Inspection of solar dryers in Ghana

Solar Energy Centre Denmark
Danish Technological Institute

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Preface

The report describes the results from inspection visits to three solar dryers in Ghana. The work is 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 present report describes the findings from visits to a solar crop dryer, a solar fish dryer and a solar kiln for drying of wood. The report further contains the results from one week of detailed measurements on the solar crop dryer.

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1. Indtroduction

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. The crop dryer and the fish dryer is basically identical, while the wood dryer is different from the two others. For details on the development of the dryers please refer to (Jensen, Kristensen and Forman, 2001) and (Frank, 2000).

The three solar dryers were erected during September 2000 - February 2001. As part of the start-up of the testing of the three dryers, the Danish co-ordinator of the project Søren Østergaard Jensen visited Ghaner in the period January 21-27, 2001. The aim of the visit was to inspect the dryers, to agree on any necessary changes and to agree on the test procedure for the three dryers – hereunder install a measuring system on one of the units of the solar crop dryer.

The solar crop dryer is situated just outside the small town Pokuase, the solar fish dry is situated just outside Tema, while the solar kiln is situated in the small town Mankoadze – please see figure 1.1.

The three following chapters describe the findings from the visits on the sites with the solar dryers.

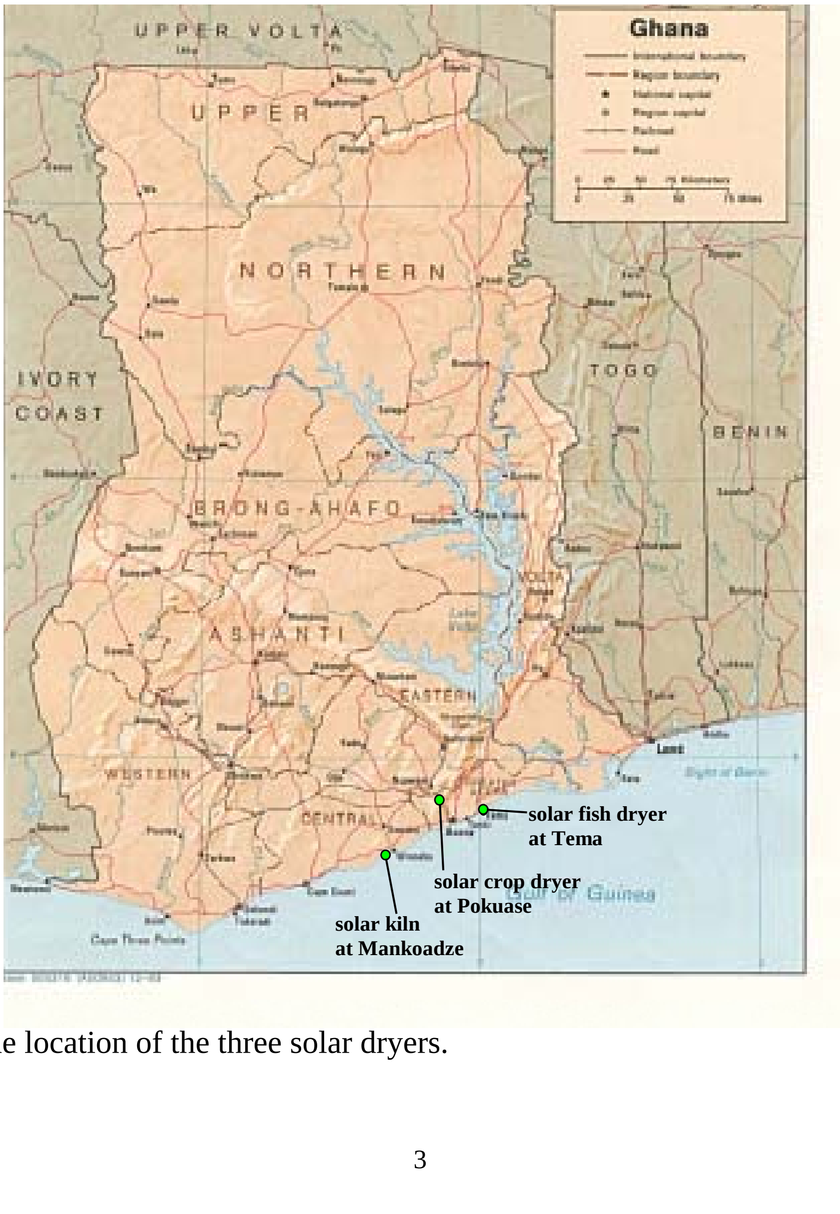

Figure 1.1. The location of the three solar dryers.

2. Visits to the solar crop dryer

The solar crop dryer is erected at Silwood Farms at Pokuase about 30 km north of Accra. Silwood Farms grows primarily maize for seed and pineapples.

The dryer consists of 5 identical drying units each with a solar air panel of 4.77 m², a PV-area of 0.64 m² (28 W_p) and a drying bed with an intended capacity of 120 kg maize. The principle of the dryer is shown in figure 2.1. For further details please refer to (Jensen, Kristensen and Forman, 2001). The 5 drying units are located in a building erected for that purpose and with the solar air collectors being the roof of the building. Figures 2.2 and 2.3 show pictures of the building containing the solar crop dryer.

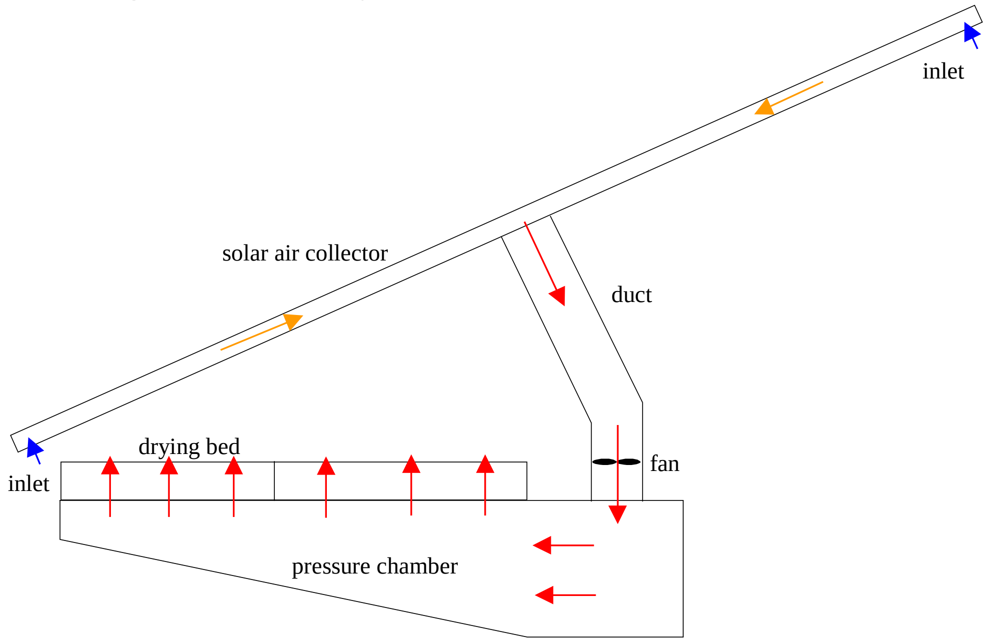

Figure 2.1. The principle of the solar crop dryer. In Ghana the tilt of the solar air collector is 15° and not 30° as shown in the drawing.

The solar crop dryer was visited several times: afternoon January 22, morning January 23, afternoon January 25 and finally morning January 27. The reason for the many visits was to make sure that the detailed measuring system (see later) was running correctly and in order to collect data from the measuring system.

The chapter contains four sections:

- the findings from the inspection on the solar crop dryer,
- description of the developed simple test method incl. the very first results,
- the results from the detailed measurements on the solar crop dryer carried out during the visit of the Danish co-ordinator to Ghana and
- plan for the tests and reporting of the tests.

Figure 2.2. The solar crop dryer seen from the south.

Figure 2.3. The solar crop dryer seen from the west.

2.1. Inspection of the solar crop dryer

The five units of the solar crop dryer were manufactured in Denmark by Aidt Miljø and shipped to Ghana with arrival in September 2000. The foundation and walls of the building containing the drying units were erected prior to the arrival of the five drying units.

A person from the Danish manufacture (Torkil Forman) went by the end of September 2000 to Ghana and installed together with DENG the drying units.

The building with the solar air collectors as roof is shown in figures 2.2 and 2.3. The duct-works and the drying beds are shown in figures 2.4-6.

Figure 2.4. The five drying units inside the building.

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.

Figure 2.5. The connecting ductwork between the solar collectors and the drying beds.

Figure 2.6. A drying bed with maize.

The only obvious fault was that only one filter was put in the inlets to the solar air collectors. There should be a filter in each end of the collectors as shown in figure 2.7. The purpose of the filters is to prevent the absorber of the solar air collectors in getting blocked by dust especially during the Hamatan. The absorber is a felt mat where the air passes through (see figure 2.7) and thereby heated – the passage through the absorber creates a higher heat transfer than if the air had passed along the absorber.

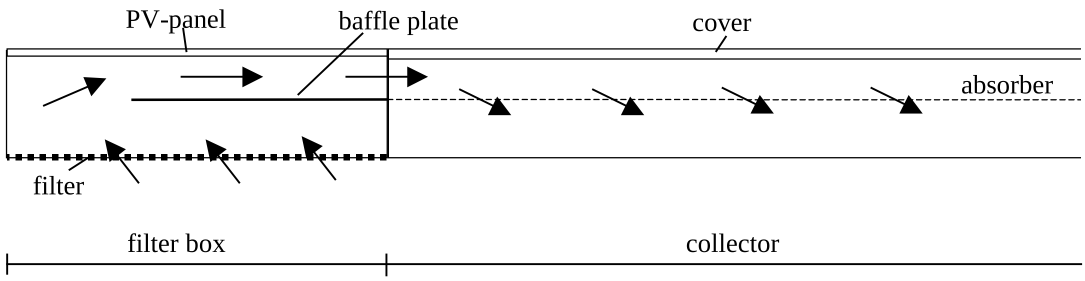

Figure 2.7. The filter arrangement at the air inlet to the solar air collector behind the PV-panels (Jensen, Kristensen and Forman, 2001).

The farmer was instructed in installing the filters and maintaining them (i.e. washing the filters when necessary). The two filters were located in the unit being monitored in order to obtain the right pressure drop and thereby realistic air flow rates.

The harvest season for maize had just begun prior to the visits to Silwood farms. By the time of the first visit the farmers had a couple of days before put maize (14.5 kg per tray) in the three middle drying units. He had left the two outer units without maize so that the Danish co-ordinator could chose which dryer the measuring equipment should be installed in – and so that wet maize could be put in the dryer immediately after the dryer had been instrumented.

The dryer chosen to be instrumented was dryer A at the far back on figure 2.4.

The farmer had arbitrarily chosen to put 14.5 kg of maize in each tray – incl. tray 18 kg. The morning after instrumentation of dryer A – dryer E was filled with 16.5 kg in each tray – incl. tray 20 kg. The farmer will experiment with the amount of maize in the dryers. However, the maize season had been very, very bad. They normally harvest 1000 bags (of 45 kg each) of maize in January but this year they only expect to harvest about 10 bags. It will thus not be possible to perform many experiments with drying of maize. The farmer will, however, perform experiments with other crops as pineapple and popo. They have already performed one preliminary experiment with pineapples.

Further tests on maize may be carried out during the main maize season in August-September.

2.2. Simple test method

The simple test method developed by the Department of Agricultural Engineering, Danish Institute of Agricultural Sciences is described in details in Appendix A. The method is based on weighting of the trays with the crops at regular intervals (morning, noon and evening) plus determination of the water content of the crop prior to the test. The farmer further has to take readings of the ambient dry and wet temperature and thereby obtain the ambient relative humidity.

The farm is in position of an instrument for direct measurement of the water content – a Dole Grain Moisture Tester (see figure 2.8). But when trying the instruments strange readings were obtained. One hour after the start of a test the instrument showed a drop in water content of 1% point. This is not possible. Erik Fløjgaard Kristensen, Department of Agricultural Engineering, Danish Institute of Agricultural Sciences was contacted. He explained that the strange phenomena was due to the fact that the water content in the maize was not even distributed after the one hour in the dryer – i.e. the water content in the outer layer of the maize was lower than in the middle. In order to obtain a correct reading it is necessary to take a sample and store it for at least 2 hour in an air tight plastic bag, before the reading is taken. The morning reading before the dryer starts is, however, correct as the water content due to the rest over night is identical all through the maize. Please also se Appendix B which contain a letter to the farmer explaining several maters on the simple test method.

Figure 2.8. The instrument for measuring of the water content present at the farm.

Figure 2.9 shows the Kreiberg psycrometer located at the north side of the building containing the drying units. The psycrometer contains a thermometer for measuring dry and wet ambient temperature. When using an accompanying table it is possible to determine the ambient relative humidity.

Figure 2.9. The location of the Kreiberg psycrometer for measuring of ambient temperature and relative humidity at the north wall of the building.

During the visits of the co-ordinator the first test was carried out – however, including the above problems with the determination of the water content of the maize. 14.5 kg of maize was put in the drying trays of dryer A in the afternoon January 22. The below table shows the water content of the maize in the morning.

Date	Time	Water content %
23/1-2001	8:35	15.7
24/1-2001	7:40	11.5
25/1-2001	8:05	11.3
26/1-2001	8:20	10.1
27/1-2001	8:30	10.7

Table 2.1. The results from the first test using the simple test method.

The table shows that the maize is dryer than expected – 16% and not the expected 20%. This is because the maize is partly dried before being threshed.

A water content of 10% was the original goals as when stored properly the maize may last for one year. However, the farm would like to dry the maize down to 8% as the maize then may last for three years when stored correctly. Further tests will show if this is possible. The temperature and humidity of the air to the drying bed – 45°C and 25% rh during daytime (see next section) makes this possible as seen in figure 2.10. However, in order to obtain such a low water content the maize may have to be taken out of the dryer during the night and stored in airtight plastic bags and put it into the dryer again in the morning after the dryer has started to blow warm dry air to the drying bed. This method is man power demanding and it will take long time to dry the maize down to 8%, as it is only few hours during the day the high temperatures and low humidities are reached. When the temperature and humidity of the drying air is 45°C and 25% rh respectively, the extra time for the drying from 10% down to 8% at a flow rate of 300 m³/h will be 24 hour according to the theoretical equations for drying of maize.

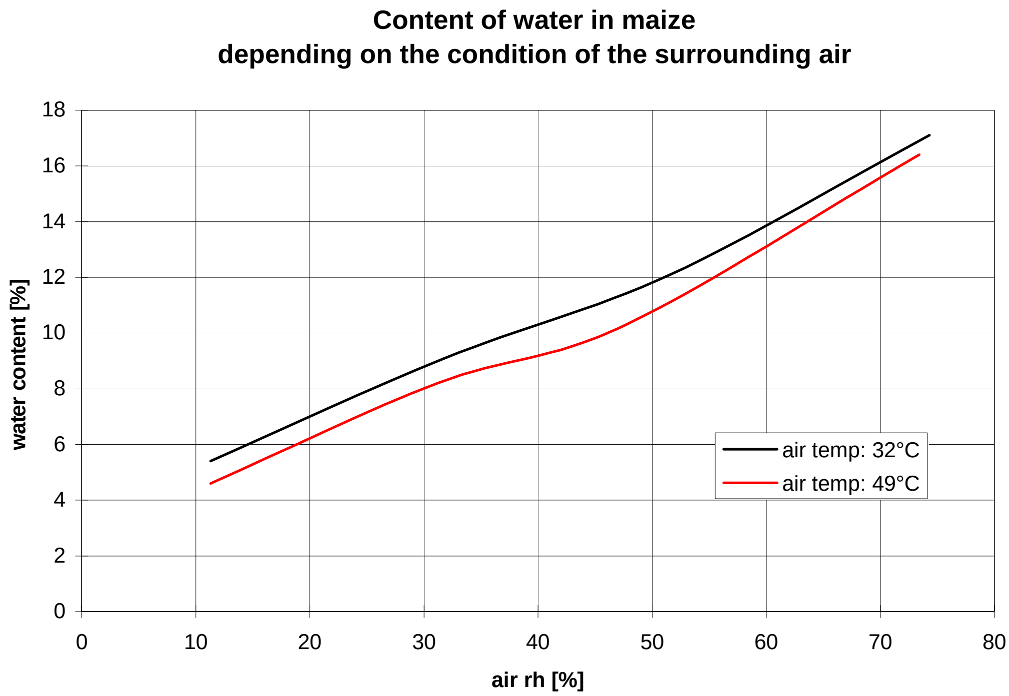

Figure 2.10. The equilibrium water content in maize dependent on the temperature and relative humidity of the surrounding air (ASAE, 1998).

2.3. Detailed measurements

The aim of the detailed measurements on one unit of the solar crop dryer was twofold:

- to test if the dryer was operating properly,
- to support the evaluation of the results from the simple test method.

During the test of the system performed while the co-ordinator visited Ghana the sensors of the measuring system was scanned each minute. After that the measuring system was changed so that sensors were scanned each 5 minutes. These latter readings will support the simple test method as it will be possible to compare the drying of the crops from the filled in tables with the actual weather conditions and the temperatures and relative humidities in the dryer.

2.3.1. The measuring system

There is no electrical power at Silwood farms. It was, therefore, necessary to apply a measuring system based on batteries and the system should further be so easy to operate and maintain so that a person from DENG within few hours could learn to operate the system. Many PC based datalogger systems are further very difficult to learn to use. It was decided to build the measuring system up using small Tinytag data loggers. A Tinytag logger is as the name indicates very small – see figure 2.11. The data loggers contain either one or two input channels and have either internal of external sensor(s).

Figure 2.11. Picture of a Tinytag for combined measuring of the air temperature and the air relative humidity together with a Danish matchbox.

Four different kinds of Tinytag data loggers where applied. These where:

- 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 2.12. The data loggers are shown in figures 2.13-15.

- 2 Tinytag Ultra – TGU-0020 for measurement of temperature with an external temperature probe (measuring range –40-125°C) – numbered 4-5 on figure 2.12. The data loggers are shown in figures 2.16-17.

- 1 Tinytag Plus – TGPR-1001 for measurement of mV (measuring range 0-200 mV). The logger is via a cable connected to the pyranometer – se later. The logger is labelled 6 on figure 2.12 and is situated below the bottom PV-panel to the left as seen in figure 2.18.

- 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 2.12 – the logger is shown in figure 2.17.

Pyranometer

One more sensor was included in the measuring system: a PV-pyranometer from Soldata type 80SP connected to Tinytag 6 for measurements of the global radiation on the collectors. The pyranometer is situated at the side of the bottom PV-panel to the left as seen in figure 2.19.

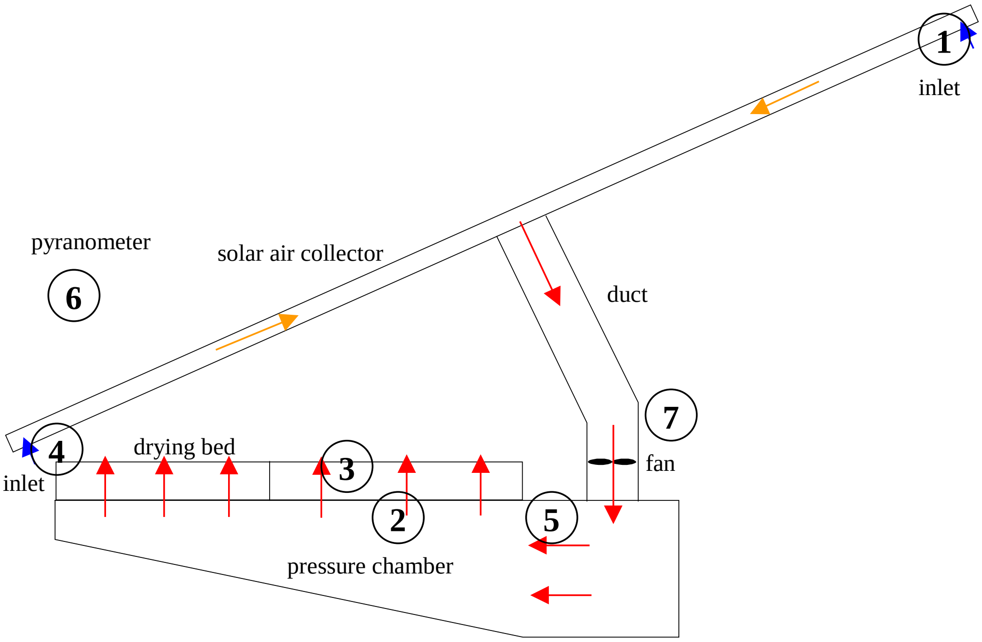

Figure 2.12. The location of the sensors of the measuring system in the solar crop dryer at Silwood Farms.

The reason for having two temperature measurements in the pressure chamber was that there was a risk that this temperature may go above 50° C, which is the limit of the combined temperature/humidity sensor. The single temperature sensor has an external probe able to measure up to 125°C.

Figure 2.13. The combined temperature/humidity sensor at the top inlet to the solar air collector.

Figure 2.14. The combined temperature/humidity sensor in the pressure chamber.

Figure 2.15. The combined temperature/humidity sensor located on top of the maize in one of the trays for measuring the condition of the air leaving the drying bed.

Figure 2.16. The temperature sensor at the bottom inlet to the solar air collector.

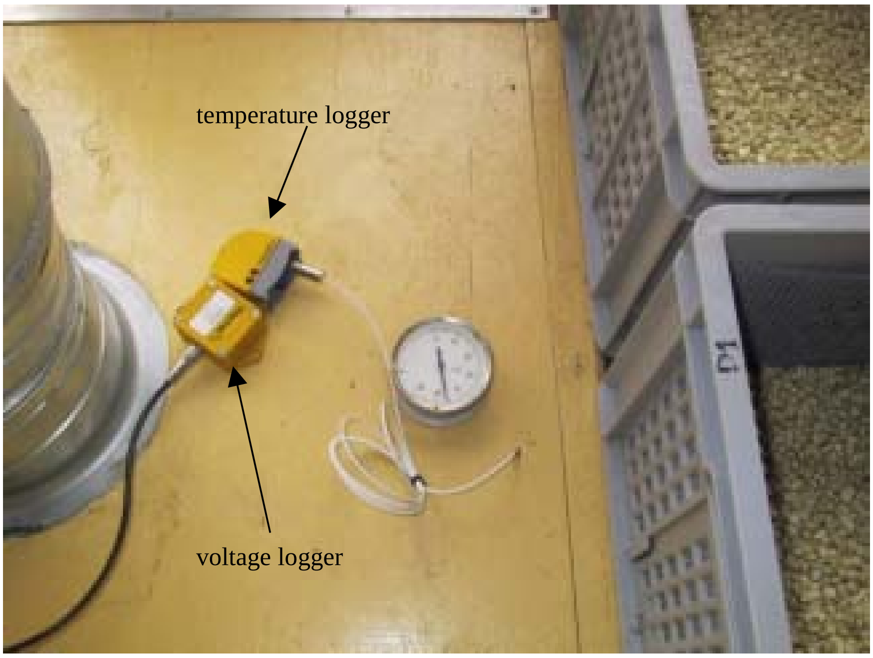

Figure 2.17. The temperature sensor measuring the temperature of the air to the pressure chamber and the sensor for measuring the voltage to the fan. The picture further shows a thermometer belonging to the dryer for showing the temperature of the air to the drying bed.

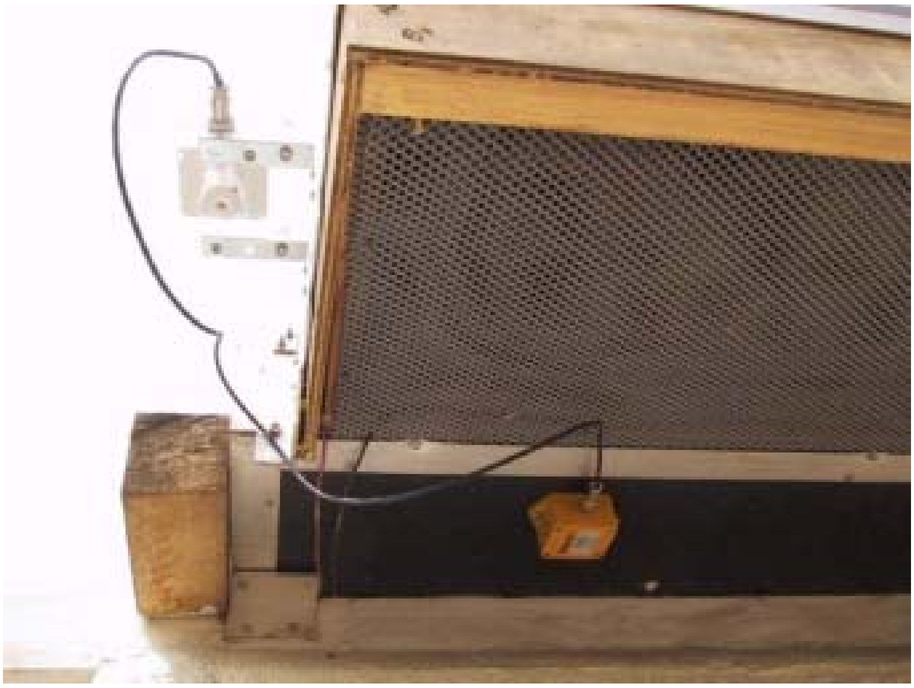

Figure 2.18. The Tinytac connected to the pyranometer.

Figure 2.19. The PV-pyranometer of the measuring system.

The data loggers are started by connecting them to at PC via the serial port of the PC. After arming the Tinytags are disconnected from the computer. The data loggers may now take up to about 8000 readings before the data are offloaded to a PC. Using a scan interval of 5 minutes the data logger take measurements for almost a month. The battery of the Tinytags is said to last for two years of measurements.

2.3.2. Results from the measurements

During the visits of the co-ordinator two series of measurements were conducted. They will in the following be described together with the measurements obtains using a handheld voltage meter and a air speed sensor. As seen from the above description of the measuring system, no air speed sensor was applied, as was the case during the tests carried out in Denmark. This is because an air speed sensor needs power supply, which is not available at Silwood Farms. It was instead decided to measure the voltage to the fan. Using the handheld voltage meter and the air speed sensor a correlation between the voltage to the fan and the air flow rate was obtained. From the test in Denmark it was shown that the fans are voltage controlled meaning that a correlation between the voltage to the fan and the air flow rate is if not ideal so at least acceptable.

The two test series was almost identical. However, in the last series the sensor 5 was moved to measure the air temperature of the air leaving the solar collector in order to make it possible to determine the efficiency of the collector. Further the location of sensor 2 was changed from at the side of the pressure chamber as shown in figure 2.14 to below the lath in the middle of the drying chamber supporting the drying trays as indicated in figure 2.20. The location of the latter sensor was changed in order to make sure, that the sensor really measured the conditions of the air to the drying bed.

Figure 2.20. The new location of the combined temperature/humidity sensor in the pressure chamber.

2.3.2.1. Correlation between voltage to the fan and the air flow rate

Figure 2.21 shows the dependency of the air flow rate on the voltage to the fan. The voltage was obtained by a multimeter E2377A from Hewlett Parkard while the air speed was obtained by a VelociGheck 8330-M-GB air speed sensor from TSI – both calibrated instruments. The values measured by the air speed sensor were transformed to air flow rates using the diameter of the duct – 200 mm and a correction factor for the non uniform air speed over the cross section of the duct. This factor is 0.96.

From the tests in Denmark it was shown that the fan do not run at a voltage below 4 V. The power to the fan is further proportional to the voltage.

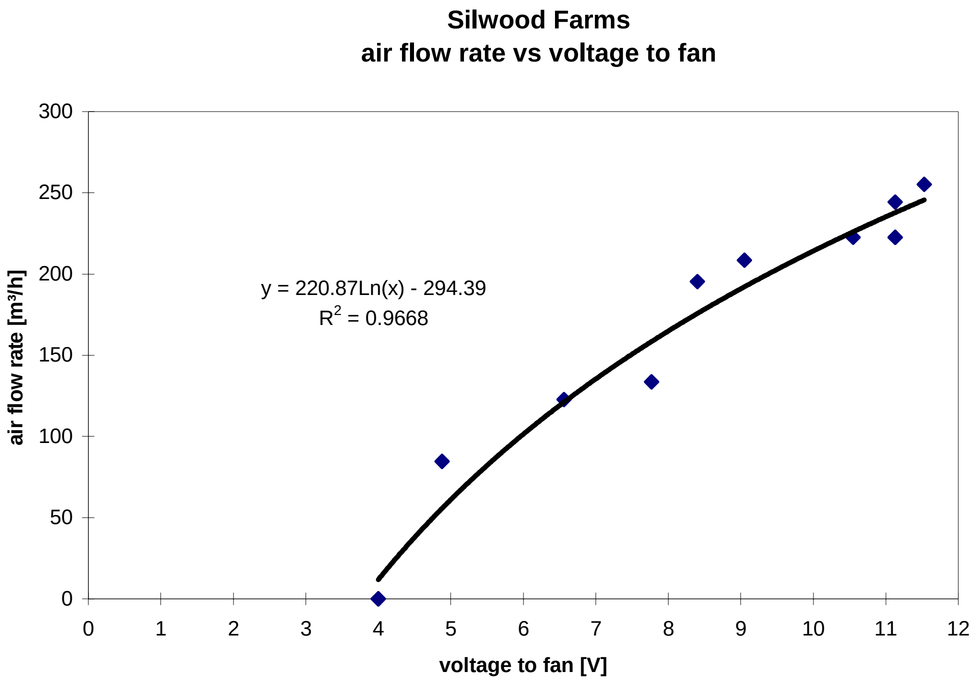

Figure 2.21. The dependency of the air flow rate on the voltage to the fan incl. the found regression equation.

The shape of the curve in figure 2.21 is as could be expected because an increase in power (here voltage) to the fan will result in reduced increases in air flow rate when going towards higher air flow rates.

The shown equation found using regression has been used in the following graphs showing the measured and calculated values from the two series of measurements. The use of a correlation equation increases of course the uncertainty of the value beyond the uncertainty of a directly measured value, however, the trend and magnitude of the values are within an acceptable range. The correlation equation is found for a situation with 14.5 kg maize in the drying trays. More or less maize in the drying trays will of course affect the air flow rate, but the pressure drop over the maize is so small compared to the overall pressure drop of the system (less than 5% (Jensen, Kristensen and Forman, 2001)) that a change to 10 or 20 kg maize in the drying trays hardly will be noticed on the air flow rate.

2.3.2.2. Results from the two series of measurements.

Figures 2.22-29 show the measured values from the two series of measurements. For the second series the reading of the pyranometer was unfortunately not recorded possible due to a wrong connection between the pyranometer and the Tinytag. This is what may happen when using Tinytags, as one never know if everything works alright until the data is offloaded even if several security checks are applied – the connection to an external probe can, however, unfortunately not be tested. Based on the first series of measurements a correlation has instead been obtained between the voltage to the fan and the solar radiation as these two values are directly coupled. The correlation is shown in figure 2.30. Again - the use of a correlation equation increases of course the uncertainty of this value beyond the uncertainty of a directly measured value, however, the trend and magnitude of the values will be within an acceptable range and it further facilitate that the other measurements of this series don't lose their relevance.

The maximum of the total radiation on the solar air collectors/PV-panels is in the order of 700 W/m² (see only the first series of measurements) and rather scattered. The radiation is rather low due to the very fine dust brought to Ghana by the Hamatan. The ambient temperature is in the range of 21-37°C (night-day). A strange phoneme is seen regarding the two ambient temperatures – the temperature at the north side is higher than on the south side of the building. It is not known why, but it may be due to the wind blowing warm air from the fields laying to the north of the solar crop dryer.

Figure 2.24 shows a rather large difference between the two temperature sensors mounted in the pressure chamber. The reason for this may be that the temperature called “pressure chamber 2” is closer to the incoming hot air, while the temperature called “pressure chamber 1” was measured at one of the sides of the pressure chamber. For this reason the location of “pressure chamber 1” was changed as already explained in order to be sure, that the sensor measures the real temperature to the drying trays. Measurements with “pressure chamber 1” in its new location is shown in figure 2.25 (here called “pressure chamber”).

Figure 2.24 shows, that the temperature of the incoming air to the drying bed may get beyond 45°C for several hours. This is more clearly seen in figure 2.31, where there is one hour between the vertical lines. “pressure chamber 2” is above 45°C for about 4 hours around noon. This is a problem as the maize in order to maintain the germination ability shouldn't be heated to above 45°C for such long periods. On the other hand – “pressure chamber 1” gets only above 45°C for about 2 hours – this is seen both in figure 2.24 and in figure 2.25 where the sensor is right below the first row of drying trays. This indicates that the air to the drying trays is cooled by the heat loss of the pressure chamber before it reaches the drying trays. This is good for the germination ability but is bad for the drying process when the temperature to the pressure chamber is below 45°C. The present design of the dryer is a compromise. A higher performance may be reached by insulating the ductworks and the pressure chamber, however, this demands for a damper in the duct between the solar air collector and the drying bed which is able to let in false air when the temperature gets too high. This is, however, for further development of the dryer.

Figure 2.25 shows the temperature of the air from the solar air collector. When comparing the curve for “pressure chamber 2” in 2.24 with the curve “out of collector” in 2.25 it may be seen that the heat loss of the ductworks only reduces the temperature to the pressure chamber with 2-4 K, which is acceptable.

Figures 2.26 and 2.27 show the measured relative humidities. The ambient relative humidity is in the range of 35-90% (day-night). The relative humidity in the pressure chamber gets as low as 21% and does not get higher than 65% during the night which indicate that no air circulation occurs during the night – which is good as the ambient air during night-time is high. The relative humidity of the air above/leaving the drying tray (night/day) lays between the two above-mentioned values.

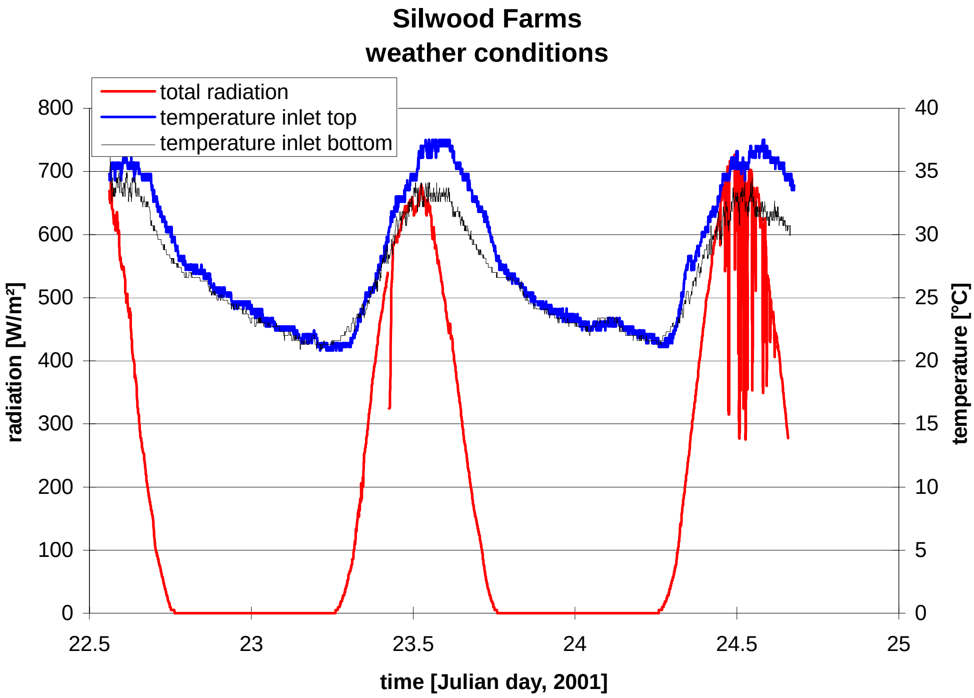

Figure 2.22. Weather data from the first series – total radiation on the solar air collectors/PV-panels and the air temperature at the inlet at both ends of the solar air collector.

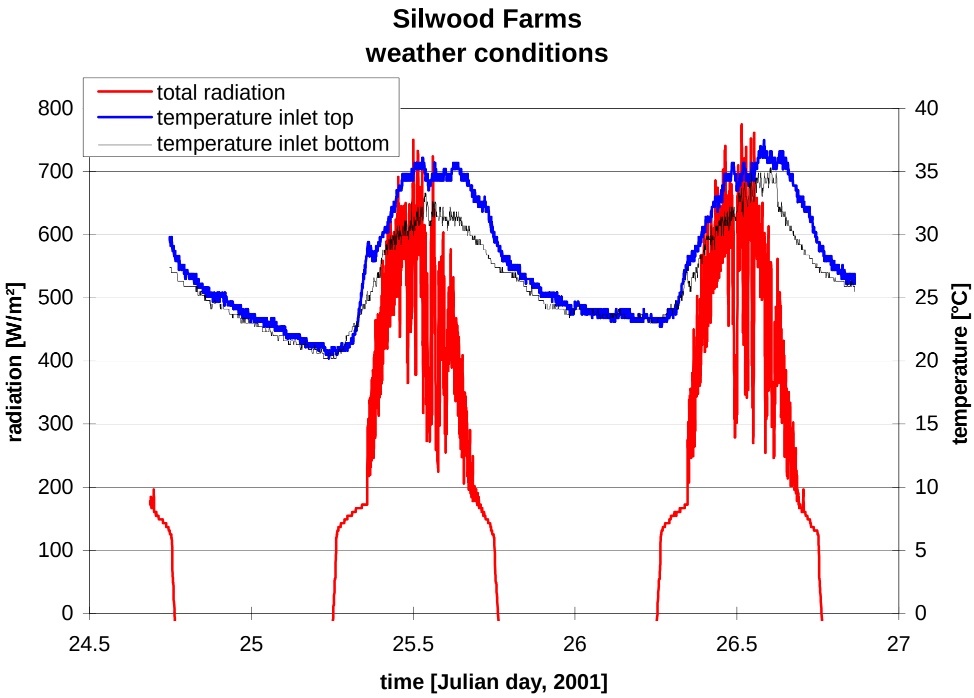

Figure 2.23. Weather data from the second series – total radiation (calculated) on the solar air collectors/PV-panels and the air temperature at the inlet at both ends of the solar air collector. The solar radiation is based on a correlation on the voltage to the fan (figure 2.30) – this correlation is not valid at voltage levels below 4.5 V, so please don't consider the "shoulders" of the curves for the solar radiation in the morning and afternoon.

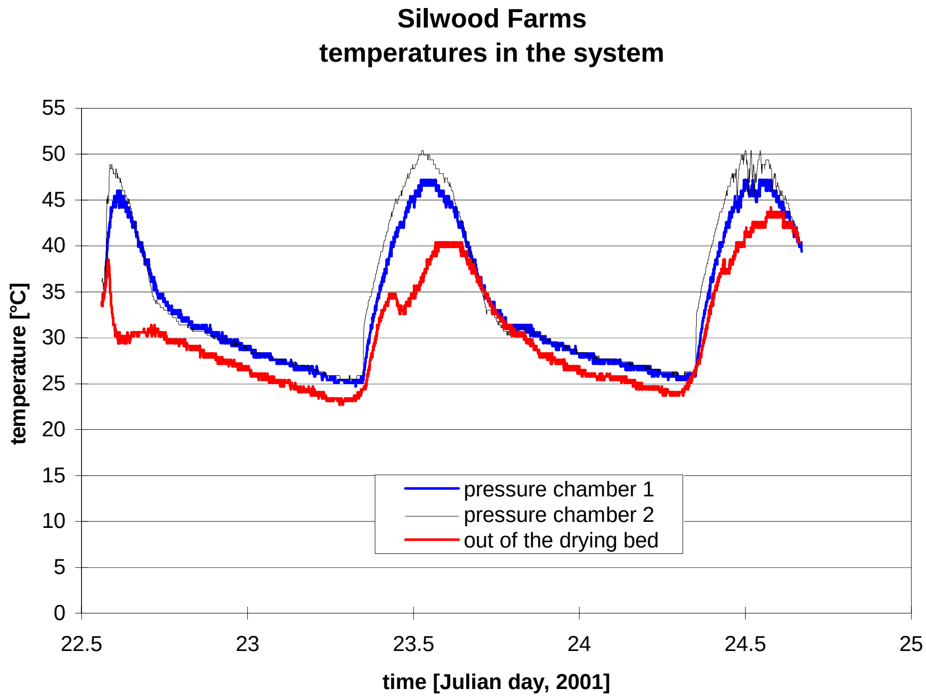

Figure 2.24. The two air temperature in the pressure chamber and the temperature of the air leaving the maize being dried during the first series.

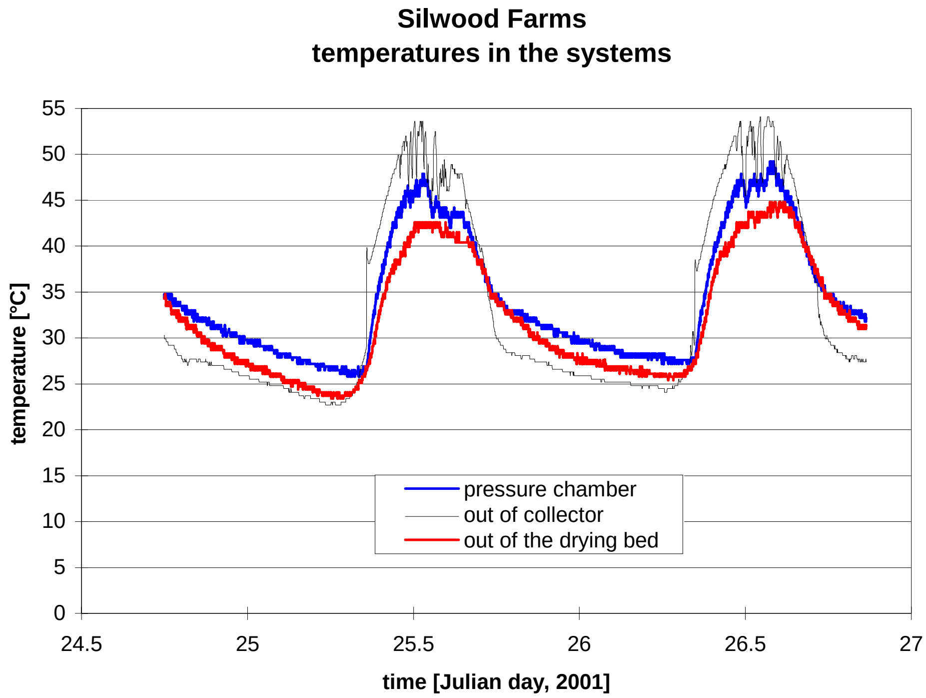

Figure 2.25. The temperature of the air leaving the solar air collector, the air temperature in the pressure chamber and the temperature of the air leaving the maize being dried during the second series.

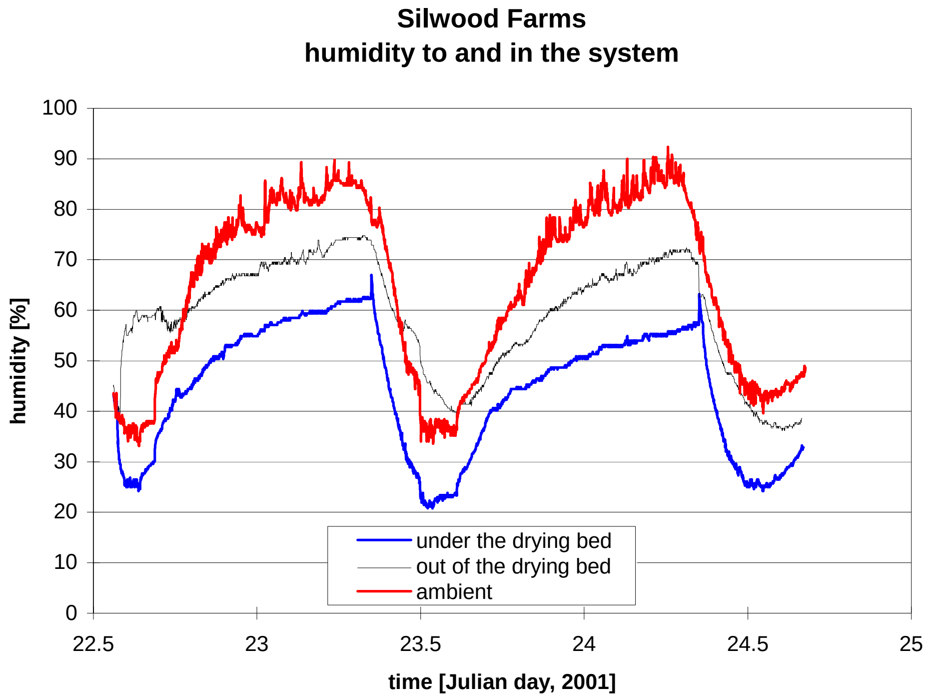

Figure 2.26. The relative humidity of the ambient air at the top inlet to the solar air collector, of the air in the pressure chamber and of the air leaving the maize being dried during the first series.

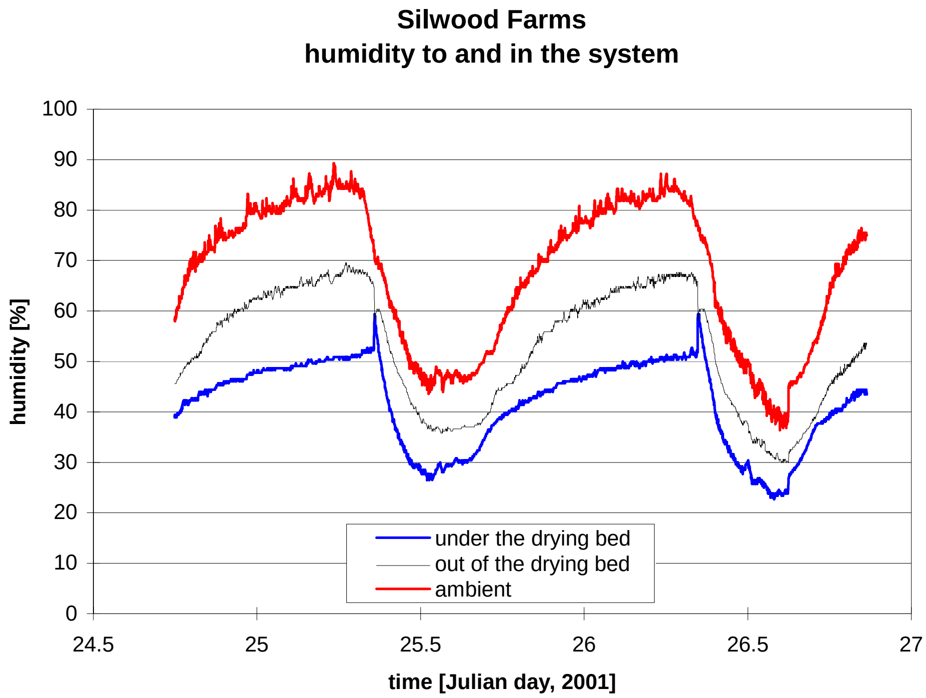

Figure 2.27. The relative humidity of the ambient air at the top inlet to the solar air collector, of the air in the pressure chamber and of the air leaving the maize being dried during the second series.

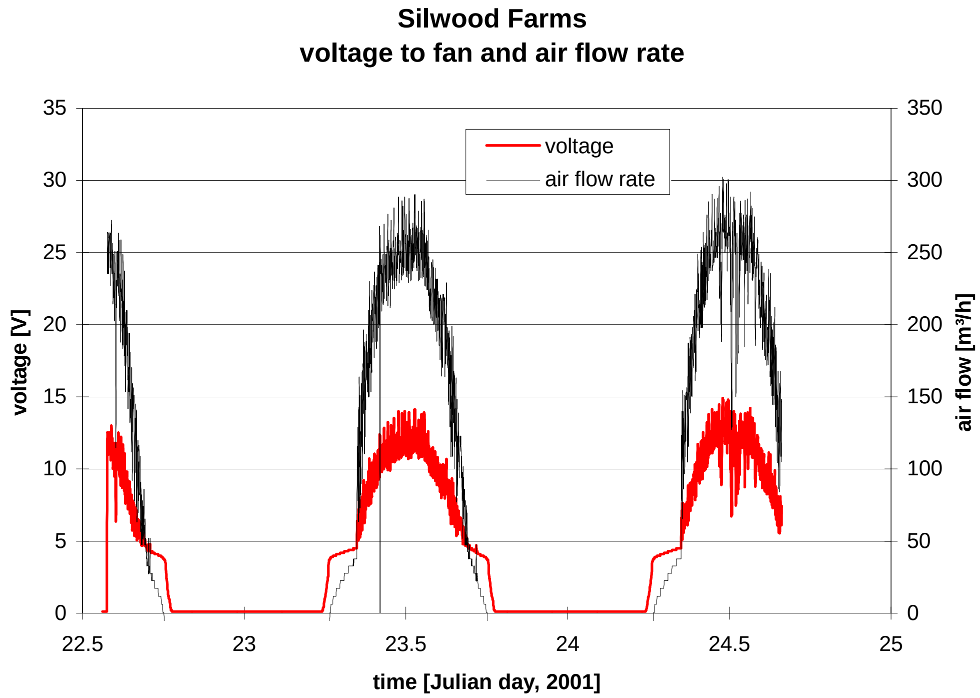

Figure 2.28. The voltage to the fan and the calculated air flow rate through the system during the first series. The correlation for the air flow (figure 2.21) is not valid for voltage to the fan below 4.5 V, so please don't consider the "shoulders" of the curves for the air flow rate in the morning and afternoon.

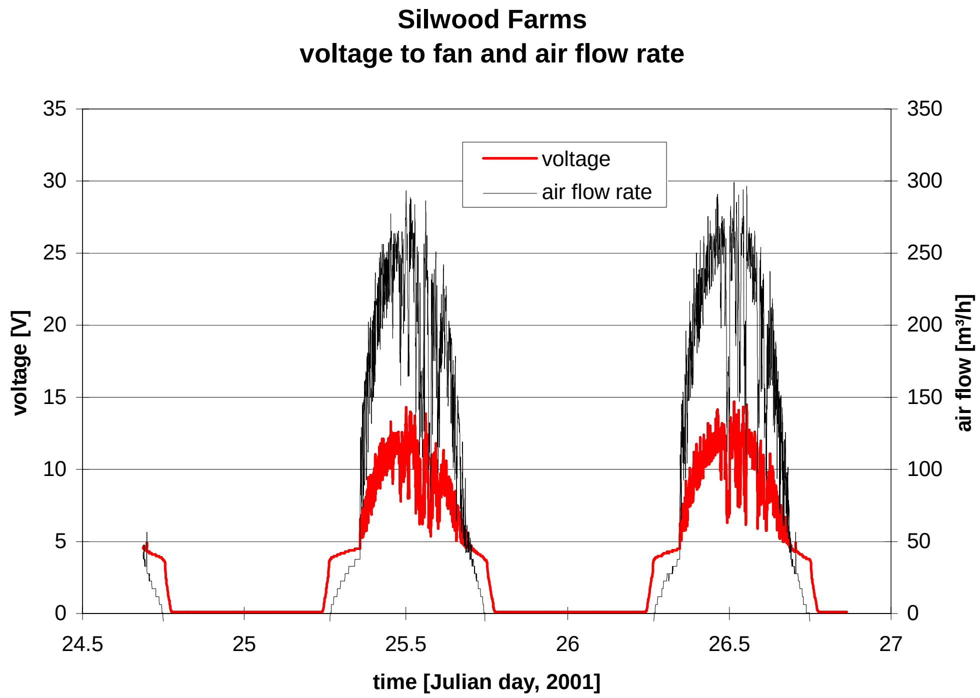

Figure 2.29. The voltage to the fan and the calculated air flow rate through the system during the second series. The correlation for the air flow (figure 2.21) is not valid for voltage to the fan below 4.5 V, so please don't consider the "shoulders" of the curves for the air flow rate in the morning and afternoon.

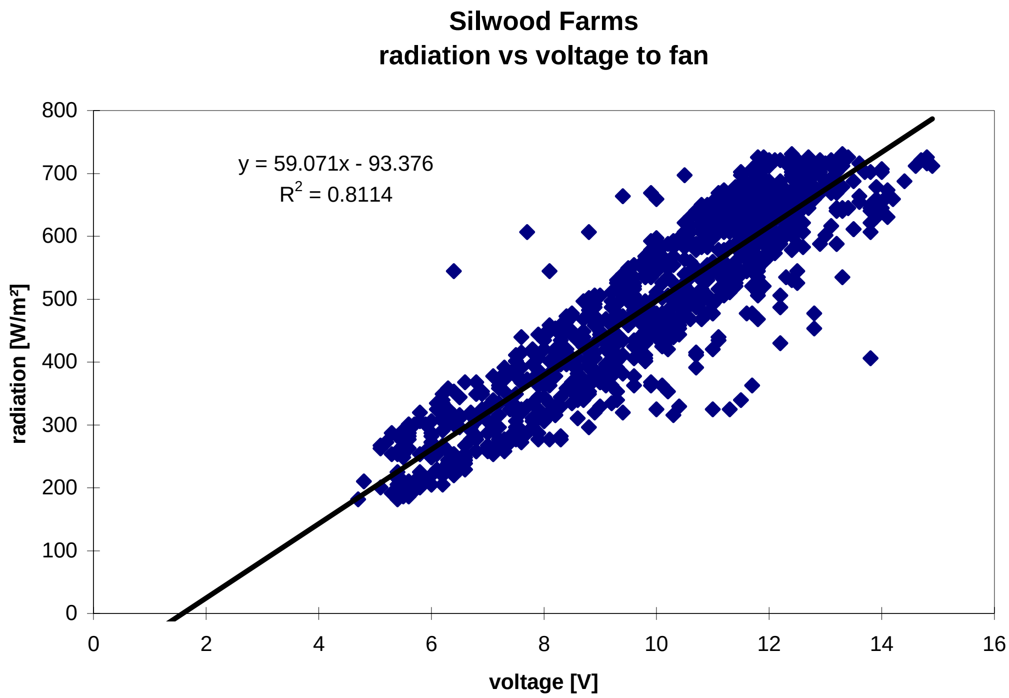

Figure 2.30. The correlation between solar radiation and fan voltage obtained from the first series of measurements.

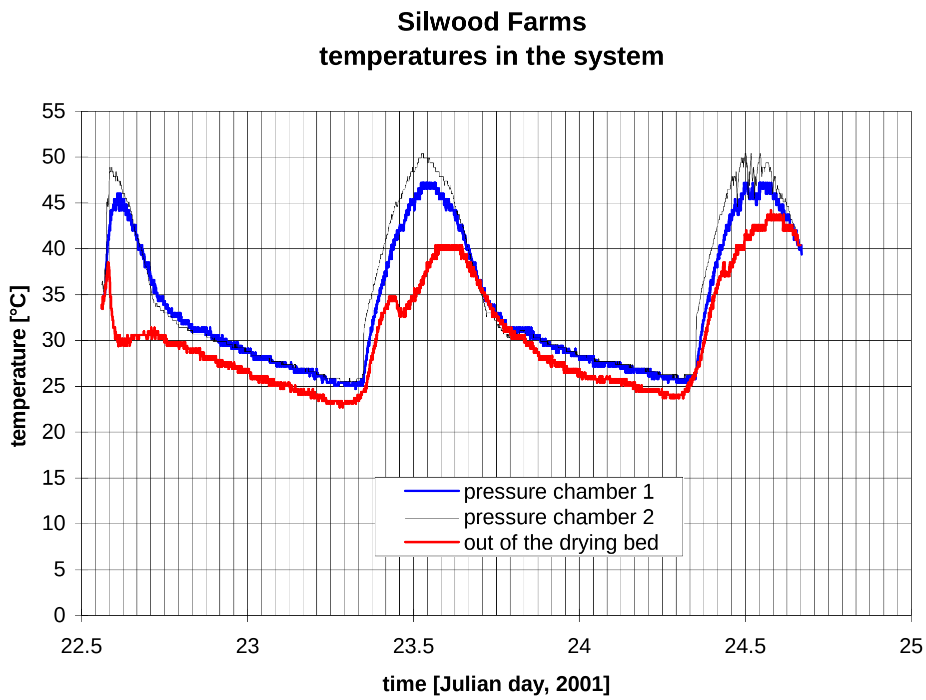

Figure 2.31. Identical to figure 2.24 but now with a vertical line for each hour of the day.

Air flow rate

Figures 2.28 and 2.29 show the voltage to the fan and the calculated air flow rate. The curves for the fan voltage shows a plateau in the morning and evening at 4.5 V. The plateau is created by the control of the fans which try to adjust the voltage and current to the fan in order to get the fan started – for the fans in Ghana obviously at a voltage about 4.5 V. The air flow rate is calculated using the correlation shown in figure 2.21. The aim is to feed the fan with a voltage of 15 V (during as long time as possible) where its performance is optimal. This value is only reached occasionally on a one minutely basis but always followed by a much lower voltage due to the scattered solar radiation. Because of the inertia of the fan the fan will, therefore, never be able to reach max rotation and thereby deliver the max air flow rate. The max mean fan voltage is as seen in figures 2.28-29 about 12 V. This means that the air flow rate of the system is lower than when tested in Denmark. The dryer is designed to reach an air flow rate of above 400 m³/h at max radiation. This was reached in Denmark but is as seen in figures 2.28-29 not reached during the two series of measurements. The max air flow rate reached is 300 m³/h.

The reason for the lower air flow rate has been investigated as it could be due to a malfunction of the drying unit. The main reason for the lower air flow rates is, however, as shown below the lower solar radiation level and higher ambient temperature level compared to the Danish conditions under which the dryer was tested in Denmark. The weather conditions during the tests performed in Denmark was: solar radiation to above 1000 W/m² and ambient temperature <27°C. In the following the test results under Danish conditions will be transferred to the Ghanaian conditions.

Figure 2.32 shows the air flow rate in the system as a function of the total solar radiation on the solar air collectors/PV-panels for the first series of measurements in Ghana (not for the second series as the solar radiation was not recorded here). Figure 2.33 shows a similar figure with data from a Danish test, where the design of the dryer was identical to the design used in Ghana.

From figures 2.32 and 2.33 it is seen that when the max radiation level during the Danish test went above 1000 W/m² it only went above 700 W/m² during the test in Ghana. For that reason the air flow rate at a total radiation of 700 W/m² is evaluated in the following. Table 2.2 shows the range of air flow for the two tests at 700 W/m².

at 700 W/m²	Ghana first series m³/h	Denmark July18-28 2000 m³/h	Ratio Ghana/Denmark %
minimum	250	290	86
maximum	300	370	81

Table 2.2. Difference in air flow rate through the system at an radiation level of 700 W/m².

The values in table 2.2 needs, however, also to corrected for a different temperature level of the PV-panels as the voltage from the PV-panels decreases with increasing cell temperature. Figure 2.34 shows the dependency of the air flow rate as function of the ambient temperature (as the cell temperature was not measured). The thick line shows the dependency of the air flow rate on the ambient temperature without the filters in the system, while the red squares are with filters. The two squares to the left were measured in Denmark while the square to the right is the expected air flow rate at an ambient temperatures of 35°C (Ghana) reached by trying to obtain a curve with the same shape as the curve for the situation without filters.

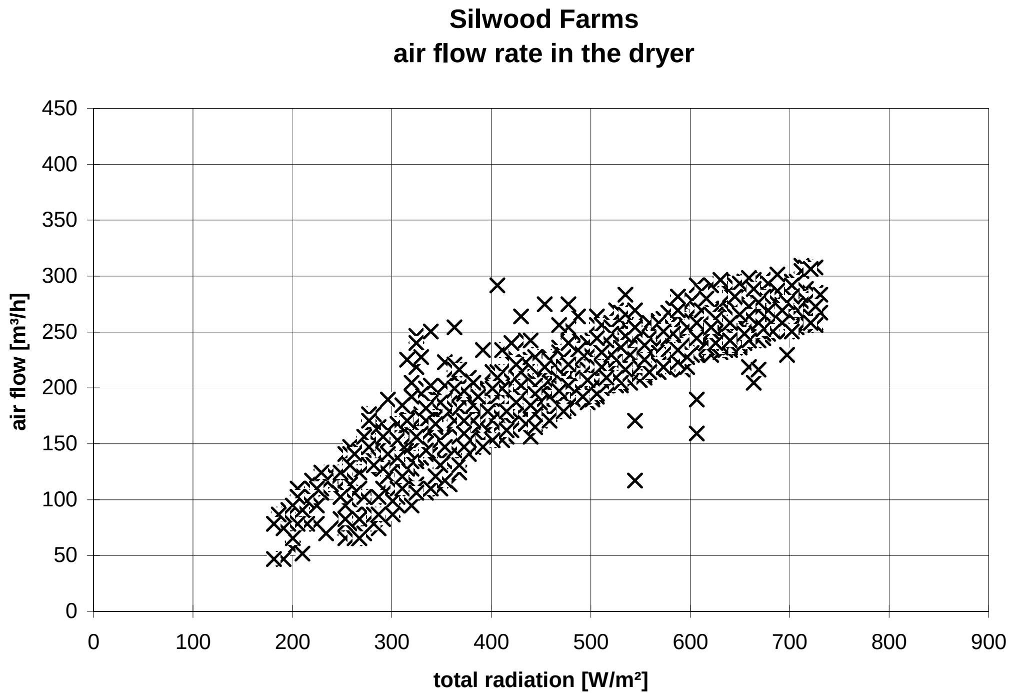

Figure 2.32. The dependency of the air flow rate through the system on the total radiation on the solar air collectors/PV-panels for the first measuring series in Ghana.

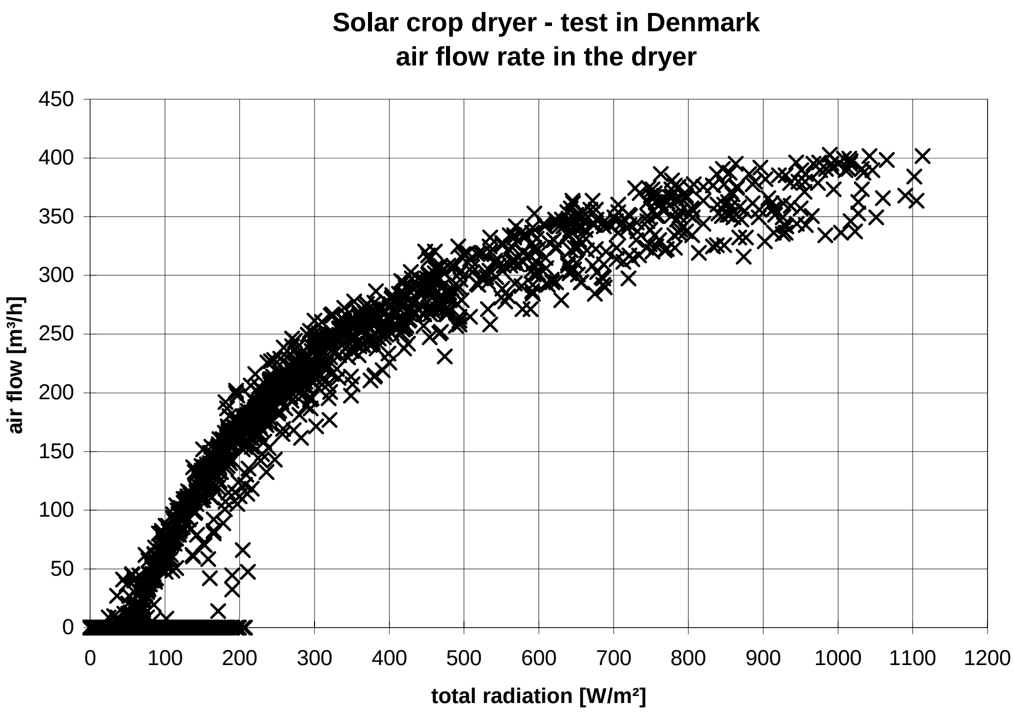

Figure 2.33. The dependency of the air flow rate through the system on the total radiation on the solar air collectors/PV-panels for a test carried out July 18-28, 2000 in Denmark – based on (Jensen, Kristensen and Forman, 2001).

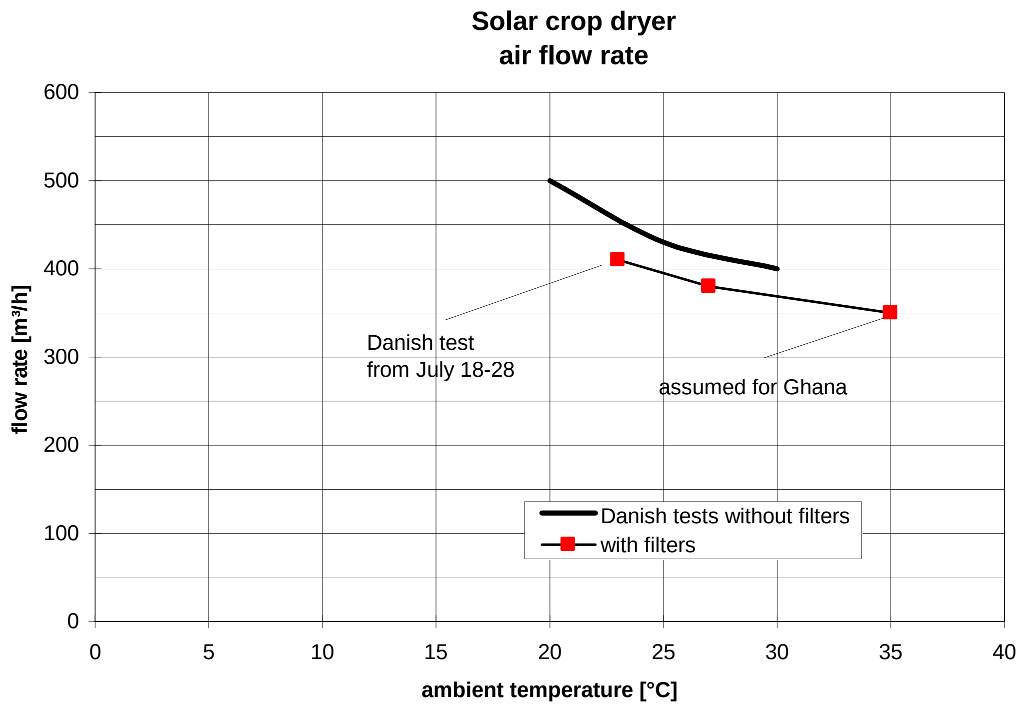

Figure 2.34. The dependency of the air flow rate through the system tested in Denmark with and with out filters (Jensen, Kristensen og Forman, 2000). In the graph is further included the expected dependency at an ambient temperature equal to the Ghanaian test situation – 35°C.

During the Danish test on July 18-28 a max air flow rate of 410 m^3/h was obtained at an ambient temperature of 23°C. If the ambient temperature had been 35°C (as in Ghana) it is as seen in the graph expected, that the air flow rate would have decreased to 350 m^3/h. So in order to correct the Danish flow rate in table 2.2, the values should be multiplied with 350/410 = 0.85. This is done in table 2.3.

at 700 W/m^2	Ghana first series m^3/h	Denmark July18-28 2000 – temperature corrected m^3/h	Ratio Ghana/Denmark %
minimum	250	250	100
maximum	300	315	95

Table 2.3. Difference in air flow rate through the system at an radiation level of 700 W/m^2 and compensated for a different temperature level.

Although the uncertainty of figure 2.32 and 2.34 is rather high – the first because the air flow rate is calculated based on the voltage to the fan, and the latter due to at very few values – table 2.3 indicates that the air flow rate through the system in Ghana is as could be expected based on the findings from measurements on a similar system in Denmark.

The solar radiation during the main maize season in August-September is in the same order of magnitude for August as in January, while it is about 10% higher in September than in January (Akufo, 1991) – weather data for Accra is located in Appendix C. The ambient temperature is 3-4 K lower in August-September than in January – Appendix C. It is thus likely that higher air flow rates through the dryer will be reached during the main maize season than the above-measured air flow rates. Actually, the measured radiation is 20% lower than the mean radiation for January stated in (Akufo, 1991) and the ambient temperature was 3 K higher than given in (Akufo, 1991).

Efficiency of the solar air collector

However, the "correct" air flow rate may be achieved because false air is drawn into the system before the fan. But if the efficiency of the collector in Ghana is as found in the Danish tests - the system in Ghana functions correctly.

The efficiency of the collector was found using the values from the second series, where the temperature of the air coming out of the collector was measured. The efficiency was found in the following way:

$$\eta = \rho \cdot c_p \cdot V \cdot (t_{out} - t_{in}) / (q_{sun} \cdot A_c)$$

where: η is the efficiency of the collector,
ρ is the density of the air [kg/m³],
c_p is the heat capacity of the air [J/kgK],
V is the air flow rate [m³/s],
t_{out} is the temperature of the air leaving the solar air collector [°C],
t_{in} is the inlet temperature to the solar air collector – here the mean value of the inlet temperatures measured at both ends of the collector [°C],
q_{sun} is the power of the total solar radiation [W/m²],
A_c is the transparent area of one solar air collector [m²].

The above equation is of course a bit uncertain as the air flow rate and the solar radiation were calculated based on the voltage to the fan. The correlation for the solar radiation seems to give a bit too high max value as seen when comparing figures 2.22 and 2.23. This will lead to a bit too low efficiencies. On the other hand the correlation for the air flow rate may give a bit too high max air flow rate leading to a bit to high efficiencies. However, together it is judge that the uncertainty of the calculated efficiencies is within an acceptable range.

Figure 2.35 shows the calculated efficiencies dependent on the air flow rate through the system. Figure 2.36 shows the same for the Danish test carried out during July 18-28, where as in figure 2.35 the total radiation has been used to calculate the efficiency.

Figure 2.35 shows less scattered and maybe slightly lower efficiencies, however, not lower than they are in the uncertainty range of the Danish efficiencies.

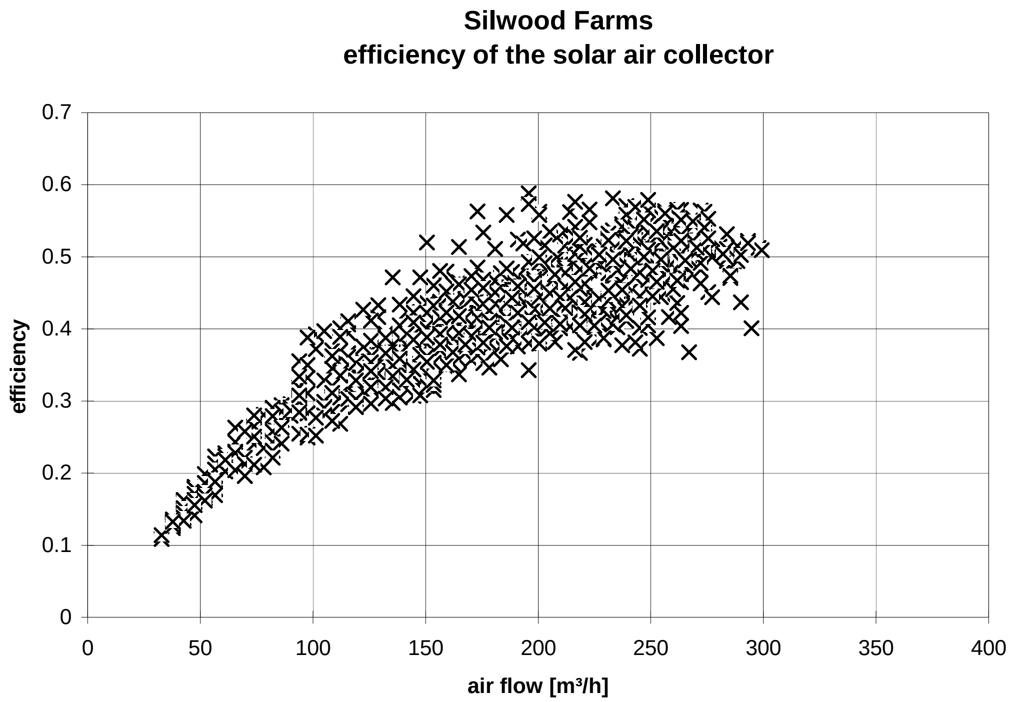

Figure 2.35. The efficiency of the collector at Silwood Farms as a function of the air flow rate through the system (based on total radiation on the collector).

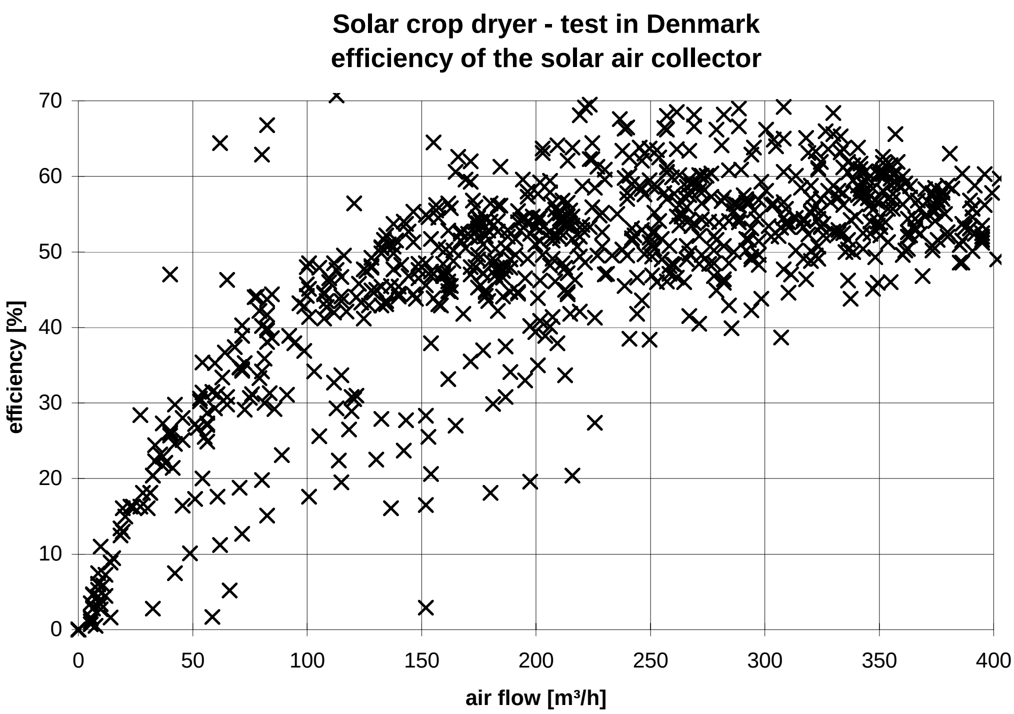

Figure 2.36. The efficiency of the test unit in Denmark as a function of the air flow rate through the system based data from July 18-28 and total radiation on the collector.

Based on the above tests it may be concluded that the system function as could be expected based on the tests performed in Denmark. However, the air flow rate is on the low side of what is wished. The max air flow rate should preferably – also under Ghanaian conditions be above 400 m^3/h, but is not possible with the lower solar radiation and higher ambient temperature. The problem is the voltage control of the fans. The max fan power is 12 W while the peak power for two PV-panels is 28 W_p. The power from the PV-panels decreases with about 0.5 % per 1 K increase in cell temperature above 25°C. It should, therefore, be possible to deliver 15 V during a large part of the day, if the voltage could be kept up. It should be investigated if it is possible by an electronic devise to boost the voltage level if excess power is available. The electronic devise may, however, not steel power at lower radiation level where too little power is available to run the fan at max speed.

2.4. Plan for tests and reporting

The tests of the solar crop dryer will as already explained consists of two levels:

1. detailed measurements of the thermal performance of the solar crop dryer and
2. tests with drying of different crops.

The reporting will consists of four levels:

a. report on the results from the detailed measurements
b. report on the findings using the simple test method
c. interview of the farmer in order to record his opinion on the solar crop dryer
d. the consultants from Econkoad (Jensen, Frank and Kristensen, 1999) should prepare an impartial report stating how well the goals of this part of the project has been reached.

1 and a: Has already been carried out and is reported in the present report

2 and b: The simple tests with maize have begun and the measuring equipment is recording:

- the farmer fills in the tables of the simple test method for different crops and amount of crops
- DENG collects the filled in tables and the data from the measuring system and send them to the co-ordinator
- the co-ordinator send the tables and the data as curves to the Department of Agricultural Engineering, Danish Institute of Agricultural Science (the data curves also to DENG)
- The Department of Agricultural Engineering, Danish Institute of Agricultural Science evaluates and reports on the results from the simple tests with different crops

c: DENG interviews the farmer and reports his view on the solar crop dryer

d: Econkoad reads the three above reports, talks with the farmer and write an impartial report stating how well the goals of this part of the project has been reached

The tests and reporting should be finilazed by the end of October 2001.

2.5. Conclusion on the solar crop dryer

The impression from the inspection of the solar crop dryer is that it is good craftsmanship and that the dryer incl. building containing it look very nice. It is clearly seen that quite a big deal of work and enthusiasm has been put into the facility.

The detailed measurements and investigations carried out on the dryer so far shows that the dryer is functioning correctly. It would, however, be preferable if a higher air flow rate could be obtained in order to decrease the max temperature to the drying bed and in order to increase the efficiency of the collector. However, at the given weather conditions (low radiation and high ambient temperature) this cannot be achieved with the present control of the fans and the present coupling of the fans to the PV-panels. If possible a cheap electronic devise which could boost the voltage level at potentially high power from the PV-panels while otherwise leave the system unchanged should be installed.

The farmer appears to be content with the dryer. The simple tests to be carried out in the coming months will further show how beneficial the dryer is for the farm and give important information on how to run the dryer for different crops.

3. Visits to the solar fish dryer

The solar fish dryer is erected at Elite Enterprise Ltd at Tema about 35 km east-north-east of Accra. Elite Enterprise Ltd buys and smokes fish.

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 2.1. 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 3.1-2 show the solar fish dryer from the south and the east respectively, while figure 3.3 shows the inside of the hut and the drying bed. Figure 3.4 shows the drying trays while figure 3.5 shows the extension box to be located on top of the drying trays – see also figure 3.3. 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 which else will rot if just being laid in the trays.

Figure 3.1. The solar fish dryer seen from the south.

Figure 3.2. 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 3.3. The interior of the hut containing the drying bed of the solar fish dryer.

Figure 3.4. The trays of the drying bed.

Figure 3.5. The extension box of the drying bed.

The chapter contains three sections:

- the findings from the inspection of the solar fish dryer,
- preliminary results from the very first simple test in the dryer and
- plan for the tests and reporting of the tests.

The solar fish dryer was visited two times: afternoon January 23 and afternoon January 26. The reason for the two visits was that the dryer was orientated wrongly at the first visit – facing east instead of south. Fish was further put in the dryer the day before the second test.

3.1. Inspection of the solar fish dryer

At the first visit of the solar fish dryer, the dryer was still standing where the truck driver had put it by the end of December 2000. No drying test had yet been carried out.

The solar fish dryer incl. hut is a bit more primitive than the solar crop dryer. 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. This may later come in handy.

As for the solar crop dryer no filters were installed in the inlets to the solar air collector. These were later put in. The cover of the solar air collector and the PV-panels were very dirty as seen in figure 3.6. More dirty than the solar crop dryer. It is believed that this is due to the salt from the sea, which make the dust stickier.

Figure 3.6. Dirt on the solar air collector – the PV-panels (not shown here) had been cleaned the day before, but already rather dirty.

3.2. Results from very simple tests

Only a few very simple tests were conducted during the stay of the co-ordinator.

Around 13:15 on January 23 the voltage to the fan was measured before and after the cleaning of the PV-panels (the PV-panels had not been cleaned since the arrival at the site). The results were: before cleaning: ≈ 10.75 V and after cleaning: ≈ 11.15 V ⇒ an increase of about 4%. This value may include fluctuation in the radiation level – i.e. in reality either be lower or higher. However, it seems to be worthwhile to clean the PV-panels and also the cover of the solar air collector at a regular basis. Elite Enterprise Ltd has been instructed on this and should also be instructed in washing the filters in the inlet to the solar air collectors at a regular basis.

Around 16:00 on January 26 with about 2 cm fish in the trays (see later) the following parameters was measured:

voltage to the fan	6.85 V
air speed in the duct	1.54 m^2 ⇒ 167 m^3/h
ambient temperature	33°C
temperature of air to fan	38°C
temperature of air living the drying bed	36°C

These values were compared to the measurements on the solar crop dryer. The above values was shown to be in the range of what could be expected which indicated that the solar fish dryer also is functioning properly.

Fish was put in the dryer on January 25 at 11:35. The dryer was inspected on January 26 around 16:00. Figure 3.7 shows the trays with fish, figure 3.8 shows a single tray with fish while figure 3.9 shows the two different types of fish put into the dryer. Two different types of fish was put in the dryer (weight and species unfortunately not recorded): small skinny fish of a length around 5 cm and larger more fat fish with a length between 8 and 12 cm. By the time of the visit (the day after the fish was put into the dryer) the small fish seemed nearly dried, while the larger fish seemed not even half-dried. Tests with the dryer have to show which species can be dried in the dryer, the amount of fish per drying and the necessary length of the drying.

Figure 3.7. The drying trays with fish.

Figure 3.8. One drying tray with fish.

Figure 3.9. The two different species of fish dried during the first test.

3.3. Plan for tests and reporting

The test on the solar fish dryer will be a lot more simple than on the solar crop dryer.

1. tests with drying of different species of fish and amount of fish.

The reporting will consist of three levels:

a. report on the findings from drying different species and amounts of fish
b. interview of Elite Enterprise Ltd in order to record their opinion on the solar fish dryer
c. the consultants from Econkoad (Jensen, Frank and Kristensen, 1999) should prepare an impartial report stating how well the goals of this part of the project has been reached.

1 and a report on drying time and especially quality. Will be carried out by DENG

b. determine how Elite Enterprise Ltd uses the dryer, does the dryer add value to the dried fish and if so will this be enough to pay for a dryer. Will be carried out by DENG.

c. Econkoad reads the above reports, talks with Elite Enterprise Ltd and write an impartial report stating how well the goals of this part of the project has been reached

The tests and reporting should be finilazed by the end of October 2001.

3.4. Conclusion on the solar fish dryer

The impression from the inspection of the solar crop dryer is that it is good craftsmanship and that the dryer incl. building containing it look good.

Based on a few very simple tests the dryer seems to operate as intended. The tests on the dryer had just started so it is not yet possible to state anything about the value of the dryer for the company hosting the dryer.

4. Visit to the solar wood dryers

The solar wood dryers are erected at Clipper Design Ltd at Mankoadze about 65 km west-south-west of Accra. Clipper Design Ltd produces mainly doors.

Not one but two solar wood dryers has been/were being erected at Clipper Design Ltd:

- one forced open-air dryer based on recommendations from Wood Technology, Danish Technological Institute (Frank, 2000) and
- a closed version designed by DENG and Clipper Design Ltd where it is possible to control the temperature and humidity level of the air in the solar wood dryer (hereafter solar kiln).

Figure 4.1 shows the two chambers for the forced open-air dryer and the solar kiln. The forced open-air dryer was by the visit operational while the solar kiln was expected to be ready by mid February.

Figure 4.1. The two chambers for the open-air wood dryer (to the left) and the solar kiln (to the right) seen from the north.

The reason for the two different types of solar wood dryers is the fear at the design by Wood Technology, Danish Technological Institute (the forced open-air dryer) will be of less value because it has been designed on a wrong basis. The dyer was based on the information on the climate (ambient temperatures and humidities) from (Akuffo, 1991). In (Akuffo, 1991) it is stated that the ambient humidity hardly ever will go below 60% rh and mainly stay above 80% rh – see Appendix C. Under such conditions the concept of forced open-air drying make sense. However, the reality is very different from (Akuffo, 1991). Measurements on sites reveal a totally different situation. The ambient relative humidity gets very often as low as 30% rh and from time to time even lower. Without forced air flow – i.e. simple air drying – the wood often gets damaged – i.e. get cracks and get twisted and thereby useless. Forced open-air drying may easily worsen this situation. However, Wood Technology, Danish Technological Institute insisted that the forced open-air dryer was the right design for the purpose and location. In order to overcome this situation DENG and Clipper Design Ltd made it possible to build two dryers as described above. In this way it will be possible to test which design is the best. The dryers are built in such a way that each of them easily may be changed into the other design. In this way no recourses will be lost.

The chapter consists of three sections:

- brief description of the design of the two solar wood dryers
- the findings from the inspection of the two dryers
- plan for the tests and reporting of the tests

4.1. The design of the two solar wood dryers

The design of the two solar wood dryers will briefly be described in the following.

The floor plan of each of the two chambers of the dryers is 4.5 x 2.48 m². The roof is slightly sloped to the south with a tilt of 4°. The height of the chambers is 2.75 m at the entrance (see figure 4.1) and 2.42 m at the back. The dryers may contain up to 10 m³ wood each. The chambers consist of a wooden skeleton with aluminium sheets on both sides except for the roofs where aluminium sheets only are mounted on top.

4.1.1. Forced open-air dryer

The forced open-air dryer is based on a design developed by Wood Technology, Danish Technological Institute. The design is described in details in (Frank, 2000).

The design is very simple. It consists as seen in figure 4.2 of a pressure chamber with 6 dc fans as seen in figure 4.3. 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.

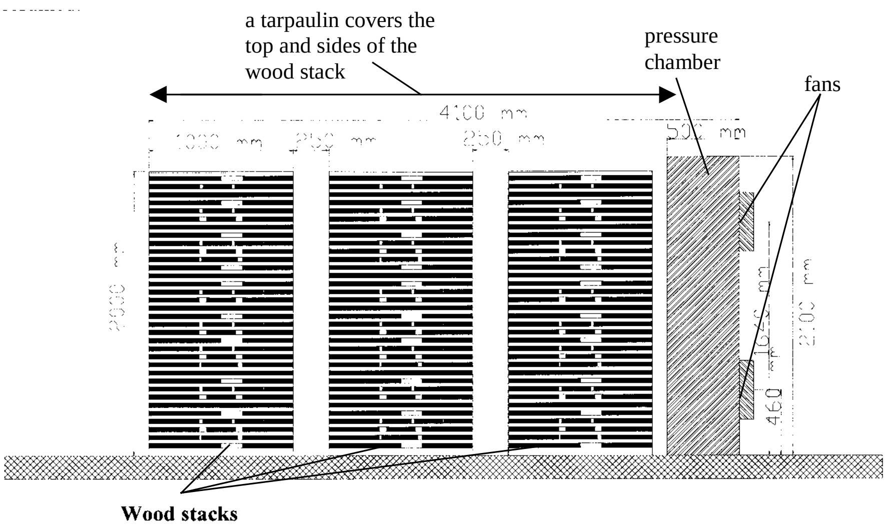

Figure 4.2. The principle of the forced open-air dryer.

Figure 4.3 shows the pressure chamber and the tarpaulin seen from the chamber. The chamber is mainly to protect the dryer from rain. Figure 4.4 shows the pressure chamber from the south togetter with the PV-panel. The PV-panel is movable in order to allow for tracking the sun during the day - as seen in figure 4.5.

Figure 4.3. The pressure chamber of the forced open-air dryer with fans and the tarpaulin.

Figure 4.4. The pressure chamber of the forced open-air dryer and the PV-panel in front seen from the south.

Figure 4.5. The PV-panel turned to face west – being cleaned.

Components of the dryer:

Fans: 6 dc fans, diameter: 40 cm, max power: 50 W each (for further details see (Frank, 2000))

PV-panel: area 9.6 m², 30 panels 14 W_p each, 24 panels = 336 W_p connetcted to the fans
6 panels = 84 W_p connected to a battery

4.1.2. Solar kiln

The solar kiln is design by DENG and Clipper Design Ltd. Figure 4.6 shows the principle of the kiln. A false ceiling 2.1 m above the floor will be installed in the chamber – figure 4.7 shows the chamber without the false ceiling. Two fans circulated 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 the PV-panels circulate the air at a lower air speed during the night. A smaller exhaust fan with at damper extract humid air from the kiln when the humidity or the temperature level get 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 is sprayed on the inside of the roof when the humidity level gets to low. This feature is also controlled by a hygrostat. The roof acts as solar collector for heating the air in the kiln. The tests will show if it is necessary to paint the roof black externally in order to increase the efficiency of the roof as collector.

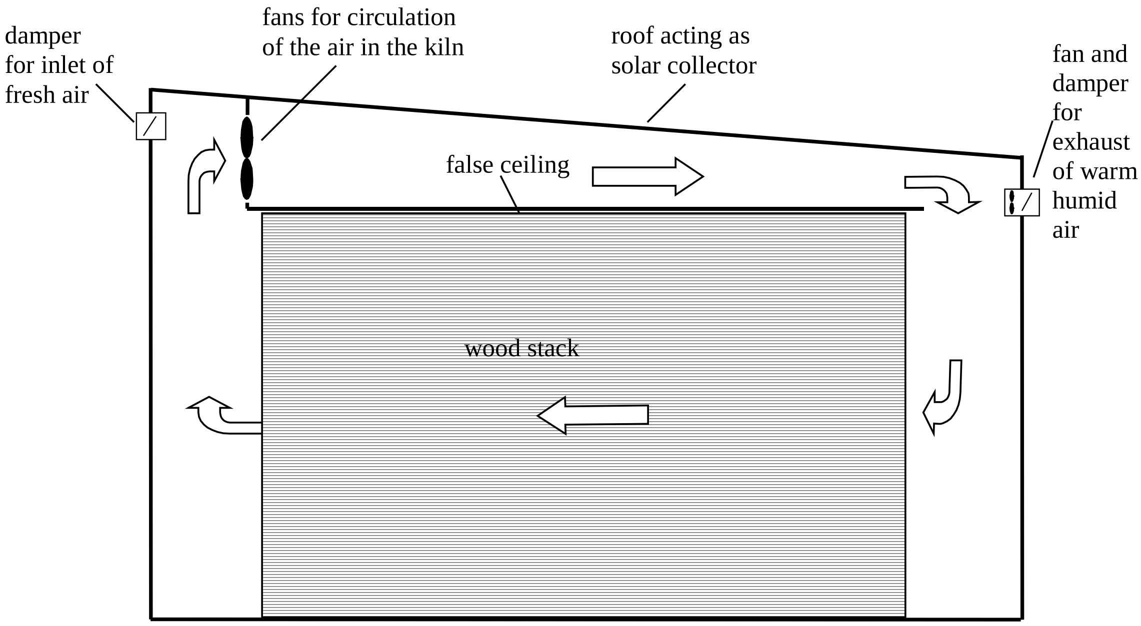

Figure 4.6. The principle of the solar kiln.

Figure 4.7. The chamber of the solar kiln before the false ceiling and fans were installed.

Components of the dryer:

Fans: 1 dc fan for daytime circulation, diameter: 60 cm, max power: 550 W
1 dc fan for night-time circulation, diameter: 40 cm, max power: 50 W (for further details see (Frank, 2000))
1 dc fan for exhaust, diameter:11 cm, max power: 7 W

PV-panel: 10 panels of 80 W_p each = 800 W_p

Battery: 260 Ah (intended)

4.2. Inspection of the solar wood dryers

The solar wood dryers show good craftsmanship. The forced open–air dryer was operational, however, some final details were still missing. The false ceiling, fans, control, PV-panels, battery, air tight entrance, etc. still needed to be installed in the solar kiln.

Clipper Design Ltd has carried out tests regarding tracking of the sun with the PV-panels for the forced open-air dryer. If tracked the fans will start one hour earlier in the morning and stop one half hour later in the evening. The tracking will further lead to a higher power to the fans in the morning and evening – how much has, however, not been measured. The tracking is now performed manually but an automatically tracking devise is planned.

The wiring between the PV-panels and the fans of the forced open-air dryer should be made nicer.

The ten crystalline PV-panels for the solar kiln is not part of the project but has been lent in order to allow for parallel tests with the two kilns.

It is difficult to run a kiln as detailed knowledge on the temperature and humidity level of the air and wood is necessary in order to obtain a good quality of the wood being dried. Tonny Larsen at Clipper Design Ltd has former been in charge of running manually controlled commercial kilns. Although hygrostats will be installed in the solar kiln the control of the drying process will still be mainly manually. Due to the experience of Tonny Larsen a high outcome of the tests with the solar kiln is expected.

It is the hope by Clipper Design Ltd that the drying time of today 90 days will be cut down with more than 50% and that the quality of the dried wood will increase.

4.3. Plan for tests and reporting

The tests of the solar wood dryers will consists of two levels:

1. parallel test(s) with the two dryers in order to determine which concept is superior
2. tests with different types and sizes of wood

The reporting will consists of three levels:

a. report on the results on the parallel test(s) with the two dryers
b. report on the results on the tests with different types and sizes of wood
c. the consultants from the University of Science & Technology, Kumasi (Jensen, Frank and Kristensen, 1999) should prepare an impartial report stating how well the goals of this part of the project has been reached

1 and a: One or more test(s) will be carried out in parallel in the two dryers in order to define which of the two concepts is best and if both concepts are useful. The test(s) will be carried out and reported by Clipper Design Ltd. Clipper Design Ltd will write a detailed logbook on each test. DENG will start and offload data from three combined temperature/humidity Tinytag dataloggers – se section 2.3. DENG will deliver curves for the measured temperatures and humidities to Clipper Design Ltd in order to support the reporting

2 and b: Tests will be carried out in the best dryer with different types and sizes of wood. The tests will be carried out and reported by Clipper Design Ltd. Clipper Design Ltd will write a detailed logbook on each test. DENG will start and offload data from three combined temperature/humidity Tinytag dataloggers – se section 2.3. DENG will deliver curves for the measured temperatures and humidities to Clipper Design Ltd in order to support the reporting

c. The consultants from the University of Science & Technology, Kumasi reads the above reports, talks with Clipper Design Ltd and write an impartial report stating how well the goals of this part of the project has been reached

The tests and reporting should be finilazed by the end of October 2001.

4.4. Conclusion on the solar wood dryers

The impression from the inspection of the solar wood dryers is that it is good craftsmanship and that the two drying chambers look nice although the final finish still was lacking.

The forced open-air dryer was operational, while the kiln still lacked the last installations. It is believed that the erection of two different dryers will maximize the outcome of this part of the project. It is, however, too early to state anything about the performance of the dryers – the tests will by time show this.

5. Conclusion

The impression from the inspection of the solar dryers is that the dryers show good craftsmanship and that they look nice. It is clear that quite a lot of enthusiasm has been put into the dryers.

A week of detailed measurements on the solar crop dryer revealed that the dryer was performing as expected. A few simple tests on the fish dryer indicated that this dryer also was performing as intended. Of the solar wood dryers only the forced open-air dryer was running by the time of the inspection. This dryer seemed to run as expected. The solar kiln was still under construction during the inspection. The solar kiln was soon after the inspection put into operation.

Plans for the test of the solar dryers and reporting on the findings from the tests have been developed. Tests on the solar dryers are by the time of writing this being carried out. The tests will show how well the dryers perform and if the aims of the project have been reached.

6. References

Akufo, F.O., 1991. Climate Data for Solar and Wind Energy Applications in Ghana. University of Science & Technology, Kumasi.

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Appendix A

Simple test method

Test of solar crop dryer in Ghana

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 must be the same for all six trays per drying section.

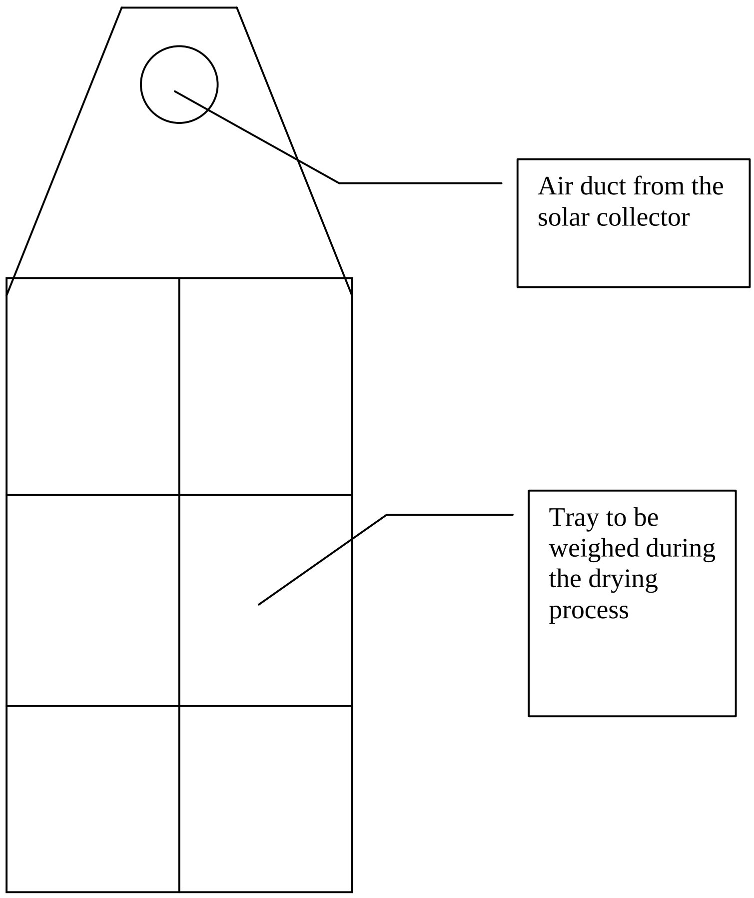
For the drying of other crops, e.g. pepper, the drying process may be performed in one step. The fresh material is filled into the drying trays, and remains in the trays until the drying is finished. Cassava and similar large vegetables or fruits must be sliced or cut into small pieces prior to drying.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

The drying process may be registered and illustrated 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 (see the paragraph “Determination of moisture content”). 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.

Figure1: Sketch plan of one section of the crop dryer



Determination of moisture content

An electric moisture meter of good quality may be used to determine the moisture content of the grain or crop. If a reliable moisture meter is not available, 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 grains is dried at a temperature of 130 degrees C in an oven. For wheat, barley, rice and sorghum the drying time must be 2 hours. For maize the drying time must be 4 hours, according to international standard, but for oriented or instructive moisture determination a drying time of 2 hours will be sufficient.

Calculation of moisture content:

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

where

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

Step by step outline

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.

<u>All data and relevant comments should be noted on the enclosed form.</u>

Test No.: Dryer No.:

Crop:

Date of harvest:

Date of start of drying:

Moisture content at start of drying:

Date	Hour	Weight, kg				Ambient air			Water content in the maize %	Comments B)
		Tray (1)	Tray+crop (2)	Crop (3) = (2)-(1)	Weight loss A)	Dry temperature, °C	Wet temperatur °C	Humidity, %RH		

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

Table: Drying shrinkage when drying grain or similar products in the crop dryer.
(E.g. maize and wheat).

Loss in weight when drying 1 kilogram of crop, Gram/kg					
Moisture content before drying, %	Moisture content after drying, %				
	14	13	12	11	10
24	116	126	136	146	156
23	105	115	125	135	144
22	93	103	114	124	133
21	81	92	102	112	122
20	70	80	91	101	111
19	58	69	80	90	100
18	47	57	68	79	89
17	35	46	57	67	78
16	23	34	45	56	67
15	12	23	34	45	56

Example

When drying 20kg maize with 22 % moisture content to 11% moisture content the loss in weight will be:
Weight loss = 20kg × 124g/kg = 2480 gram = 2.48kg

Table: 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 × 625g/kg = 5000 gram = 5kg

Table: Drying shrinkage when drying products with low moisture content (E.g. millet seeds and nuts).

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

Appendix B

Letter to the farmer at Silwood Farms

Dear Frank,

I write this letter to you in case I don't meet you on Saturday January 27.

Remember to put in the filters in the inlet to all of the solar air collectors. The filters should regularly be inspected and washed if necessary. Based on you experience from the inspections of the filters you will be able to define the necessary interval between the inspections.

Please be careful when weighting the drying tray in the system, where I have put up measuring equipment. Try to read the scale within +/- 100 g, as the drying down from 15 to 10 % water content only will reduce the weight of the tray with about 1 kg.

I have a problem with your meter for measuring the water content in the maize. You may remember that when starting the dryer I measure on, the water content dropped from around 15.5 % just when the maize went into the dryer to 14.5 % after about 1 hour. I have been in contact with an expert in Denmark who says that this is because the surface had been dried more than the middle of the maize – ie you obtain a wrong reading. I order to get a precise reading you have to take a sample, put it in a tight plastic bag and first perform the measurement after 2 hours (preferably longer). Will you do this on the dryers you perform the tests on? The time you write into the drying table should be the time when you pick the sample up and not the time when you after a couple of hours perform the reading with your instrument. The morning reading – if performed before the dryer starts – may be correct as the water in the maize during the night has been levelled out.

Based on a mail from the Danish expert I believe that it will be rather difficult to dry the maize down to 8% - at least it will take long time. However, the tests will show. To dry the maize down to a very low water content will take long time, so you should maybe consider to dry all of the maize down to 10% so it can be stored without problems – after that you can start to dry the maize further down.

From the measurements I have obtained so far it is seen that the temperature of the air to the drying bed exceeds 45°C during 4 hours around noon. The Danish expert who I have been in contact with is worried about this. It may decrease the germination ability of the maize. One way maybe to overcome this is that you steer the maize several times during the 4 hours around noon so that not only one layer of the maize is exposed to the >45°C during all 4 hours.

Could you please state on the drying table you fill in, which dryer the test is run on. Please call the dryer I have installed the measuring equipment on for dryer A, the dryer next to it B and so on to the last one (longest away from the A dryer) E.

Could you please conduct a test where you at the same time fill one dryer with 14.5 kg in each tray and another dryer with 20 kg in each tray. In that way we will be able to investigate how more maize in the dryer will affect the drying time.

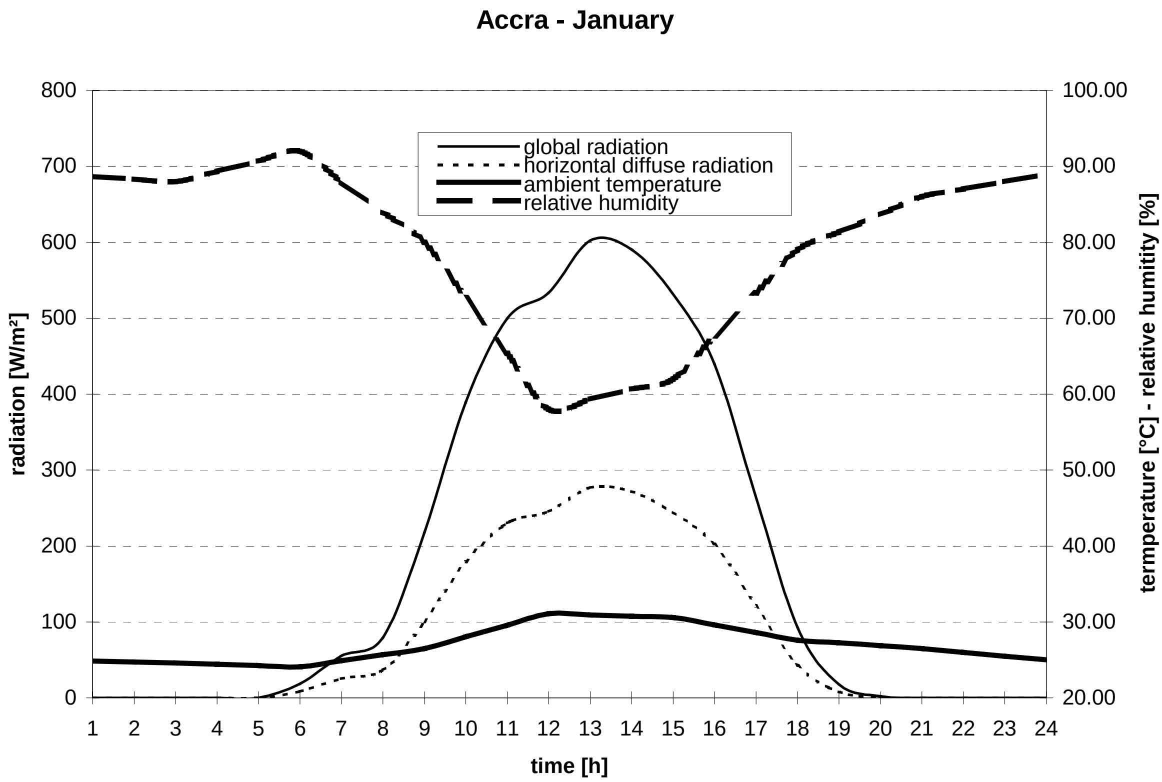
Finally I would like to thank you for good co-operation and wish you all the best with the dryer – I hope you will be happy for having it.

Yours sincerely,
Søren Østergaard Jensen

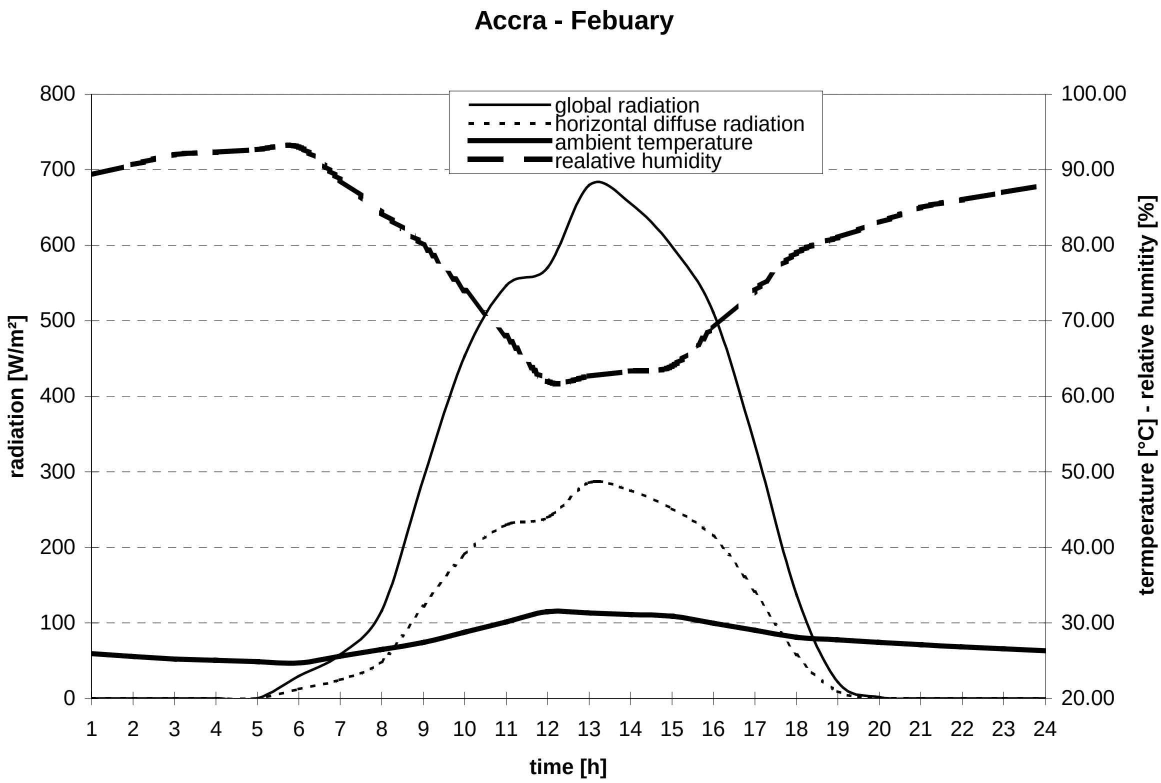
Appendix C

Weather data for Accra

from (Jensen, 2000) based on (Akufo, 1991)

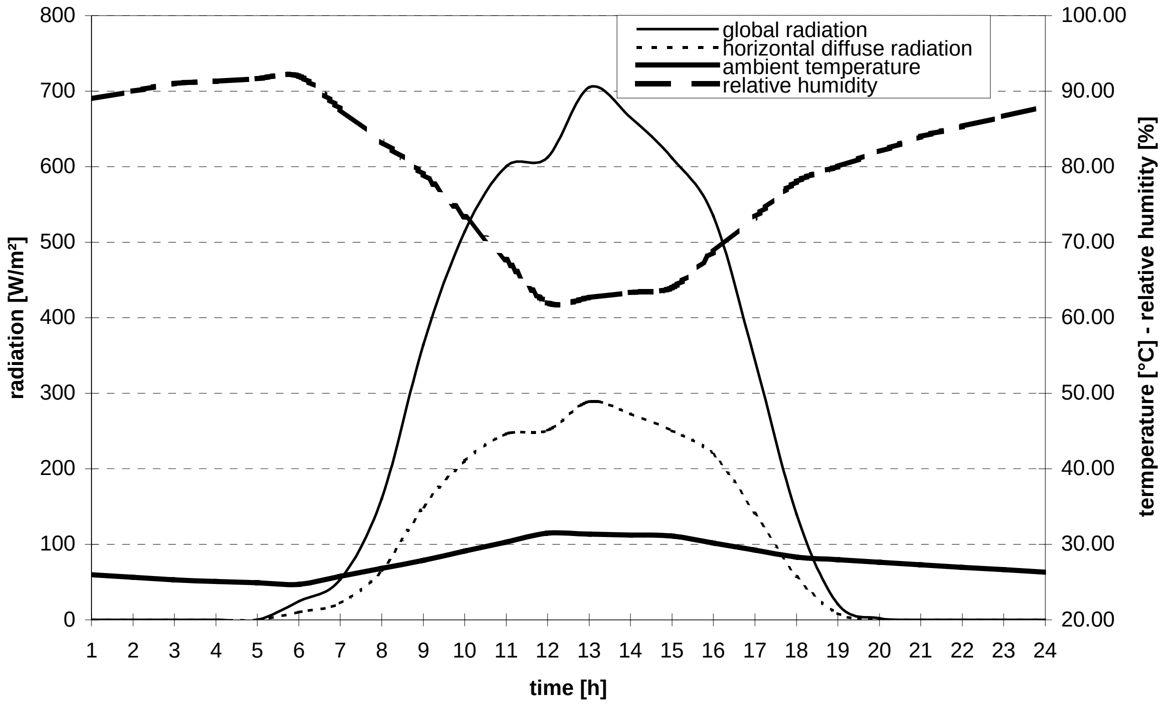


Accra - January
global radiation
horizontal diffuse radiation
ambient temperature
relative humidity
radiation [W/m²]
termperature [°C] - relative humitity [%]
time [h]
0
100
200
300
400
500
600
700
800
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

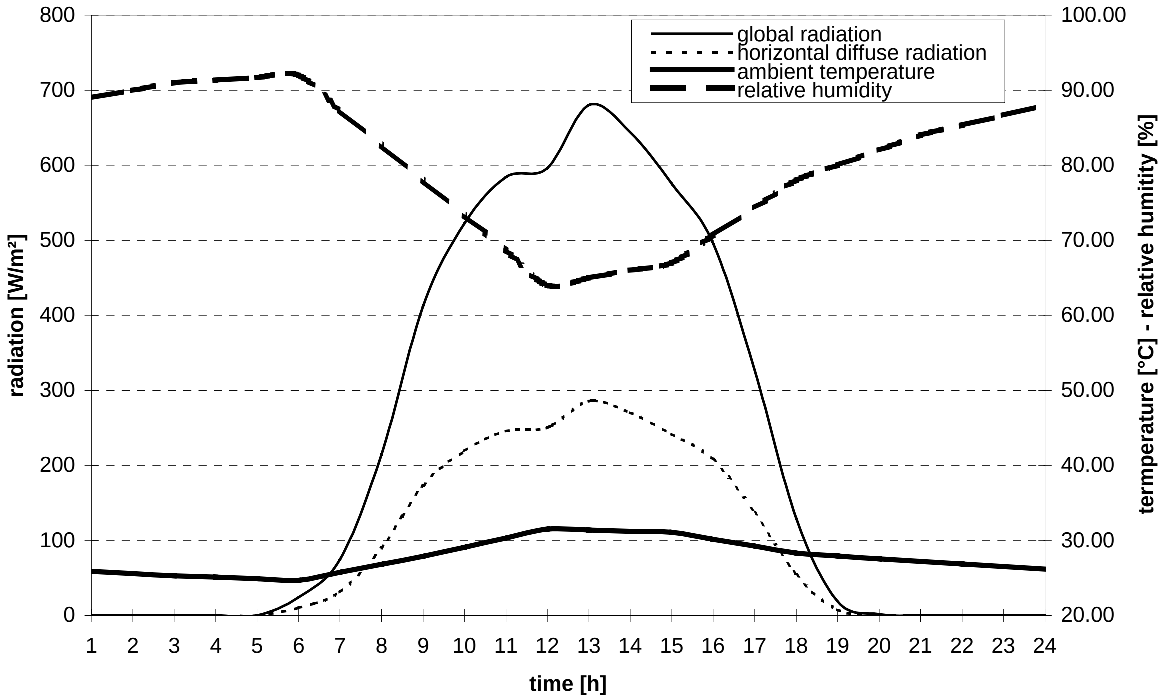


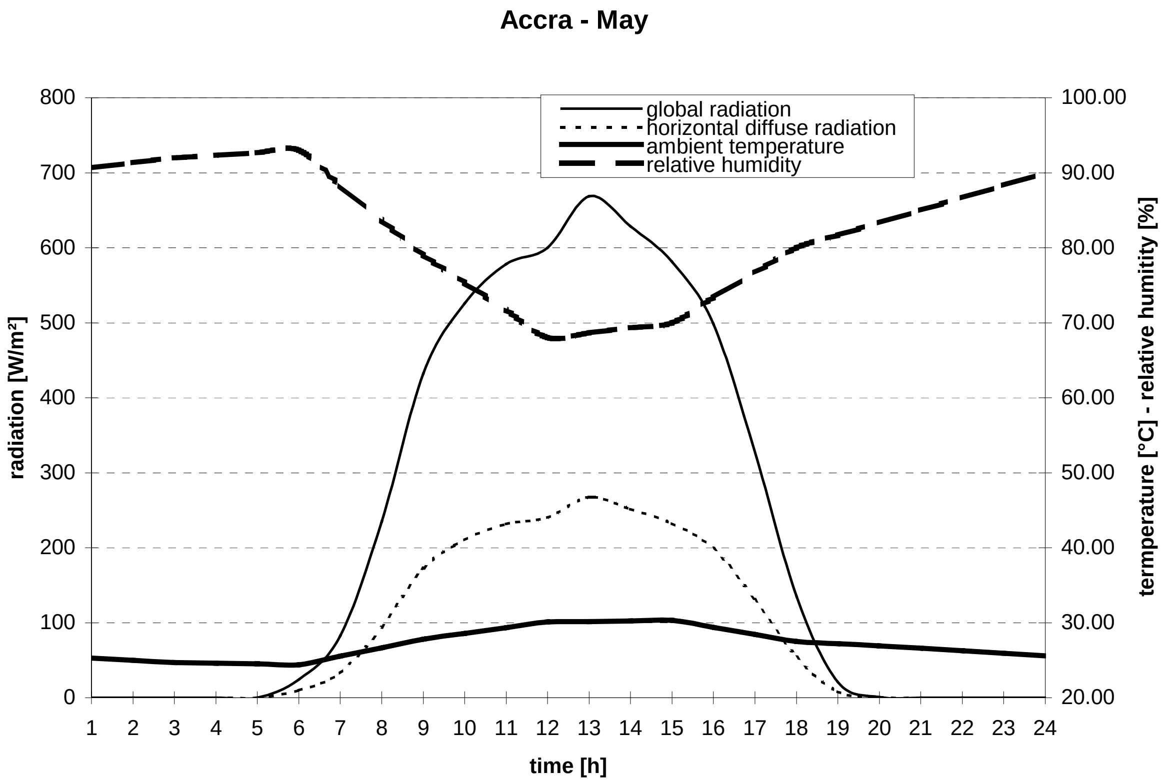
Accra - Febuary
global radiation
horizontal diffuse radiation
ambient temperature
realative humidity
radiation [W/m²]
termperature [°C] - relative humitity [%]
time [h]
0
100
200
300
400
500
600
700
800
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

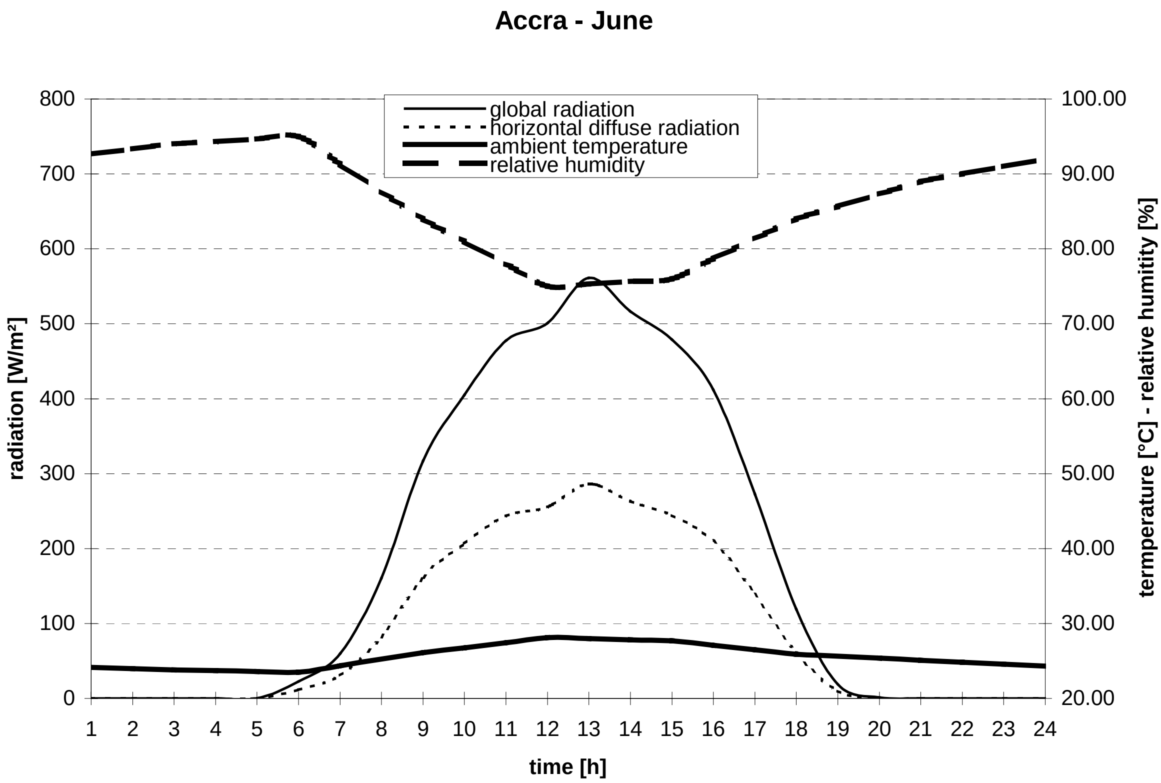
Accra - Marts



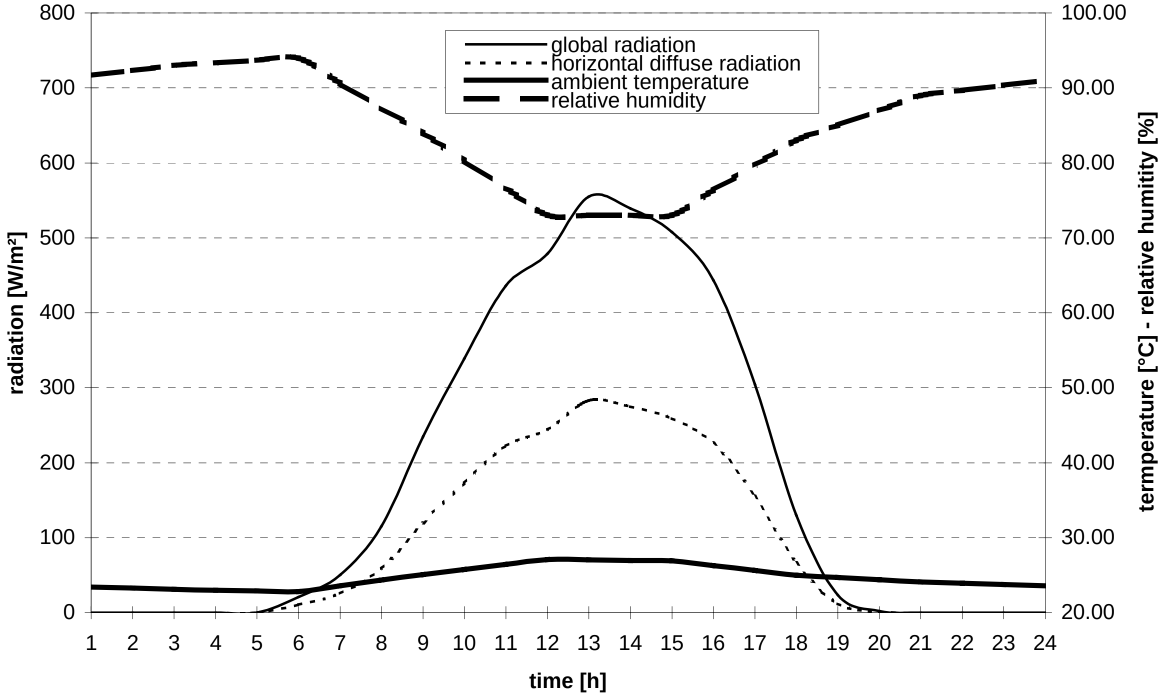
Accra - April



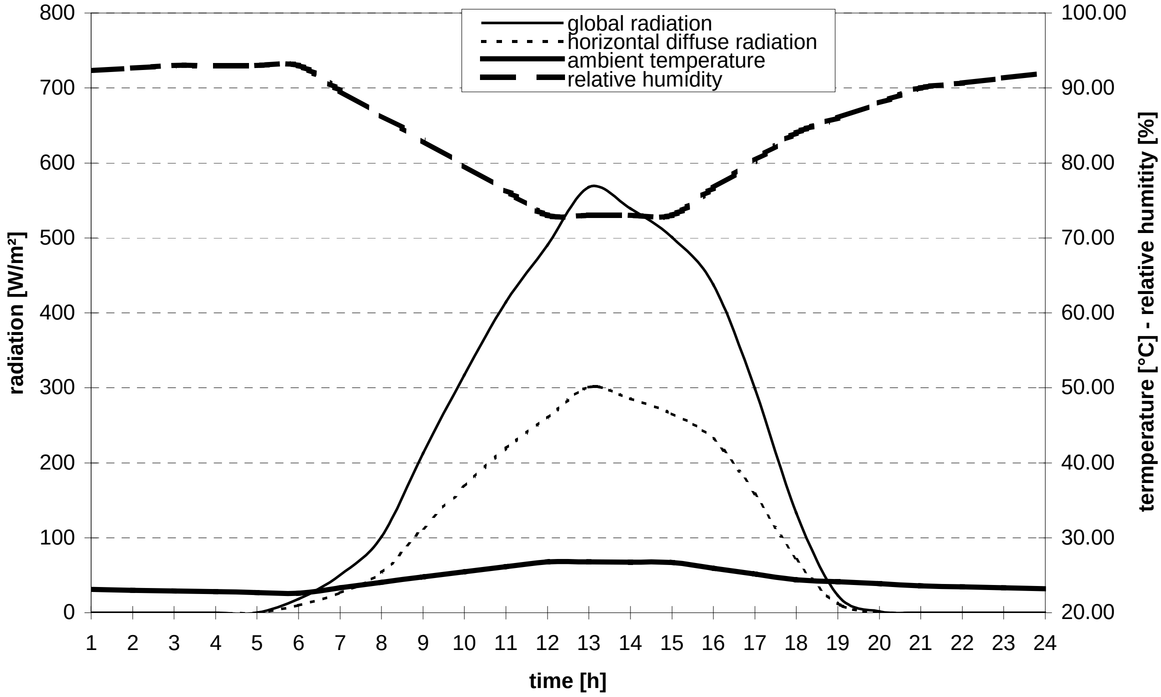

Accra - May
global radiation
horizontal diffuse radiation
ambient temperature
relative humidity
radiation [W/m²]
termperature [°C] - relative humitity [%]
time [h]


Accra - June
global radiation
horizontal diffuse radiation
ambient temperature
relative humidity
radiation [W/m²]
termperature [°C] - relative humitity [%]
time [h]

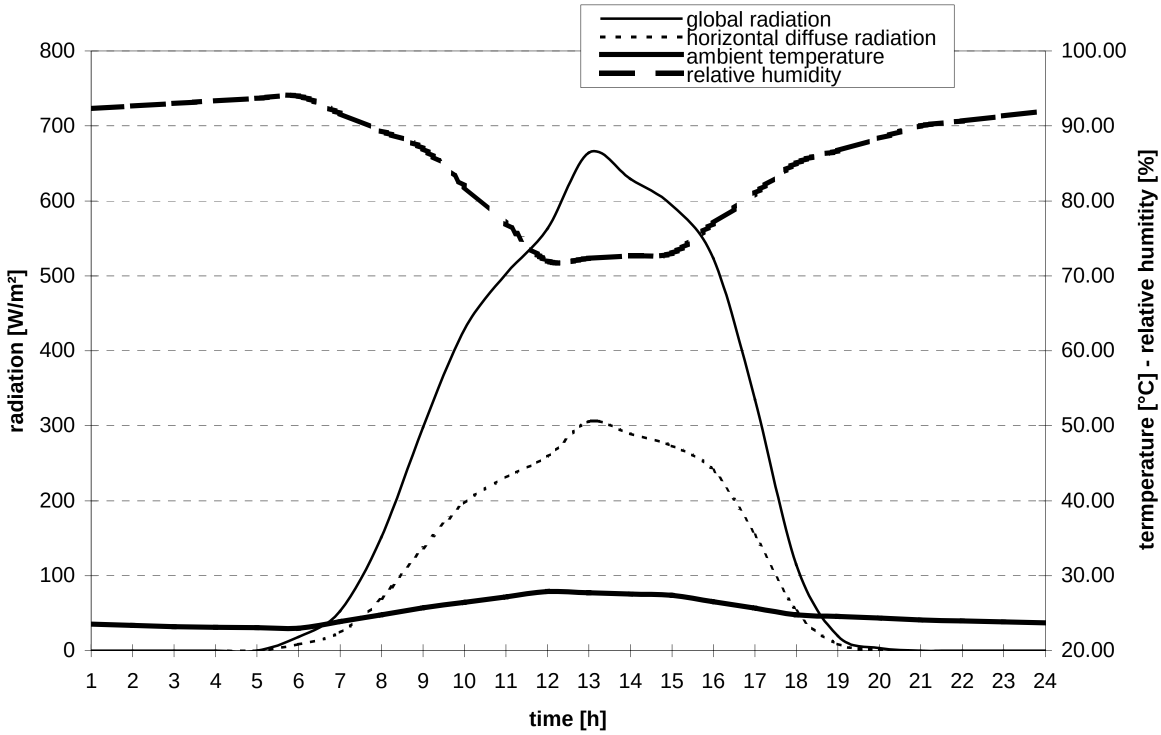
Accra - July



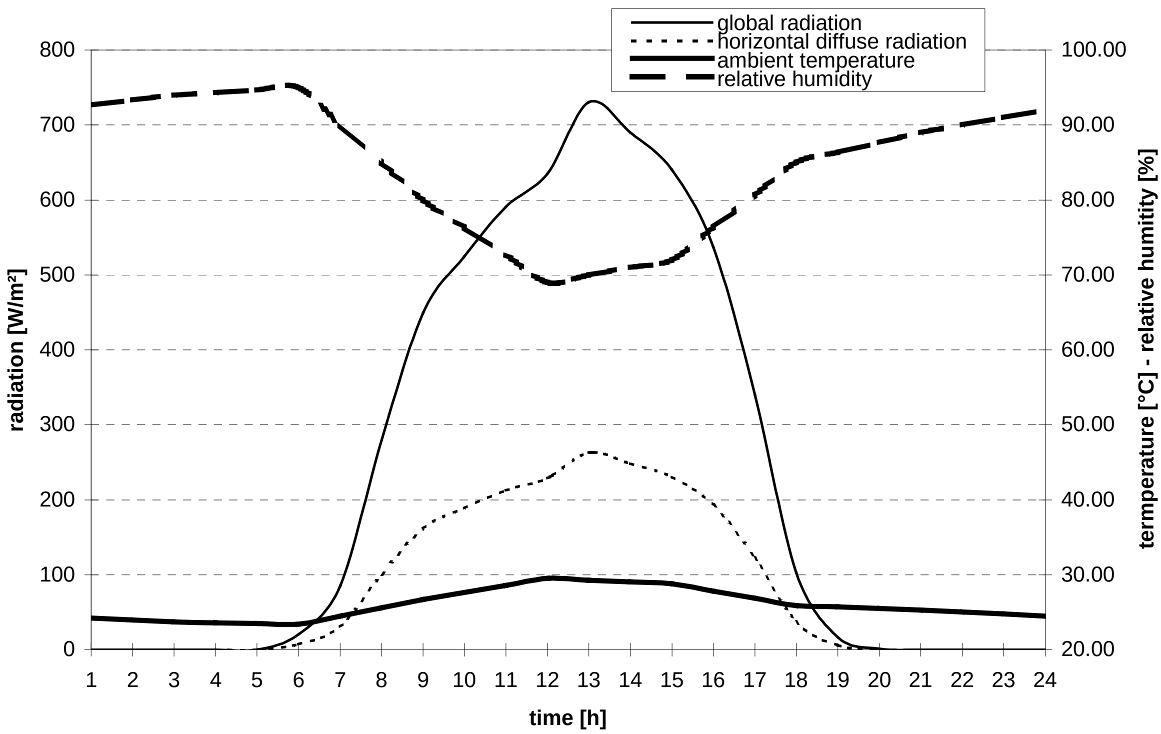
Accra - August

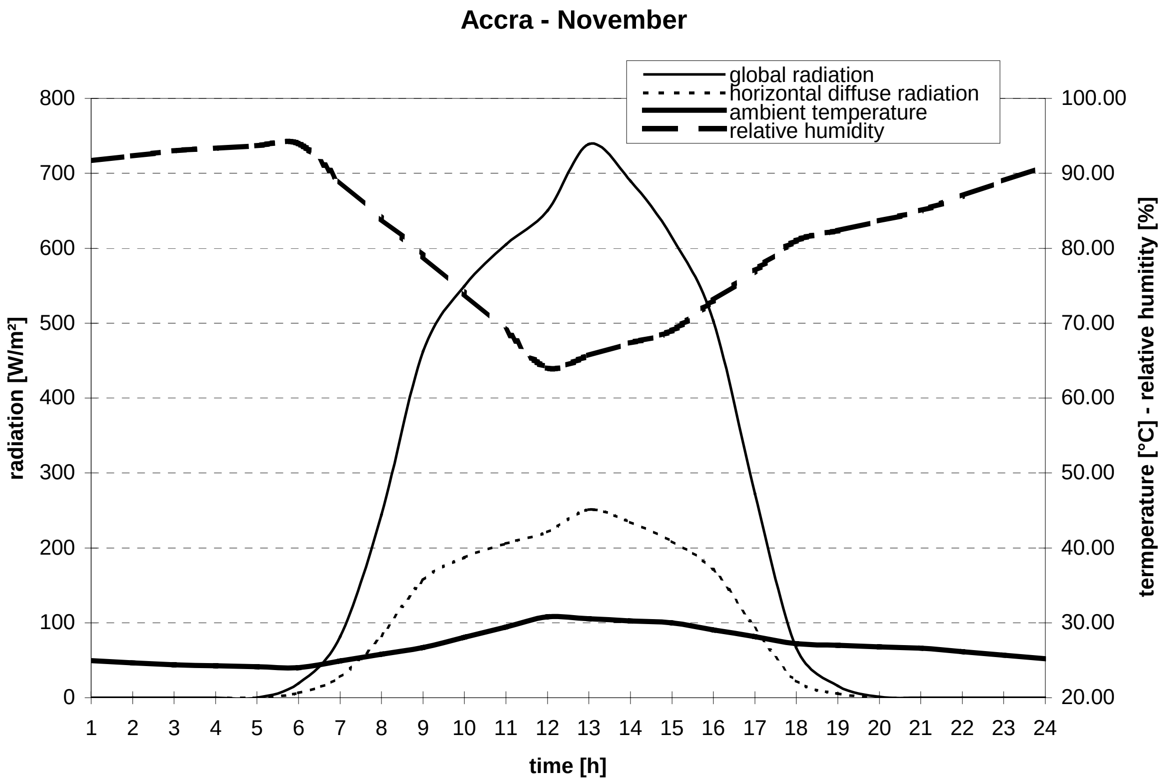


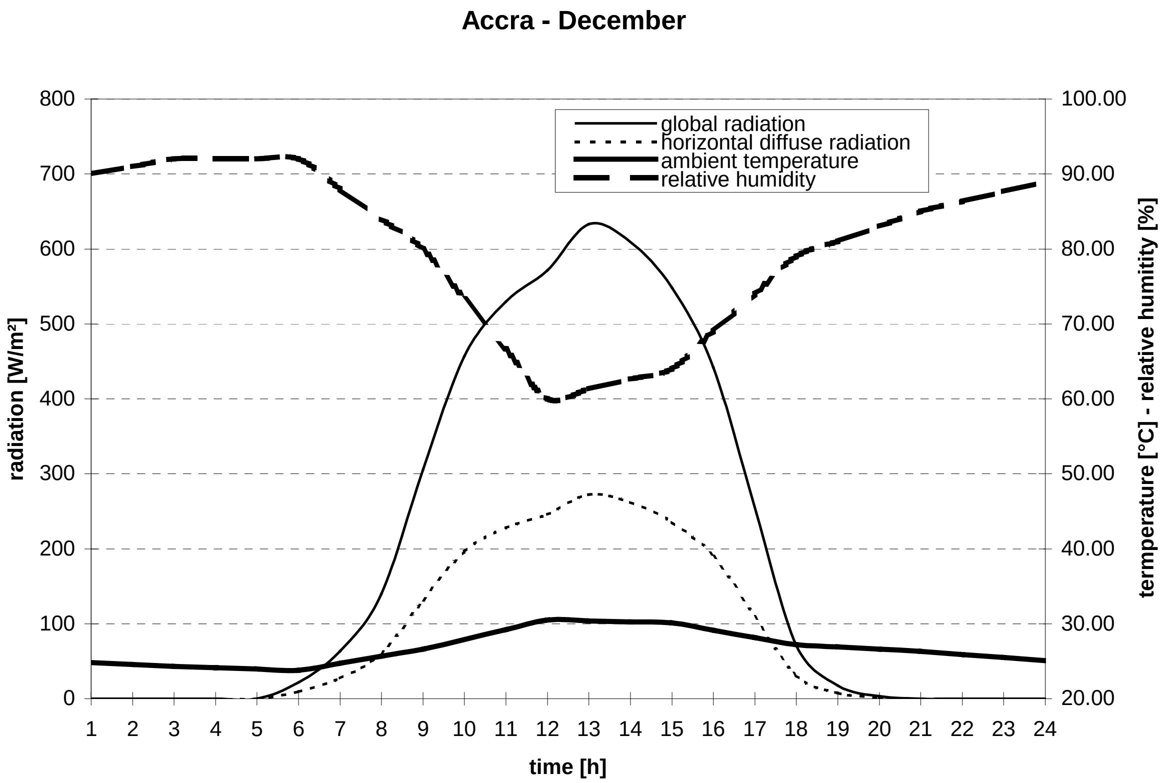
Accra - September



Accra - October




Accra - November
global radiation
horizontal diffuse radiation
ambient temperature
relative humidity
radiation [W/m²]
termperature [°C] - relative humitity [%]
time [h]
0
100
200
300
400
500
600
700
800
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Accra - December
global radiation
horizontal diffuse radiation
ambient temperature
relative humidity
radiation [W/m²]
termperature [°C] - relative humitity [%]
time [h]
0
100
200
300
400
500
600
700
800
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24