made to cut and the dried products are very fragile and tend to break during transport.

3. Materials and Methodology

3.1 Materials

3.1a Three (3) kilograms of fresh fish purchased from the open market. The species with the average length and width is as follows:

Type of fish	Ave. length(cm)	Ave. width(cm)
A. *Ilisha sp.*	22	5.5
B. *Pseudotholitus sp.*	17	4.0
C. *Sardinella maderensis*	11	2.0
D. *Ethmalosa fimbriata*	11	8.0
E. *Engraulis encrasicolus*	4	0.6

3.1b Solar fish dryer

3.2 Methodology

The solar panel was washed with clean water to remove any dust deposits. The trays on the drying bed were washed and dried in the open environment. The fish were washed in clean water (bruised and mutilated fish were discarded), placed in the trays (one layer) in non-specified arrangement. The spacing was close but uneven. The trays were allowed to stay on a table for some few minutes to allow excess water to drip from the fish. They were then placed on the drying bed under the extension box in the solar dryer, in the morning, at 8.00am on 6/10/2001.

The total weight of fresh fish in the four trays was three kilograms. The fish were turned up-side down to ensure uniform drying in the trays. The fish were dried whole without any cut on them, and kept in the dryer day and night.

Control: Sun dried fish of the same species on the open market should have been analyzed for per cent moisture content. However such specimens were not available on the open market

4.0 Results/Observations

It was observed at 5.30pm on 6/10/2001 that the moisture content of Engraulis encrasicolus had reduced significantly. Even though the moisture content could not be determined, fish samples taken from the test tray could break easily. The other fishes were however not dried. The odour from the dried fish was unpleasant but normal of dried fish. The five different species of fish were taken out of the dryer at 8.00am on 9/10/2001.

4.1 Temperature

The temperature in the solar dryer was recorded every hour on each day of the experiment, starting from 8.30am. The highest recorded temperature for the 3 day drying period was 32oC. The temperature readings for the period of drying were as follows:

Local time	1st day Temp(°C)	2nd day Temp(°C)	3rd day Temp(°C)
8.30 am	10*	11*	10*
9.30 am	17*	13*	10*
10.30 am	15*	25	15*
11.30 am	23	30	24
12.30 pm	30	32	29
1.30 pm	27	30	27
2.30 pm	22	22	22
3.30 pm	19*	20	20
4.30 pm	10*	10*	12*
5.30 pm	5*	3*	4*

NB. Observation of temperature readings:

It would be noted that the temperature readings in the early mornings and late evenings were unreasonably low. This is an indication that the thermometer in the solar dryer system is faulty leading to inaccurate temperature reading.

For future experiments, it would be necessary to fix a thermometer outside on the system to record the ambient temperature for objective comparison with temperature inside the system.

4.2 Calculated weight Loss

Weight loss

Calculated weight loss is as follows:

Weight of fish before drying	=	3.0 kg
Weight of fish after drying	=	2.32 kg
Weight loss	**=**	**0.68 kg**
% wt loss in 3 days	=	(0.68 kg * 100) / 3.0 kg = **22.7 %.**

4.3 Moisture content

When the moisture of fresh fish is reduced through drying to around 25 per cent, bacteria growth and spoilage caused by the action of enzymes (autolysis) is minimized. A moisture content of 15 per cent prevents the growth of mould (ILO, 1982).

Samples of the dried fish were sent to the Food Research Institute for the per cent moisture content analysis. This is attached as Appendix 1.

The letters A-E found in Appendix 1, is indicated below with the corresponding fish type.

Specimen	Name of fish
A	*Ilisha sp.*
B	*Pseudotholitus sp.*
C	*Sardinella maderensis*
D	*Ethmalosa fimbriata*
E	*Engraulis encrasicolus*

5. Evaluation of performance and conclusion

After three days of drying the five different species of fish, it is evident that the solar fish dryer is satisfactory for the drying of the smaller fishes.

Engraulis encrasicolus, the smallest fish had moisture content reduced to 21.1% within three days of drying. The moisture content of specimen C&D probably could have been reduced further if the drying had continued after the third day.

It is evident from the moisture content analysis results that, much longer time will be needed to dry bigger fishes to the required moisture level. It is also relevant to note that there was only one layer of fish in the test trays, and that drying could have been more delayed if the layer was more than one. The quality of fish was good taking into consideration the colour and odour.

In conclusion, the fish dryer may be appropriate for drying small pelagic fish. It could be modified, by way of hybridizing the system, and maintaining factors essential for drying, ie temperature and relative humidity.

Chapter 3

EVALUATION OF SOLAR FISH DRYER AND ITS POTENTIAL FOR COMMERCIALIZATION IN GHANA

1. Background information

The ability to produce energy economically and efficiently is a critical factor in Ghana's industralization process. Utilizing photovoltaic (PV) powered systems to produce electricity would partially satisfy this requirement, hence the need to master the technology and promote in-country manufacture and commercialization.

Deng Ltd. is presently undertaking a project that involves the use of solar crop and fish dryers.

The solar crop dryer has chalked some success in the drying of maize, however test experiments on the solar fish dryer is limited or lacking. A first experiment using the solar fish dryer by an entrepreneur in Tema proved futile. A second experiment to evaluate its potential for commercialization was undertaken on the premises of Deng Ltd. The following have been identified as factors that may affect the commercialization process.

2. Constraints

- High initial cost of the technology

Due to limited funds on the part of users, concerns may be raised on the amount of money to be invested in the hiring or absolute purchase of the technology. Even though hiring rates for the drying cannot be determined/estimated at the moment, a high price may be a disincentive to the adoption, utilization and dissemination of the technology, since majority of the potential users will be fishermen and fish traders with relatively low income. The terms for hiring /purchasing should therefore be favourable in order to encourage its adoption and utilization.

- Conditions for usage

Any stringent or unfavorable conditions against the hiring or acquisition of the system could deter potential users from adopting the technology.

- Availability of technology

Since most components of the solar dryer are imported, this could limit the distribution.

- Competition with traditional sun drying

Competition with existing traditional sun drying may be high, considering the fact that open sun drying is invariably free or cheaper, in terms of infrastructure. This is in addition to favourable weather conditions for most of the year, eg., in the coastal savannah zone.

- Acceptability of the technology

Acceptability by potential users may be slow for fear of unreliability or failure of the system.

- Technical appropriateness

The system may be suitable for the drying of small pelagic fishes. The current inability of the system to effectively dry bigger fishes could be a threat to it utilization.

- Weather changes

Changes in the weather affect the performance of the technology. Because the factors for drying are not constant, the duration for drying is affected.

- Output of technology

The output per drying process is limited compared to the open sun drying. This may not be able to meet the demand/supply of the user or customer. Output per drying process may be very low and uneconomical in the solar dryer.

- Marketing demand and pricing

The target market should be identified. Altogether, dried fish is particularly suited for low-income groups, which cannot afford expensive fish products. Dried fish are comparatively cheaper. Considering the initial capital cost, pricing the fish from the solar dryer at the same level as the traditional method will be a disincentive to potential users.

3. Socioeconomic Benefits/Potentials of the Solar Fish Dryer

Simplicity of technology

The usage of the technology is simple just like the open sun drying but more hygenic, it may require less labour and efforts. Solar radiation, which is the source of electricity, is freely available at high intensities in the tropics. This may contribute to the sustainability of the technology.

Environmental protection
A great deal of attention is being given nowadays to the topic of conservation and protection of the environment. The technology is a cleaner type of production, benign in terms of global warming or destruction of the ozone layer.

Longevity of system
Solar devices have been proven to have long life span.

Provision of cheap electricity

The technology will provide relatively cheaper electricity for fish traders to dry excess fish for preservation in order to minimize post harvest losses through spoilage.

Reliability
The technology could be viable and appropriate for the country. It will have the advantage of being installed anywhere in the country (rural, urban), provided space is available and weather conditions are suitable, since solar energy abounds plentifully in the country.

Occupational hazard
The potential user is assured of a safe working environment, since the technology does not emit any harmful substances such as smoke, or dust that could affect the health of the user.

Quality of produce
Literature on fish drying with solar fish dryer is limited. However, available information indicates that fish quality from solar dryer is relatively better in quality than fish dried in the open sun. Furthermore USDA (United State Development Agency) has ranked dried food to be nutritionally better than canning, since the taste is related to the food (Kerr Barbara, 1998).

4. Recommendations/Conclusion

- The level of awareness among policy makers on Renewable Energy development eg. solar dryers should be heightened, and the integration of renewable energy development into the national development plan should also be strengthened. The Energy Commission (EC) may take the lead in this action.

- Publicity /advertisement of the technology should be promoted by Deng Ltd.in order to increase public awareness on the potential and usefulness of the solar dryers. The programme for popularization should include:

i. advertising on TV
ii. human resource development/capacity develpoment
iii. involvement of NGO's and the private sector (GTZ) as facilitators of the technology.
iv. Collabration with commercial private farmers eg., Kristo Asafo Farms.

- Action plans establishing mechanisms for use and adoption of the technology should be initiated by Deng Ltd. to include the following:

i. introduction of incentives for potential users, eg., access to market
ii. encouraging relevant institutions, eg Ministries of Agriculture and Fisheries to consider adopting the technology
iii. persuading and educating the district assemblies to embrace and implement the technology
iv. institute taxe incentives for development of renewable energy eg., solar dryers
v. encouraging existing research institutions, schools with requisite capability to utilize the technology
vi. bottom up approach method to be practiced in the technology transfer, views of users should be solicited.

- There should be aggressive programmes by Deng Ltd. to accomplish the goals of technical capability in the PV system through developing local manufacturing, distribution, installation and maintenance capacities to ensure the availability of products on local market.
- The system should be modified (hybridized) to enable it operate during unfavourable weather and throughout day and night.
- Because of time constraints, no comparison with sun dried fish was made, therefore future experiment with the solar fish dryer should be conducted along sun drying under similar conditions

In conclusion, the solar fish dryer may be considered as a feasible and viable technology, but should be modified and improved for the purpose of commercialization

5 References

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APPENDIX 1

FOOD RESEARCH INSTITUTE

LABORATORY REPORT

Sources of Sample: **FLORENCE ADJEI**
Address: C/0 DENG LTD, ACCRA
Description: **DRIED FISH A, B, C, D, E**

Chemistry Div
P. O. Box M 20
Accra, Ghana

Date Received: **10-10-01**
Date Examined: **11-10-01**
FRI Reference Lab. No: Lab/CID Ref. No 01/263

11th Oct, 2001

RESULTS:

	A	***B***	***C***	***D***	***E***
% MOISTURE	47.8	49.1	25.1	25.8	21.2

Supervised By: **W. K. AMEVOR**
PRINCIPAL TECH. OFFICER

Signature:------------------------------
Signed:------------------------------
NANA ANNAN (MRS)
HD/INDUST. SERV. UNIT.

TO: FLORENCE ADJEI

Solar wood dryers
Clipper Design Ltd.
Mankoadze

Description of the dryers and inspection report

Søren Østergaard Jensen

Brief description of the solar wood dryers

It was difficult to come to a consensus among the partners of the project for the solar wood dryer. The option was between a forced open air solar dryer and a solar kiln.

Based on the weather data obtained by Professor Akufo, University of Science & Technology, Kumasi (Jensen, 2000) the Danish wood experts recommended a forced open air dryer, with ambient air driven by PV powered fans as seen in figures 1-2.

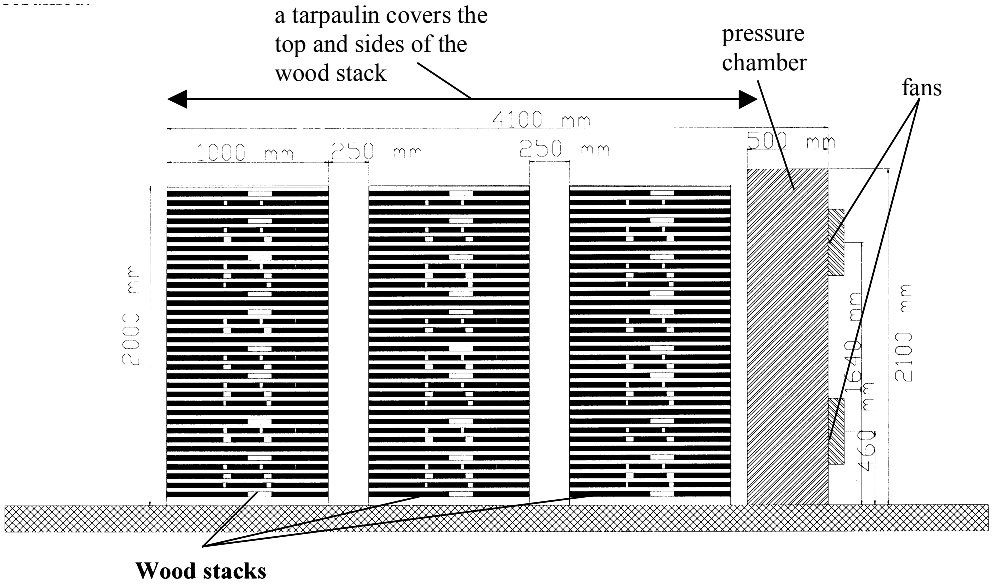

Figure 1. The principle of the forced open-air dryer.

Figure 2. The pressure chamber of the forced open air dryer with fans and the tarpaulin.

The design is very simple. It consists as seen in figure 1 of a pressure chamber with 6 dc 50 W fans – also seen in figure 2. The wood stack is located in front of the pressure chamber. A tarpaulin mounted to the pressure chamber is pulled over the wood stack in order to ensured that the air is only sucked through the wood stack. The fans are powered by an array of PV-panels seen in figure 3. The array of PV-panels consisted of 30 panels of 14 W_p each.

Figure 3. The PV-panel of the forced open air dryer – here turned to face west – being cleaned

However, measurements in at Monkoadze have shown that the humidity of the ambient air is far lover than given by Professor Akufo meaning than an forced open air dryer would be of little benefit. Control of the temperature and humidity level of the air surrounding the wood is, therefore, of major importance. A design of a solar kiln was, therefore, also proposed – figure 4.

The solar kiln was design by Clipper Design Ltd and DENG Ltd. A false ceiling 2.1 m above the floor is installed in the chamber – see figure 4. Two fans circulate air trough the wood stack and the space between the false ceiling and the roof. A large fan directly connected to the PV-panels circulate the air during daytime, while a smaller fan connected to a battery charged by a PV-panel circulate the air at a lower air speed during the night. A smaller ex-haust fan with at damper extract humid air from the kiln when the humidity level gets too high – at the same time a damper is opened in the other side of the kiln. The fan and dampers are controlled by a hygrostat. Water can be sprayed on the floor when the humidity level gets to low. This feature is also controlled by a hygrostat. The roof and walls act as solar collector for heating the air in the kiln. The roof and walls were at first left metal blank, however, the tests revealed, that it should be painted black externally in order to increase the efficiency of the roof and walls as solar collectors.

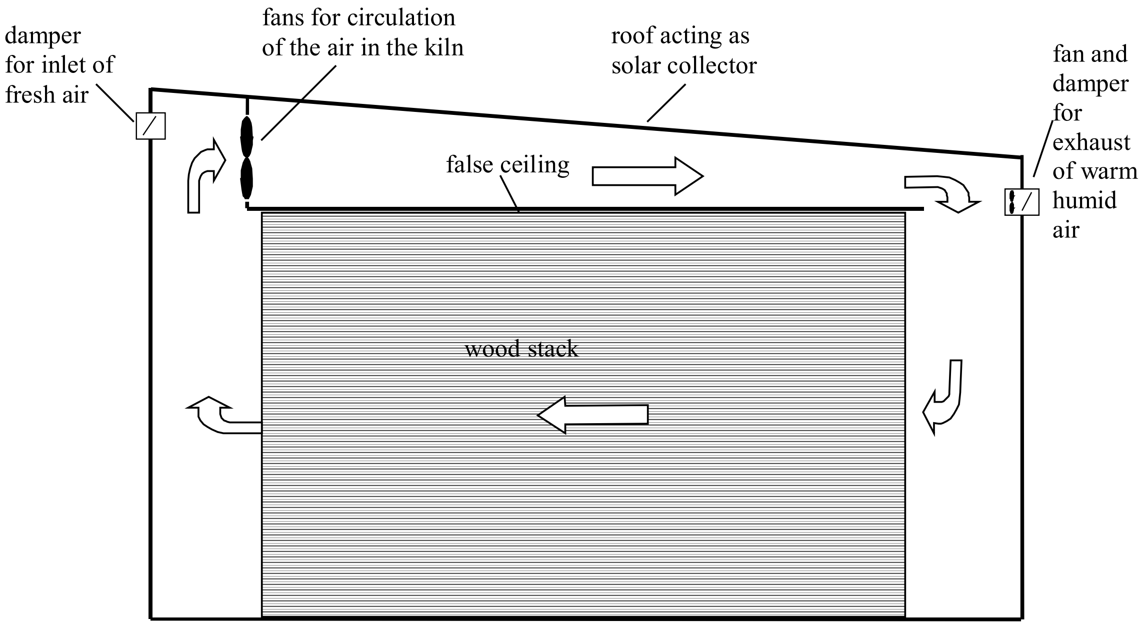

Figure 4. The principle of the solar kiln.

Components of the kiln:

Fans: 1 dc fan for day-time circulation, diameter: 60 cm, max power: 550 W
1 dc fan for night(and day)-time circulation, diameter: 40 cm (16"), max power: 50 W (for further details see (Frank, 2000)). The fan is also run during the day directly coupled to the PV-panels as the large day-time fan.
1 dc fan for exhaust, diameter: 11 cm, max power: 7 W

PV-panel: 14 panels of 60 W_p each = 840 W_p

Battery: 260 Ah charged by a one 60 W_p PV-panel. The battery charge the 50 W night-time fan during periods with no or very low solar radiation.

Figure 5 shows the drying chamber of the solar kiln, while figure 6 shows the fans of the solar kiln. The array of PV-panels for both solar dryers is shown in figure 7. Figure 7 also shows the exhaust duct of the solar kiln.

As no consensus could be reached on which design to chose it was decided to build both – however, in such a way that each of the designs easily could be turned into the other design.

It was decided that each solar wood dryers should be able to contain 10 m^3 wood.

As described in the next section the forced open air dryer was later converted into a solar kiln using the 6 dc 50 W fans for daytime ventilation and one of these fans for night time ventilation powered by a 260 Ah battery which is charged by one 60 W_p PV-panel. This kiln was as the originally kiln equipped with a small exhaust fan (though only a 5 W fan) and a battery bank. Figure 8 shows the fans of the new kiln. Both kilns are shown in figure 9. Figure 10 shows the two PV-panels for charging the batteries, which run the night fans.

Figure 5. The pressure chamber of the solar kiln.

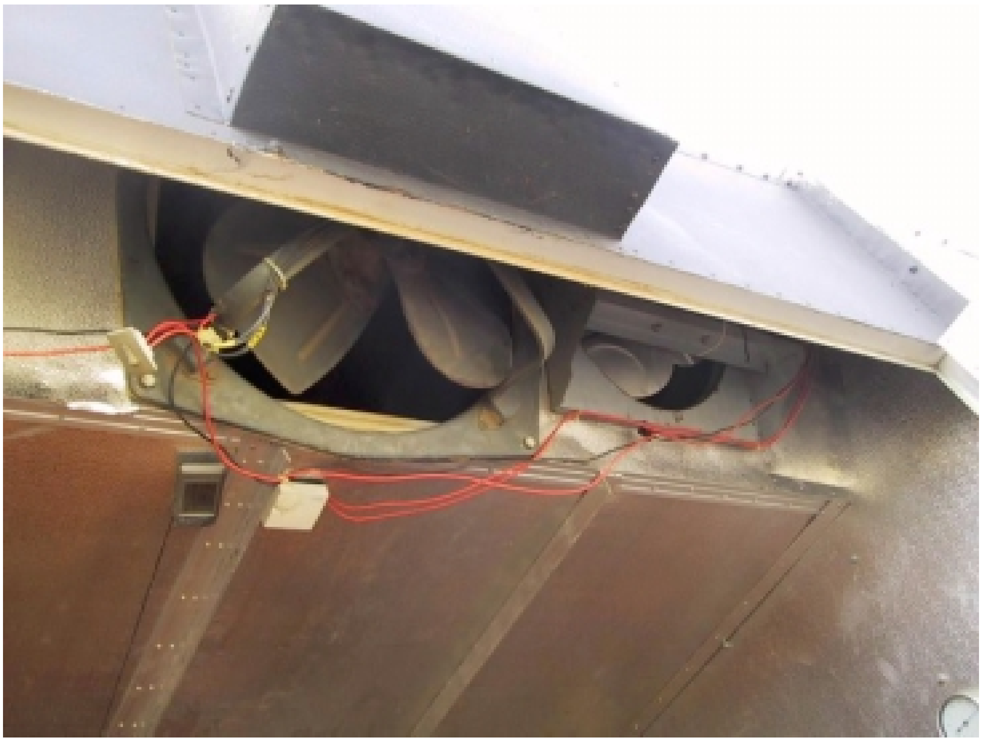

Figure 6. The fans of the solar kiln.

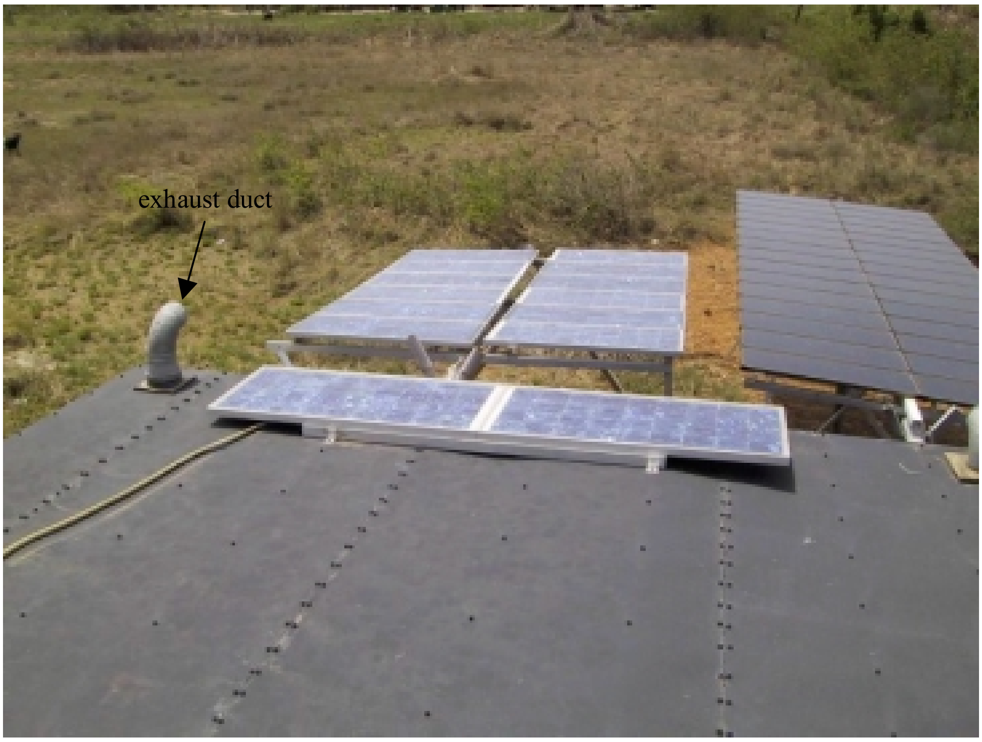

Figure 7. The array of PV-panels for the two solar dryers. For the solar kiln to the left including two panels on the roof of the kiln. The exhaust duct of the kiln is also shown.

Figure 8. The daytime fans of the new solar kiln after conversion from a forced open air dryer.

Figure 9. Both solar kilns after conversion of the forced open air dryer into a kiln.

Figure 10. Two PV-panels for changing the batteries powering the night fans.

An inspection in January 2001 of the co-ordinator of the project (Jensen, 2001) lead to the following conclusion: The solar wood dryers show good craftsmanship. The forced open–air dryer was operational, however, some final details were still missing on the solar kiln: the false ceiling, fans, control, PV-panels, battery, air tight entrance, etc. still needed to be installed in the solar kiln.

Inspection of the solar wood dryers at Clipper Design Ltd. - March 4, 2002

The above-mentioned details, which still had to be finalized on the solar wood dryers at the inspection in January 2001 has all been finalized. The forced open air dryer has further been converted into a solar kiln as it turned out that a forced open air dryer was of no use as the humidity at Mankoadze often is so low, that the wood are being damaged in the dryer.

The two solar kilns looks nice and are working even better than expected. The user of the solar kilns (Clipper Design Ltd.) is very happy about the kilns as the next section will reveal.

References

Frank, F.C., 2000. Test and Research Project into the Drying of Food and Wood Products with Solar Heat – Part: Wood Drying. Wood Technology, Danish Technological Institute.

Jensen, S.Ø., 2001. Inspection of solar dryers in Ghana. Solar Energy Centre Denmark, Danish Technological Institute. ISBN 87-7756-615-7.

Description of the tests and test results

Tonny Larsen

Preface (editor's remarks)

The below reports are based on detailed logging of the conditions in the solar dryers and the wood – manually and by Tinytag data loggers. The manually logging compresses logging of temperatures and humidity in the solar kiln and ambient – morning, noon and afternoon together with measurements of the moisture content in several of the planks in the morning: min, max and average moisture content. The electronically logging comprised logging of the humidity and temperature in the solar wood dryers and of the ambient air each 30 minutes. The logbook and curves from the data loggers are available at Clipper Design Ltd.

In the following reporting the wood has mainly been dried from green. The moisture meter at Clipper Design Ltd. is only able to measure moisture in the wood of up to 40%, however, people with knowledge of wood should be able to determine the moisture content at green stage for the different wood spices mentioned in the following reports

Report on the solar wood dryers – March 19, 2001

Forced open air dryer

The forded open air dryer has not been used yet because of the relative humidity, which ranges from 75-80% at midnight to 55-60% at 8:00 and now mid March down to 30% at noon. In one period during February it even dropped below 10%. All this data have been collected on a calibrated mechanical hygrometer.

The low relative humiditymeans that the forced open air kiln cannot be used for 4-6 months of the year since a too fast drying will give badly degraded wood.

Kiln

The accelerated air kiln as originally designed by Cliper Design Ltd. at Mankoadze and operating with borrowed equipment (PV-panels etc) is however, operating perfect with a controlled climate and a temperature of up to 40°C. Final position of hygro- and thermostat are to be determined.

The first batch of 5 m³ Ofram has been dried from above 35% down to an average of 17.5% in lees than 2 weeks. This would before with normal outside air drying take 4-5 weeks with some degrading (twists + cracks). What is coming out of the kiln now is totally without degrading.

The next batch of wood to go in is close to 8 m³ of hard wood. Also here I expect at least a 50% reduction in drying time against previous.

The kiln as in use now uses 10 pieces of 80 W panels to drive one large fan during the day and one 16" fan driving on battery during the night as well as a small 5 W exhaust fan (later replaced with a 7 W fan (ed.)) to take out moist air controlled by a hygrostat – this latter through on a 24 hours basis.

To put it bluntly it is a conventional kiln but driven by the sun and heated by the sun and it works perfect.

Report on the solar wood dryers – April 2001

Kiln

Electronic monitoring of the kiln started on April 11, previously unmonitored of 5 m² Ofram has taken place. This proved that the kiln operates even somewhat better than expected. The 5 m² 1" x 12" was dried from green to just below 20% in two weeks.

On April 11, the Kiln was loaded with 1" x 12" Ofram and Edinam in total 1.5 m² - again in a green state, this load has been electronically monitored. However, as has previously been experienced, the electronic humidity consistently show values that are way too high when compared to a calibrated mechanical hygrometer showing accurate values. This does not mean that the electronic curves should be discounted, since they do give invaluable information of what is happening to the climate and the kiln around the clock.

The 1.5 m² was dried to 20% in 14 days. Again, the kiln performed very well with very little degrade and because of the reduced heat and ventilation during the night as I have previously experimented with in traditional kilns, no stress is being locked up in the wood. If comparing the drying time in the kiln to previously air drying which took 5 to 6 weeks, a lot of time has been saved and thereby accelerated the work and output from the factory.

Currently 3.5 m² of 2" x 6" Danta is being dried (should have been 8 m² as mentioned in the report from March (ed.)). Danta is notorious for shell drying, but because of the reduced ventilation during the night it is expected that the moisture in the centre of the wood will have time to wander to the surface, and avoid shell drying as the moisture only is being blown off during day hours. The batch went in the kiln on April 24, 2001.

The only improvement it has been decided for the kiln is to paint the roof black to raise the temperature inside the kiln as the evaporation of moisture from the wood cool the air below a desired level.

Report on the solar wood dryers – June 2001

Forced open air dryer

The forced air dryer is drying 1½" x 12" Danta but with the relative humidity running up and down, it is almost impossible to keep control of the drying. A problem, which is now cropping up is that even wood cut from the same log have different rates of drying. In the current load, I can measure from 18% - 29%. This makes it even more difficult to monitor the overall process.

It is definitely not a method to use for a beginner in wood drying. It is a method to use in a far more stable climate with reasonably study relative humidity and by someone with a lot of experience with wood and its drying process and who therefore is able to judge how much the wood can take.

Kiln

The kiln since painting black has shown a remarkable improvement in operation. The temperature has now increased to what I consider ideal hovering around 40°C, and it has now also started to equalise the moisture in each separate plank. It has also brought the relative humidity inside to my desired level, considering the moisture in the wood, this level was difficult to reach previously because of low evaporation. In a the morning, one can actually feel the moisture on the wood, by noon, the surface is dried up until about 15:30 where lower voltage and slower ventilation will again allow moisture coming slowly to the surface only to be blown away next day.

However, because of the now increased heat, evaporation will continue during the night with slow ventilation, the vapour is continuous being moved only to be taken away by the exhaust fan and so allow the relative humidity to be somewhat higher during the night. Therefor no degrading of the lumber is visible.

Report on the solar wood dryers – July 2001

Forced open air dryer

From 26/04/01 to 01/08/01 approximately $1 m^3$ Danta has been dried from green to approximately 21% dimensions 1½" x 12" x 7 feet.

Initially until the rainy season was well advanced the ambient relative humidity dropped very sharply during the day recording below 40% resulting in frequent shut down of the fans once the wood was below saturation.

Unfortunately inspite of all my precautions at the end of the cycles the wood showed tendencies of shell drying and the necessity of removing it to the solar kiln for conditioning which took a further 9 days.

As the rainy season now slowly peter out and the relative humidity fall off it will become increasingly difficult to use the forced open air dryer and unless the operator are skilled and have a deep knowledge and feeling for the wood, and such people are not impossible to find in Ghana but one will have a hard time doing it, then it will damage more wood than it dries.

My present conclusion is that the forced open air dryer has very limited commercial value, and then only with a very good operator.

Kiln

From 26/04/01 to 01/08/1 approximately 3.5 m^3 Danta has been dried from green to as low as 15% and average 19% dimension 2" x 6" x 7 feet. Danta is slow and difficult to dry.

The solar kiln have dried this load to perfection: no shell dry wood, no degraded wood and absolute no stressed wood. This I have to admit came as a surprise to me since even air dried Danta can produce stress, currently I have no explanation except it could be the reduced ventilation at night that may be the cause.

This load of Danta the kiln save me at least 6 month in drying time.

The next load for the kiln will be loaded 17/9/01 and is also 2" x 6" Danta. This may produce an answer.

On August 2nd I had to load the 1½" x 12" from the forced air dryer into the kiln for conditioning. Luckily it was a period with sunshine and therefore high temperature in the kiln. With frequent watering I kept the relative humidity fairly high and got the wood saved from shell drying.

This operation took 9 days to do.

Since painting the kiln black I can now reach up to above 45°C in the kiln.

Report on the solar wood dryers – August 2001

Forced open air dryer

The forced air dryer is performing, but with the high relative humidity during the night at the moment and the sharp fast drop in relative humidity during the early hours of the day, one need to keep a wake full eye on the wood and its moisture, and unless a knowledgeable person is assigned on a more or less full time to monitor, it is my humble opinion this method could in the long run prove to be very costly.

Kiln

The kiln is continuing to perform admirably in that the 2" x 6" Danta have now come out with a maximum moisture of 19.5% and a minimum of 15.5% and so far no degrading of the wood have been observed. No shell-dried wood has been found, even deep probing into the wood show the same uniform moisture. The wood that have been cut have had no stress locked up, this is unusual for kiln dried Danta which is usually full of internal stresses due to the fast drying process in a conventional kiln. The 3.5 m^3 load was dried in 94 days (until 01/08/01), granted considerably longer than the 35-40 days in a conventional kiln, but a vast difference to the 9-13 months used for air drying which also give a considerable amount of degrading.

When one consider that the solar kiln overall give a far better quality of the wood. The extra time used over a conventional kiln is well worth it, since there is no stresses and no shell drying and therefore no rejects.

The next load to go in will again be 2" x 6" red wood and again straight out of the bush. This wood should arrive within a week (but didn't (ed.)).

The solar kiln is only monitored as close as it is to collect data. Normally it would only be checked once and occasionally twice a day, and maybe only checked moisture in the wood every two days and if the wood is green and 2" x 6" maybe not even for the first 10-15 days depending on the specie of wood.

With the experience now gained with the solar kiln, I can highly recommend it for commercial use in Ghana, I will also be happy to put the facility for the use of instruction and demonstrating to potential users and operators.

Report on the solar wood dryers – September 2001

Forced open air dryer

The dryer was loaded 24/09/01 with 1 m³ 1¼" x 12" x 7 feet Esa, The moisture of the wood at time of loading was 22.6%, which is below saturation point. As relative humidity at the moment is rather high 55-70% around noon the dryer should be able to dry the wood down to between 11-14% moisture within a reasonable time. At the moment we are at the tail end of the rainy season. Once this is over, the relative humidity will drop below 40% around noon, and during the night go as high as 70-80%. Since the dryer cannot control the humidity or the temperature and cannot run during darkness it cannot be used below saturation point and will therefore just sit useless and empty.

The above load of wood got due to shell drying full of cracks in the surface and had major cracks from the end. The wood very only worth for firewood and eventually used as such.

A few small and medium size wood working shops in Ghana have an intimate knowledge of the nature of wood and even less have a capacity to or understanding of the importance of measuring the moisture in wood to a certain content before working it.

I have yet to meet anyone who can remotely know what the average moisture should be in the wood used along the coastline provided it is not being installed in air-conditioned rooms where the wood must be brought to a lower moisture.

I am afraid that with the lack of understanding predominately prevailing in the industry, the forced open air dryer will do more harm than good until the general knowledge and understanding of wood and moisture have been brought to a much higher level than is the case today.

Kiln

The solar kiln continues to perform far beyond my expectation as soon as the temperature in the kiln gets above 32°C water starts running off the wood so the floor is sailing.

The current load of Danta 2" x 6" and 1¼" x 12" was loaded 18/09/01 in green state and now 8 days later I have noticed that some of the wood is getting close to the point of saturation or 32-33%. However, because of the rest, the wood gets during the night (lower temperature and lower ventilation) I have no qualms about running it hard during the day to see how fast I can bring it down.

This kiln type is very easy to operate. It only need a hygrostat, an accurate thermometer and a calibrated mechanical hygrometer plus knowledge of wood with the means of measuring the moisture in the wood.

I can highly recommend this type of kiln in the tropics. By using this and keeping an eye on the relative humidity it is almost impossible to spoil the wood. It is easy to learn to operate and maintain.

Someone with a reasonable IQ and a good command in English should be able to run their 3rd load independently with only sporadic checks on the log keeping and the wood in the kiln.
It should be noted that different types of wood dries different and it is therefore imperative to keep a log for later reference.

Report on the solar wood dryers – December 2001

The forced open air solar dryer has been converted to a solar kiln and is also working very efficiently.

The old kiln (kiln no. 1) is operated with 14 60 W_p Gaia PV-panels. The PV-panles drive the 300 W/24 V day fan and one 16" 50 W fan directly.

The new kiln (kiln no. 2) runs on 30 14 W_p Intersolar PV-panels which drive 6 16" 50 W day fans.

For each kiln there is a 260 Ah deep cycle solar battery, which is being charged by one 60 W_p Gaia PV-panel (i.e. two panels and two batteries in all). Each battery run one 16" 50 W fan to circulate the air during the night.

An AC battery charger has also been installed to top up the batteries in the event of bad weather to ensure continuous operation of the systems.

There is also a 7 W/12 V fan in kiln no. 1 and 5 W/12 V in kiln no. 2 controlled by a hygrostat to control the humidity level in the kilns. These fans also run on the batteries.

Performance of the solar kiln

The old kiln was loaded on 18/09/01 with 2" x 6" and 1¼" x 12" in all 2.5 m^3 green Danta. Within 8 days the wood was below saturation point except for a few planks and after 12 days average moisture was measured to 25.5%.

This is amazing since Danta normally is very slow and difficult to dry, however, the weather has been good with plenty of sun and temperatures in the kiln of up to 41.5°C has been recorded. To dry this load from green state to an average of 19.5% took in all 22½ days.

Currently, we have loaded 2" x 6" and 1¼" x 12" in all 1 m^3 Jnokko (Odum) also in a green state and after 3 days in the kiln some planks are now beginning to show a moisture % that is dependable – again, this is an amazing short time and no degrading.

On the 12/10 the kiln was again loaded with approx. 1 m^3 Jnokko (Odum), which again was dried in a green state 2" x 6" and 1¼" x 12". 14 days after it was at 18.9% and now 23 days in the kiln it stands at 11%. This is a very amazing result.

Again, I can highly recommend this type of kiln for small and medium size wood shops or even the bigger one will benefit from it, since it size for size will be much less expensive to run than a conventional kiln with boiler and net power connection.

Report on the solar wood dryers - January 2002

A load of Danta has been dried from green state down to 19.5% in 23 days, dimensions of the wood was 50 x 150 x 2100 mm³. Another load of Iroko 50 x 150 x 2100 mm³, and 32 x 300 x 2100 mm³ was dried from green state to 17.5% in 17 days and bringing the same load down to 10% took a total of 34 days.

The following logger curves showing the humidity and temperature in the kiln will make any one with a serious knowledge of wood drying see that on the above-two loads, I have cut the time below a conventional kiln. The curves correspond with the log.

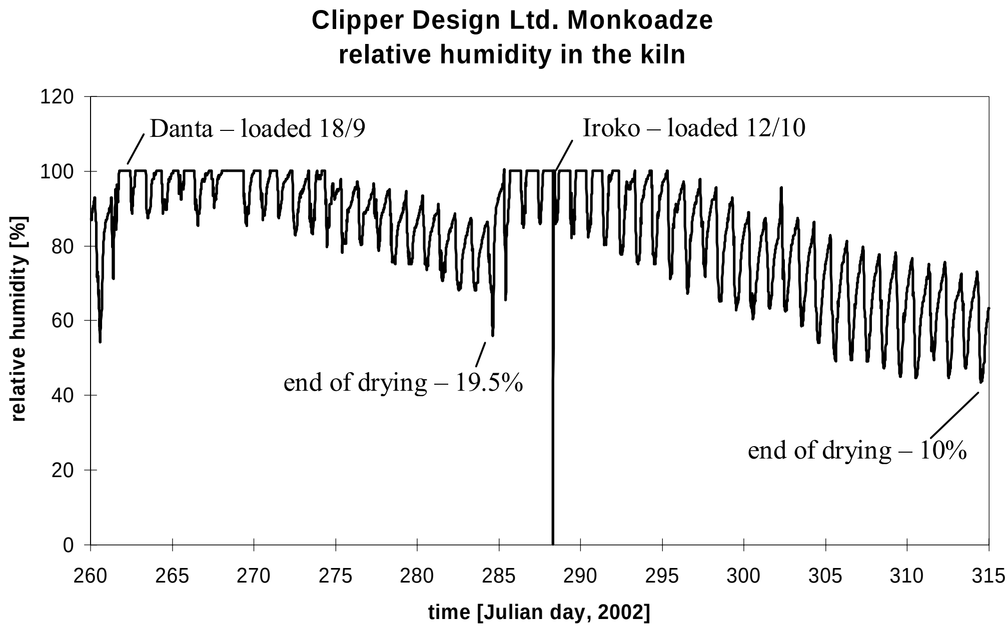

Figure 1. Humidity in the solar kiln during the drying of the above-mentioned loads.

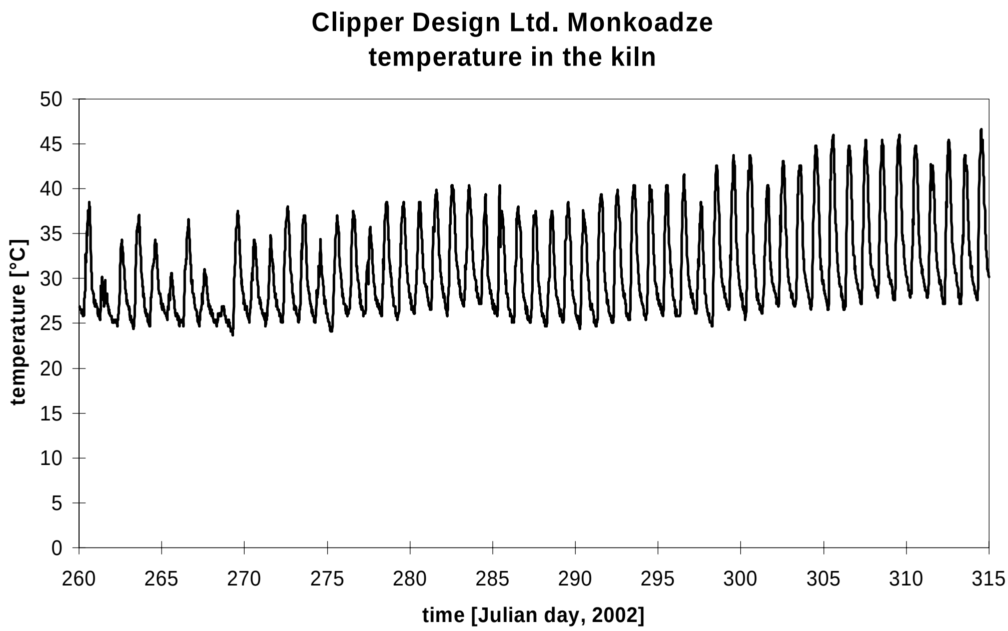

Figure 2. Temperature in the solar kiln during the drying of the above-mentioned loads.

I expect this to continue in the future now that I have found the formula. The next load will be approximately $5m^3$ Masonia (Mansonia Altissima) as with the previous loads. I do not expect any degrading but Mansonia can be ticklish to dry, it will go into the kiln no. 1.

The loads in the kiln has all been below 5 m^3, however it is my humble opinion, that a full load – 10 m^3 - will not increase time with more than 10 – 15%.

The temperature in the kilns is now in the high 40'ties (°C). The only 3 problems I now have is: my electronic thermometer in the old forced open air dryer can only measure 39.9°C. The one I used in kiln 1 is an inside – outside with a feeler for outside that goes up a above 50°C. The small vent fan in kiln no 2 is only 5 W it should be a 7 W as in kiln no. 1. The 50 W night fan in kiln 1 has from the beginning been badly off and now hammers very badly (are now repaired (ed.)).

The solar kiln looks like a normal kiln with its fan and false cycling but no heat element, there is no secret there. The secret is knowing how to operate it. All the experts said it would not work, however, I am doing it.

I shall do my part in promotion by showing any one interested how it works and let them have a trip into the sauna. I shall do that any day I am asked, as I have done many times already.

However, operating a solar kiln is not straightforward so training in the use of the dryer is needed. Such training may be offered by DENG Ltd. in co-operation with Clipper Design Ltd. As mentioned in (Frank, 2000), also I have found a general lack in knowledge of wood and how it behaves here, I did not originally think this possible in a lumber country, but there is. So a training course should also contain general aspects on how to handle wood.

The companies who will really benefit from this kiln system will be around my size (if finance system can be found). The bigger shops may already have invested in conventional kilns that may be bigger, which I doubt is possible to make the solar kiln. Unfortunately, it is also the smaller firms that lack most in knowledge,

Economics

I have made an economical calculation, on the running cost of a conventional kiln versus the solar kiln based on current prices, and it is a know fact that electricity will at least double this year in price, both cases 10 m^3 lumber, you can pay for the solar kiln in 4 years with the savings in the running costs of a conventional kiln.

Cost of a solar kiln in a 20 foot container

Item	quantity	cost US$	total cost US$
60 W PV-panels	14	270	3780
260 Ah battery	1	295	295
50 W fan	6	300	1800
7 W fan	1	50	50
Aluminium sheets 4' x 8" x 0.6 mm	24	80	1920
Aluminium angles 50 x 50 mm	7	40	280
Solstice M x 120 control box	1	116	116
Hygrostat	1	250	250
Thermometer	1	300	300
Mechanical hygrometer	2	200	400
Assorted screws and bolts (set)	1	800	800
6 A battery charger	1	40	40
Flat bar 2 mm x 40 mm aluminium	16	20	320
Pop rivets (pcs)	10	20	200
Subtotal for equipment			10551
Cost of container or constructed kiln including installation	1	2350	2350
Total (without VAT)			12901
Total including 12.5% VAT			14514

It is assumed that the solar kiln can be controlled by one person: 2,400,000 Cetis per year = 320 US$.

Annual running cost of a conventional kiln

Item	Cetis	US$
Continuously running of a 3.5 kW fan	21,231,450	2831
Personal for controlling the kiln – 3 persons per day	7,200,000	960
Personal for controlling the boiler – 1 person per day	2,400,000	320
Total		4111

Simple payback time: 14514/(4111-320) = 3.8 years. However, this is not the real economics of the solar kiln as the initial cost of a conventional kiln is not included. A conventional kiln is in fact more expensive than the above solar kiln. The price of a conventional kiln for drying 10 m³ wood is in the order of 30.000 US$ (without VAT), which is more than double the price for the solar kiln.

The solar kiln will thus under all circumstances be more profitable that a traditional kiln – both with regards to initial cost of the kiln and with regards to running cost.

Conclusions and recommendations on the solar wood dryers

After installation and operation of two types of solar dryers for nearly one year certain conclusions can be drawn.

Forced open air dryer

The forced open air dryer was unfortunately designed on a wrong basis, which Wood Technology, Danish Technology was made aware of in August 2000 by email.

The relative humidity in Ghana do not correspond with Akufo, 1991 (also in (Jensen, 2000)). Whether this is caused by climate change or some other cause is not for me to speculate, the net result is that this type of dryer is not suited here. I could go further in critic, but it is suffice to say, that it was an unfortunate experiment that could have been avoided.

Kiln

The solar kiln is a design done by Tonny H. Larsen of Clipper Design Ltd. with the solar equipment dimensioned by DENG Ltd. design team and with copyright for the two companies as designed on original drawing.

This kiln has performed beyond expectation from day one, drying the wood at the start in approx. 1/3 of the time used in simple air drying, this in itself was an enormous improvements. However, as this went on and more experience with the dryer was gained it was found that time could be cut down even further. A load of Danta has been dried from green state down to 19.5% in 23 days, dimensions of the wood was 50 x 150 x 2100 mm^3. Another load of Iroko 50 x 150 x 2100 mm^3, and 32 x 300 x 2100 mm^3 was dried from green state to 17.5% in 17 days and bringing the same load down to 10% took in total of 34 days. This is below the time required in a conventional kiln.

The forced open air dryer was subsequently converted to a kiln during December, certain improvement learnt from experience with the original kiln has been implemented and will make it even more effective.

None of the loads dried have shown any mentionable degrading even when I have dryed the wood hard. This can only be explained by the relative rest period the wood gets every 24 hours, and which apparently do not influence the drying time to any noticeable degree.

Kiln II the old forced open air dryer will shortly be loaded with approximately 5 m^3 green 50 x 150 x 2100 mm^3 Mansonia Altissima. This wood can be rather ticklish to dry but no degrading is expected.

The kiln can economically be installed and operated in 20 foot container with certain very small modifications, and you will then have a kiln totally independent of power and heat supply, and is moveable. If needed instead of drying wood in 7-foot lengths the container can be adapted to dry 14 foot length, but that will necessitate additional equipment and fans.

An idea would be to place containers in clusters at timber markets, where local small carpenters could then get their wood dried at a reasonable cost, or one or several small firms get together to acquire a kiln.

Courses for operators of these kilns must be set up, and the general knowledge of wood and its behaviour in relation to drying and its relationship to its surrounding and use must be improved especially at the grassroots where there is very little knowledge about wood and moisture or even how to store the wood to avoid damage, or even the ability to see that the wood is damaged.

The use of moisture meters must be encouraged at all levels since knowing the moisture percentage is paramount to quality of the finished product. Grading of the wood is another very critical area where knowledge is lacking, wherefore one often see totally unsuited wood being used where it shout not.

As to moisture meters: the best one I have ever worked with is the Delmhorst which can be adjusted for specie and temperature so you can read the actual moisture in the wood without manual compensation it can also give you an average reading of up to 100 tests, which is important in a kiln, it will further tell you if the wood is above saturation point, this feature is very important with kilns as that will determine how hard you can drive your drying process, and when to slow down.

An economical run down of solar kilns versus conventional kilns have been done in both cases using $10m^3$ lumber as reference it shows using current pricing that the solar kiln can be paid for within a period of 4 years by saving on running cost. With rising cost in electricity that period will become shorter. The initial cost of the solar kiln is further only half of the cost of an identical sized conventional kiln. The solar kiln will thus under all circumstances be more profitable than a traditional kiln – both with regards to initial cost of the kiln and with regards to running cost.

Prices on kiln equipment etc will always be available from Deng Limited.

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Evaluation of the dryer and tests

K.S Nketiah

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Advantages of Drying Wood

Before processing wood into most end products, it is important to dry the rough green lumber sawn from the log. Drying gives several advantages including the following:

a. Weight reduction: hence reduction in shipping and handling costs.
b. The shrinkage that accompanies drying takes place before the wood is used as a product. Thus the final product has greater dimensional stability.
c. As wood dries, it increases in most strength properties.
d. Dried wood gives stronger joints with nails and screws and also takes polish (and other finishes) better.
e. Drying reduces the likelihood of attack by mold, stain or decay fungi.
f. Drying also increases electrical resistance and thermal insulating properties.

Drying thus adds value to the wood and therefore increases its price.

1.2 Current Practices (of Wood Drying) in Ghana

In a bid to promote value addition, the Government has put in place a policy, which requires that the export of green lumber in some prime wood species attracts a levy. These species include *Odum*, *Afrormosia, Sapele* and *Makore.*

The percentage of kiln-dried lumber exported has since been gradually increasing over the years. The ultimate goal of the policy is to discourage the export of green lumber of any species altogether. This policy has driven many large and medium sawmills to acquire drying kilns of different capacities and makes.

As at the end of May 1998, there were a total of 65 woodworking companies with kiln drying facilities (Forestry Commission, 1999) as against the 21 in 1986. These span both secondary and tertiary processing companies. Altogether, the total installed kiln drying capacity may now be close to 20,000m^3. Individual company capacities range from 15 to 1,000m^3; usually the tertiary processing companies have lower installed drying capacities. Most of the kilns are fired by wood residues. A few however are oil-fired. A couple of mills also use the dual system. In recent times, some few mills have experimented with solar kilns.

In spite of the increasing installed capacities of drying kilns, expertise in wood drying is still lacking; kiln control has not been the best as evidenced by the wide ranges of the moisture content of dried batches of wood. A range is high as 6 – 40% m.c. has been reported. The timber industry is very much aware of this problem and efforts are being made to address it, even though the progress is rather too slow. Another problem associated with the conventional kilns is the very high initial capital outlay required.

1.3 Experience with Solar Kilns in Timber Drying in Ghana

The use of solar kilns to dry timber is no novelty, even in Ghana. The Forestry Research Institute of Ghana has done considerable research work in this area. They have reported 30 - 60% reductions in air drying time, depending on species and thickness. Commercial use is however limited, even though some mills re reported to have tried it at one time or the other. Experiences have been limited to the green house type. Currently it is known that at least two companies use solar dryers. It was also reported that some mills use solar pre-dryers.

1.4 Assessment of Solar Kilns

Solar kilns usually have relatively lower capacities and lower initial costs, especially for the simple green house types. Being dependent mainly on solar energy, their operating costs are generally lower than diesel or electric powered kilns and even for those using the so-called wood processing residues. A crucial problem with solar kilns however is how to control the drying conditions. Without controls and a heat storage system, the inside temperatures can be too high during a hot sunny day and very cold during a damp day and in the night.

Even though Ghana may appear to have ample sunny days, studies have shown that as much as 90% of the solar radiation may be diffused, a situation that is not too favorable for solar heating. Solar kilns with collectors and heat sinks however could be very expensive to install. Operating costs could still be low though.

2.0 BACKGROUND

In 1999 DANIDA provided some funds for Danish Experts from the Danish Technological institute (DTI) to assess the prospects for introducing Danish technology in solar drying to Ghana for the drying of food crops, fish and timber. The team accompanied by local counterparts, visited Accra, Kumasi, Asamankese, Akim Oda and Mankoazde, near Winneba in October (1999).

A report of the Danish Wood Drying Expert on the field visits recommended the establishment of a test unit for only forced air-drying of wood in Ghana, where solar energy is used for running the fans. The basis for this recommendation however is not very explicit from the field survey report. In fact Frank (2000) noted that " *it is…obvious that air-drying and forced air-drying alone are not sufficient to bring timber fit for indoor use, where the wood moisture (EMC) will be between 8 and 12%".* The report suggested that the test unit could be placed at Clipper Design Limited at Mankoadze, near Winneba. But the final location of the unit was to be decided by DENG and the Ghanaian Consultants, based on the availability of know-how and experience as well as the possibility of the unit serving as a demonstration for other interested parties.

Frank (2000) identified the lack of understanding of wood when it dries and the improper operation of kilns as the main reasons for the unsatisfactory quality of the dried wood in Ghana. From these observations, he could not recommend an accelerated air-drying unit for the test. Rather, he recommended a strong effort for widening the know-how of wood drying. He went further to itemise a five-step plan for future work. These were as follows:

1. Evaluation of the test results from this actual project (forced air-drying)
2. Training courses for a number (5 – 10) of Ghanaian instructors in drying of wood.

3. The instructors' activities in Ghana: Education and training of drying operators
4. Establishment of and test runs with drying units for accelerated air-drying.
5. Test runs with fully equipped kilns for wood drying.

Unfortunately however, this plan was apparently not adopted fully. Only the forced air-drying unit (the first step) was implemented. This was compared with the solar kiln. But as pointed out earlier, the basis for recommending this test was not adequately explained in the initial documents. It was later explained that the forced-air dryer was initially selected based on the available weather data; the solar kiln was also originally discarded because of the perception that it could not be made as a stand-alone unit (without connection to external source of electricity). This perception has however been proved wrong from the tests.

2.1 Plan for Tests and Reporting

The test of the solar wood dryers consisted of two levels:

a. Parallel tests with the two dryers in order to determine which concept is superior.
b. Test with different types and sizes of wood.

The reporting was to be at three levels:

a. Report on the results on the parallel test with the two dryers
b. Report on the results of the tests with different types and sizes of wood.
c. An impartial report by the Consultant stating how well the goals of this part of the project has been reached.

2.2 Specific Assignments

Clipper Design Ltd. was also required to write a detailed logbook on each test and to carry out tests using the better of the two dryers for different types and sizes of wood.

DENG was to start and off-load data from three combined temperature/humidity Tinytag data-loggers. DENG was also to deliver curves for the measured temperatures and humidities to Clipper Design Ltd. in order to support the reporting.

2.3 Terms of Reference for the Consultant

The Consultant was engaged to make a total of three (3) visits to the project site before a final visit at the end of the project. He was also to talk with Clipper Design Ltd, assess the reports by Clipper Design and write an impartial report stating how well the goals of this part of the project has been reached.
The tests and reporting were to be finalized by the end of October 2001.

3.0 ACTIVITIES CARRIED OUT

3.1 Dryers Tested

Two (2) solar wood dryers were erected at Clipper Design Limited at Mankoadze, near winneba. The first is a forced open-air dryer based on a recommendation from Wood Technology, Danish Technological Institute (DTI), of Denmark. The second was a closed version designed and constructed through the joint effort of DENG and Clipper Design Ltd. The latter one makes it possible to control both temperature and humidity level of the air in the solar wood dryer. The design and construction details are provided in Frank, 2000 and Søren Østergaard Jensen, 2001.

3.2 Consultancy Services

In line with the Terms of Reference, the Consultant visited the project site on three (3) occasions, twice with staff of DENG, and once on his own. Several meeting were also held with DENG both in Kumasi and in Accra. Records of tests of wood drying using the two dryers were inspected and discussions held with Mr. Tony LARSEN of Clipper Design Ltd, at the project site. A copy of the final report by Mr. Tony LARSEN was also studied.

4.0 FINDINGS AND EVALUATION

4.1 Dryers

The solar kiln designed by Clipper Design Ltd. and Deng Limited performed very well. It was used to successfully dry samples of different wood species including *Danta* (50mm X 150 mm), a species with a high tendency to shell-dry. The products showed very little drying defects with no stresses.

The wide variations in relative humidity that prevailed made the use of the open forced-air dryer very difficult. It could however be used to dry 11/2" x 12" x 17" (38mm x 300mm x 2100mm) *Danta* boards in 94 days from green condition to 21% M.C. But the product exhibited shell-drying and other drying defects. It had to be conditioned in the solar kiln for another 9 days to attain a final moisture content of 19.5%.

4.2 Tests

To make for easy comparison, attempts have been made to summarize the test results reported by Clipper Design, in the two tables below.

Table 1: Summary of Test Results using the Forced-Air Dryer

SPECIES	SIZES	INITIAL M.C.	FINAL M.C.	DRYING TIME	REMARKS
Danta 1m^3	1½" x 12" x 7"	Green (>35%)	21%	26/4 - ⅛ 94 Days	Wood from same log showed different drying rates; wide range of m.c. 18% - 29%; Wide variation of ambient RH; wood showed tendency of shell drying; had to be conditioned for 9 days in solar kiln.
Essa, 1m^3	1¼" x 12" x 7"	22.6%	14.9%	39 days	Reported shell-drying, full of surface cracks and end-checks.
Danta 3.5 m^3	2" x 6"				Roof of kiln painted black; temp increased to 40^{o}C. Trial abandoned

Table 2: Summary of Test Results using the Solar Kiln

SPECIES	SIZES	INITIAL M.C.	FINAL M.C.	DRYING TIME*	EST. /D TIME	REMARKS
Ofram 5m^3	1" x 12"	>35%	17.5%	2 wks	4 – 5 wks	No drying degrade
Ofram & Edinam 1.5 m^3	1" x 12"	Green (>35%)	20%	14 days	5 – 6 wks	Readings from electronic hygrometer much higher than those from calibrated mechanical hygrometer
Danta 3.5	2" x 6" x 7	Green	15.5 – 19.5%	26/4 - ⅛ (94 days)	9 – 13 months	Roof of kiln painted black; temp increased to 45^{o}C; No shell drying, no in-built stresses
Danta, 2.5 m^3	2" x 6"& 1¼" x 12"	Green	19.5%	22.55 days		Good weather, plenty of sunshine, kiln temps up to 41.5^{o}C
Iroko 1 m^3	2" x 6": 1¼" x 12"	Green	11%	23 days		
Danta	50 mm x 150 mm x 2100 mm	Green	19.5%	23 days		
Iroko	50 x 150x 2100 mm^3 32 x 300 x 2100 mm^3	Green 10%	10%	34 days		

* Estimated drying time for ordinary outside shaded air-drying (Tonny Larsen)

From examination of the test records and data sheets, it is apparent that the tests were meticulously carried out.

Even though there was a general indication that the solar kiln was much more efficient than the forced-air dryer, the trial wood samples were not of the same species and sizes. There were also no replications. This makes it difficult to rigorously compare the performance of the two dryer designs. This defect in the experimental design was possibly due to the fact that Clipper Design Limited, being a purely commercial set-up, processed only wood that was required for a particular job. This however compromised the scientific quality of the trials to some extent.

Significant discrepancies were reported between weather data (particularly the relative humidity) as provided and what was actually recorded. It has not been possible to explain this. Discussions with Prof. F. O. AKUFFO revealed that the data for his publication was sourced from the Meteorological Services Department. He could therefore not vouch for their reliability. It is worth noting however that the data is based on averages over a longer period and for different geographical areas. (Winneba *per se* does not have a weather station). Inaccuracies in the equipment used in the tests can also not be ruled out. Nevertheless, further investigations would be necessary to explain the discrepancy.

4.3 Economics

The comparative data provided for assessing the economics of the solar kiln and conventional kiln is very useful. But as the report indicated, the calculations do not provide the real economics of the solar kiln. Besides the initial cost of the conventional kiln, the relative drying times for the two kilns were ignored.

For small scale drying assignments, a lot can be said for the solar kiln. But for large scale/commercial drying purposes, the frequency of loading and off-loading the kilns will make nonsense of the comparison. Thus, the statement that the solar kiln will 'under all circumstances be more profitable than a traditional kiln' could only be true for the same size kilns ($10m^3$ as compared in this case).

The price of a conventional kiln of $30,000 might be about right. Quotations for a 45 m^3 is between $40,000 and $50,000. Normally they come in bigger sizes than 10 m^3 and it is not certain to what extent the smaller size may be cheaper

5.0 CONCLUSIONS

To a very large extent, the goal of this part of the project has been reached. Generally, the tests have confirmed that the solar kiln as designed and constructed by Clipper Design and DENG Ltd has far outperformed the forced-air dryer both in the rate of drying and the quality of the dried products. The tests have also demonstrated that it is possible to build and operate a solar kiln as a stand-alone unit, with no external power source.

The capacity of the solar kiln however makes it best suited for small to medium wood-working companies, where there is still a great need for drying wood for local processing.

Mr. Tony LARSEN has a good appreciation of the principles involved in the drying of wood; he has shown a lot of enthusiasm and initiative through out the test period; but as a purely commercial set-up, he has been constrained in the experimental design for the tests.

DENG has a good grasp in the construction of both Forced-air dryer and the solar kiln; given the chance they could replicate the experience in other parts of the country especially in areas with several woodworkers. In this way, the multiplier effect could be higher.

Using only the operating costs of a conventional kiln and the full cost of construction, installation and running of a solar kiln, the study has indicated a payback period of 3.8 years for the latter kiln. But still, given the capital base of most wood workers who could most benefit from the technology, it makes much sense to encourage communal ownership where several people pool resources together. Better still, if strategically located, the solar kiln could provide kilning services for several wood-workers.

The consultant basically agrees with the conclusions drawn from the tests, but finds the basis for comparing the two solar dryers tenuous. The forced open-air dryer is supposed to be an improvement over the simple air-drying, which is widely practiced in Ghana.

It therefore appears unfair to pitch this simple kiln against the solar kiln. In any case, the economics of the two solar dryers should have been compared as well.

6.0 RECOMMENDATIONS

a. It is strongly recommended that the many useful lessons learnt from this project be put to use by supporting the duplication of the solar kilns at strategic locations.
b. In addition to this, massive education would be necessary on the nature of wood, wood-water relations and the drying and handling of wood generally. This will be particularly useful for small- and medium scale wood workers.
c. Already, the Timber Industry Development Division of the Forestry Commission, under the E.U-sponsored Wood Sector Development Programme, is offering assistance to the industry to improve wood drying in Ghana. Any future activities in solar drying of wood could be linked to this on-going effort.
d. The baseline weather data may have to be validated and updated.

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