DEVELOPMENT OF A SOLAR CABINET DRYER FOR ROOT CROPS CHIPS IN NIGERIA

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ABSTRACT

A solar cabinet dryer was developed and tested using cassava chips. The test involved drying experiments with fresh cassava chips of average size of 3.5 cm. In the trial experiment, the dryer was not loaded with the product rather, temperature of the collector, the dying chamber/plenum and chimney were taken at intervals of 30 minutes. The highest temperature attained by the solar dryer was 45.5°C. A sample of 200g of cassava chips was thereafter loaded in each of the three trays and dried from moisture content of 80% (wb) to 14.3 % (wb) in tray 1, to 15.3% (wb) in tray 2 and to 14.3% (wb) in tray 3 respectively in four days. The quality deterioration of the dried cassava chips based on colour change was not significant by visual observation. This indicates that there was little or no fungal (mould) infestation and is therefore recommended for use for cassava chips drying in Nigeria if similar tests are carried out in other agro-climate zones of the country. A performance test for other sizes of the chips is ongoing.

KEYWORDS: Solar cabinet dryer, cassava chips, root crops.

1. INTRODUCTION

Sun-drying method may be efficient and cheap process but has disadvantages such as contamination, insects and bacteria infestation and loss due to wetting by rain squalls. In order to protect the products from above mentioned disadvantages and also to accelerate the time for drying the products, reduce the moisture and hence wastage through bacterial action, different types of solar dryer has been developed (Excel 1980, Janjaia et al 2008, Yaldyz and Ertekyns 2001).

During the mid 1970's shortages of oil and natural gas, increase in the cost of fossil fuels and the depletion of other fossil fuel resources stimulated efforts in the development of solar energy as a practical power source. Thus, interest was enkindled in the harnessing of solar energy for heating, cooling, generation of electricity and other purposes. It also found applications in the area of agriculture for crop drying, irrigation pumping, and numerous other thermal processes in food industries.

Cassava is one of the most widely used foods in Nigeria. Its storage poses big problem to farmers and is traditionally left in the soil until it is set to be used. It has high moisture content and high respiration rate thereby subjecting it to microbial, mechanical and physiological damages after harvest. All these factors lead to high post-harvest losses, thereby necessitating drying of the portion of the production that will not be readily consumed. However, drying faces a big challenge because of the rising energy cost and the global disapproval of the conventional fossil fuels as sources of energy.

The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration after harvest (Rajkumar, Kulanthaisami et al. 2006). In many parts of the world there is a growing awareness that renewable energy sources have an important role to play in extending technology to the farmer in developing countries to increase their productivity (Waewsak et al., 2006). Solar thermal technology is rapidly gaining acceptance as an energy saving measure in agricultural application. It is preferred to other sources of energy because it is abundant, inexhaustible and non-polluting (Akinola, 1999; Akinola and Fapetu, 2006; Akinola et al., 2006). Solar air heaters are simple devices that raise the temperature of air by solar energy and are employed in many applications requiring low to moderate temperature below 80^0C, such as crop drying and space heating (Kurtbas and Turgut, 2006).

The post-harvest loss of agricultural products in most developing countries is enormous. This is a serious concern for an agricultural country like Nigeria where approximately 91% are dependent upon subsistence farming for their survival. As a consequence, farmers income remain low due to low farm gate prices and retail prices remain high as the losses are passed on to consumers. However, several factors contribute to post-harvest losses and some of the technological factors include faulty harvesting and handling practices, poor packaging and transport systems, lack of storage facilities and poor processing techniques.

Therefore, the food processing sector can play a vital role in reducing the post-harvest losses through processing and value addition. The objective of this work, therefore, is to develop a solar dryer that will serve the purpose of the rural farmer to address the problems of preservation of such high moisture content crops like fruits, vegetables and tubers.

2. MATERIALS AND METHOD

2.1 Description of the Solar Food Dryer

The solar food dryer consists of two major integral components (Figs 1 & 2) namely:

(i.) The solar collector compartment, which can also be referred to as the air heater.
(ii) The drying chamber, designed to accommodate layers of drying trays made of chicken mesh on which the produces or food are placed for drying

The fan was powered by a solar panel connected to a controller unit.

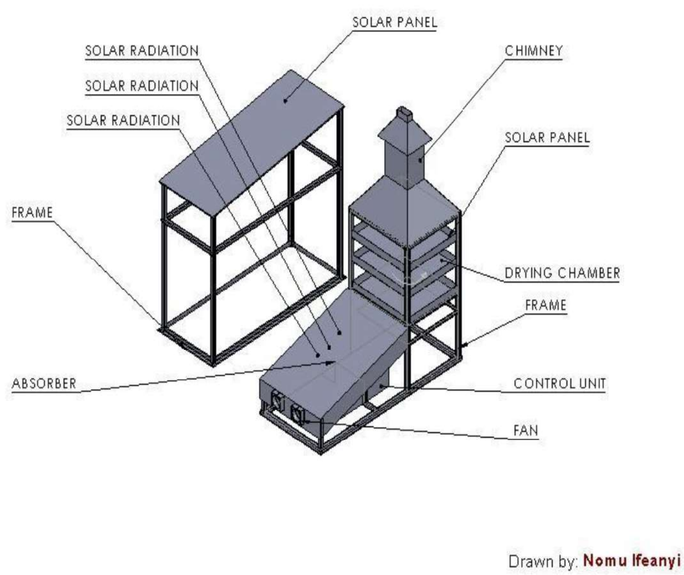

Fig. 1: The Solar Cabinet Dryer

Fig 2: The pictorial view of the Solar Cabinet Dryer

2.2 Basic Design Calculations

The size of the dryer was determined as a function of the drying area needed per kilogram of cassava chips.

Calculation of the Amount of Moisture to be removed: The amount of moisture to be removed from the product, Mw in Kg is estimated from the following expression.

$$M_w = \frac{M_g(M_i - M_f)}{100 - M_f} \qquad (1)$$

Where: M_g = initial mass of wet crop to be dried (kg); M_i = initial moisture content (%); M_f = final moisture content (%).

The Heat Gained by the Collector per Unit Time Q_c:

This is given by;

$$Q_c = A\,[I\tau\alpha - U_L\,(T_i - T_a)] \; ….. \qquad (2)$$

Where: A = area of the transparent cover (M^2)
I = incident insolation (w/m^2)
U_L = overall heat loss for the collector (w/c)
α = solar absorbance
τ = transmittance
T_i = temperature of incoming air
Ta = temperature of ambient air

Since the collector draws the ambient air directly and the length is not too long, the last term on the right-hand side vanishes and the rate of energy collection is simply estimated using;

$Q_c = AI\tau\alpha$ ….. (3)

(3) If the mass of air leaving the collector per unit time is $\dot{m}_a$, the heat gained by the air Q_a is;

$Q_a = \dot{m}_a C\,(T_o - T_i)$ …. (4)

Where: C = specific heat capacity of air (KJ/kg⁻1˚C)
T_o = temperature of out-going air

(4) A simplified energy equation for the dryer is $Q_c = Q_a$ i.e

$AI_\tau\alpha = \dot{m}_a C\,(T_o - T_i)$ …. (5)

Therefore, the required surface area of the transparent cover, which determines the size and dimensions of the dryer, is obtained from;

$$A_C = \frac{\dot{m}_a C(T_o - T_i)}{I\tau\alpha}$$

(5) The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water;

$\dot{m}_w Lv = \dot{m}_a C\,(T_o - T_i)$ …. (7)

Where L_V = specific latent heat of vaporization of water from the food surface (kJ/kg)
$\dot{m}_w$ = mass of water evaporation from the food item (kg/s)

The mass of water m_w is estimated from the initial content M_i and the final desired moisture content M_f as stated in equation (1) as

$$\dot{m}_w = \frac{M_g\left(M_i - M_f\right)}{100 - M_f}$$

(6) The Average drying rate is given by

$$M_{dr} = \frac{M_w}{t_d}$$

Where: t_d = total drying time
M_{dr} = Average drying rate (kg/hr)
M_w = Amount of water/moisture to be removed

(7) The Quantity of Air Needed for Drying

The quantity of air needed for drying may be estimated from the energy balance equation. The basic energy balance equation for drying process is

$M_w L = M_a\, L_a\, \rho_a\,(T_i - T_f)$ …… (9)

$$M_a = \frac{M_w L}{C_a \rho_a (T_i - T_f)}$$

Where: M_a = Quantity of air needed to absorb M_w kg of water (m^3)
L = specific latent heat of vaporization of water from the crop to be dried.
C_a = specific heat capacity of the air at constant pressure (kJ/kg^{0}C).
ρ_a = Density of drying air (kg/m^3)
T_i and T_f = The initial and final temperature of the drying air before passing through the drying bed (^{0}C).

(8) Quantity of Heat needed to evaporate the water.
The quantity of heat required to evaporate the water would be

$$Q = M_w .h_{fg} \qquad \ldots. (11)$$

Where: Q = The amount of energy required for the drying Process KJ
M_w = mass of water (kg)
h_{fg} = latent heat of evaporation of water (KJ/kg)

2.3 Design Consideration and Parameters

1. Angle of Tilt (β) of solar collector (Air heater).
   Duffie and Beckman, (1974) suggested that the angle of tilt (β) of the solar collector can be estimated by adding 10^o to the Latitude of the location. Therefore,

   $$\beta = 10^0 + \text{Lat } Ø$$

   Were latitude Ø is the latitude of the collector location, the latitude of Awka where the drying was designed is latitude 6.20^0.
   Hence, the suitable value of β use for the collector.

   $$\beta = 10^0 + 6.20^0 = 16.\ 20^0$$

2. Isolation on the collector surface Area. The average daily solar radiation for Awka is 5157.22kJ/m^2/day to 53002.94kJ/m^2/day (Okonkwo and Nwokoye, 2011).
3. Air gap – A gap of 5cm is created as air vent (inlet) and air passage.
4. Glass and flat plate collector – transparent glass covering of 60 x 60cm^2 and 4mm thickness glass was used.
5. Drying chamber was of average dimension of 60 x 57 x 55cm with chimney
6. Drying Trays: Chicken mesh was selected as the dryer screen or trays to aid air circulation within the drying chamber. Three trays each having dimensions of 50 x 50cm.

2.4 Experimental Procedure

The experiment was conducted in Nnamdi Azikiwe University Awka located at longitude 7.12˚E and latitude 6.20˚N from 8th April to 12th May 2011. Experiments were carried out using cassava chips. The cassava chips were prepared, washed, weighed before drying. The chips were left inside the drying chamber and monitored for weight loss at regular intervals. Temperatures of the drying medium and ambient were measured at one hour intervals. 100g of the cassava chips cut in circular shape was placed on each of the three trays in the drying chamber.

The air temperature at collector inlet, collector temperature, and surface temperature of the drying trays were measured using laboratory type digital thermometer (accuracy ± 0.5˚C) between the hours of 9.00am and 4.00pm each day. The weight of the cassava chips were taken periodically every thirty minute until no further weight loss was noticed.
Initial weight as well as the final weight was noted. The weight loss was used to calculate the moisture ratio and drying rate at 30 minute intervals as the chips dried.

2.5 Determination of Moisture Content

The moisture content of the cassava chips was determined using oven method. Chips from the same samples to be dried were weighed in moisture cans with known weights. The sample and tray were put in an oven at temperature of 103˚C. After intervals of 12 hours, the tray plus sample was weighed to note the change in weight, and was put back to the oven. The process of weighing and returning to oven continued until there was a constant weight. Thus:

$$\%\ \text{Moisture Content (wet basis)} = \frac{(W_i - W_f)100}{(W_i)}$$

Where, W_i=initial weight of sample, W_f=final weight of sample

The moisture content was determined before and after each experiment to represent the initial and final moisture contents respectively.

3. RESULTS AND DISCUSSION

The temperature profile of the dryer was determined by measuring the temperature inside the drying chamber and the ambient air hourly, between 8.am to 4.pm (local time). Moisture removed from cassava chips was monitored hourly as the weight during the day. The results are presented in Tables 1 – 3 and Figures 1 – 5.

Table 1: Result of no-load test run of the dryer (without cassava chips) in August 2012 for **(**Day 1)

Local Time (hr)	Tray1 surface tempt T (˚C)	Tray2 surface tempt T (˚C)	Tray3 surface tempt T (˚C)	Ambient Tempt T_0 (^{0}C)	Solar collector Tempt T (^{0}C)	Dryer Wet bulb tempt T (^{0}C)	Ambient Wet bulb tempt T (^{0}C)	Ambient Relative humidity (%)	Dryer Relative humidity (%)	Chimney Tempt T(^{0}C)
9.am	29	27	28	28	34	26	25	80.3	56.7	30
10.am	29	28	29	27	31	25	24	79.5	64.4	31
11.am	29.8	29	30	28	32	26	25	80.3	65.5	29
12.pm	30	30	31	28	33	25	24	73.7	55.4	28.5
1.pm	34	34.7	32	33.6	41	28	26	58.4	41.6	27
2.pm	35.2	35.7	34	32.2	45	30	27	70.3	38.6	30,5
3.pm	30	29	31	27	31	29	26	93.2	88.1	32
4.pm	32	31	30	28	32	27	24	73.7	71.2	31

Table 2: Results of experimental drying of cassava chips and dryer parameters in August 2012 (Day 2)

Local Time (hr)	Tray1 surface tempt T (˚C)	Tray2 surface tempt T (˚C)	Tray3 surface tempt T (˚C)	Ambient Tempt T_0 (^{0}C)	Solar collector Tempt T (^{0}C)	Dryer Wet bulb tempt T (^{0}C)	Ambient wet bulb tempt T (^{0}C)	Ambient Relative humidity (%)	Relative humidity of drying chamber (%)	Chimney Tempt T(^{0}C)
10.am	32.0	30	36.0	30.0	40.0	24.0	28.0	87.7	26.4	31.0
11.am	31.5	30.5	32.0	28.0	32.0	26.0	24.0	73.7	65.5	31.5
12.pm	34.0	32.0	36.0	32.0	40.0	34.0	30.0	88.4	72.4	34.0
1.pm	38.0	32.0	40.0	33.0	38.0	28.0	30.0	83.3	51.6	32.0
2.pm	34.0	33.0	39.0	32.0	34.0	28,5	30.0	88.5	70,2	35.0
3.pm	34.5	30.5	38.0	30.5	34.0	27.5	28.0	84.9	64.8	34.0
4.pm	32.0	30.0	34.0	3O.0	32.0	27.0	26.0	75.5	71.2	30.0

Table 3: Results of experimental drying of cassava chips and dryer parameters in August 2012 (Day 3)

Local Time (hr)	Tray 1 surface tempt T (˚C)	Tray 2 surface tempt T (˚C)	Tray 3 surface tempt T (˚C)	Ambient Tempt T_0 (^{0}C)	Solar collector Tempt T (^{0}C)	Dryer Wet bulb tempt T (^{0}C)	Ambient Wet bulb tempt T (^{0}C)	Ambient Relative humidity (%)	Dryer Relative humidity (%)	Chimney Tempt T(^{0}C)
10.am	32.0	30.0	32.0	31.0	34.0	31.0	30.0	94.1	83.8	28.0
11.am	34.0	30.0	38.0	32.0	40.0	30.0	28.0	77.0	54.0	35.0
12.pm	34.0	30.1	36.0	30.2	32.0	26.0	28.0	92.7	65.5	34.5
1.pm	34.0	32.0	38.0	32.0	34.0	28.0	27.0	77.0	62.1	35.0
2.pm	36.0	32.5	40.0	32.0	36.0	29.0	28.0	77.0	64.2	36.0
3.pm	34.0	32.0	40.0	32.0	36.0	30.0	29.0	88.5	64.2	38.0
4.pm	34.0	32.0	38.0	30.0	34.0	28.0	27.0	87.7	67.5	34.0

The solar radiation was discovered to fluctuate with time as shown in the plot of average daily solar radiation against the day of the month (figure 1).

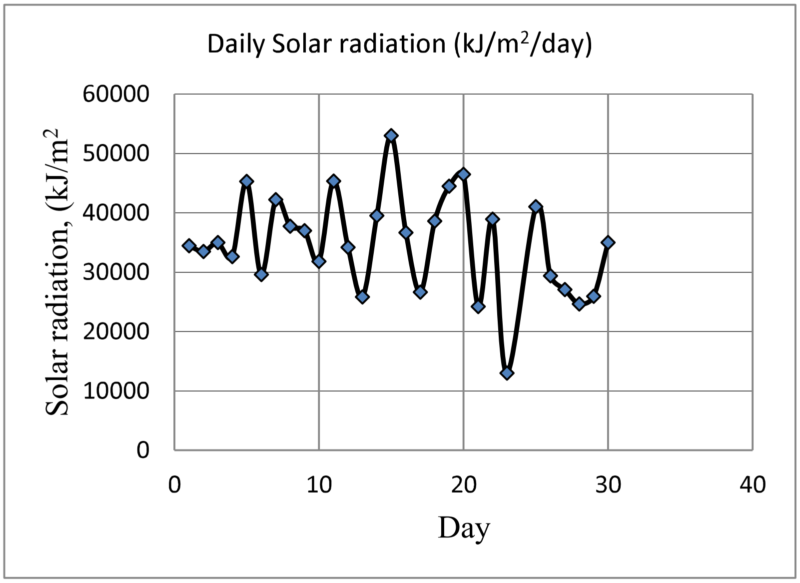

Figure 1: Daily hourly radiation at Awka for the month of April, 2011

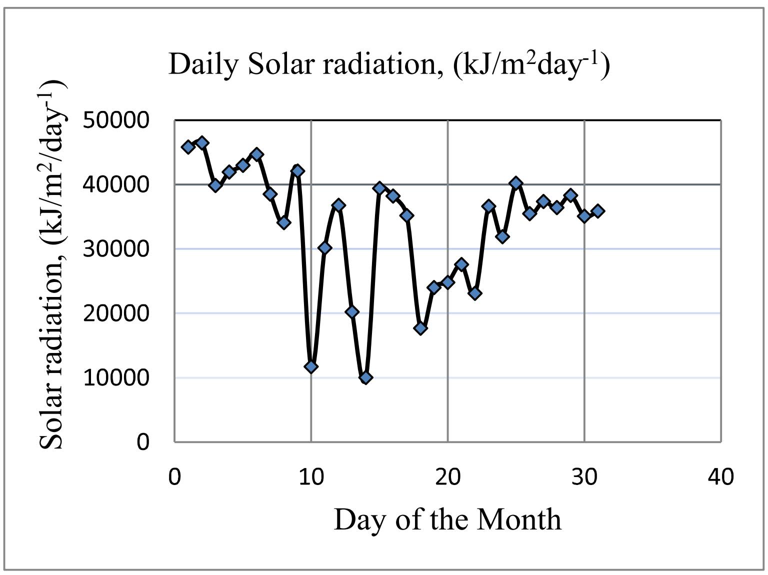

Figure 2: Daily hourly radiation at Awka for the month of May, 2011

As the time progresses, the dryer temperature increases until around 12 noon and 1.00pm local time for the ambient and dryer respectively. The ambient peaked first before the drying chamber, by a time lag of one hour. The temperature inside the dryer was higher than the ambient air temperature throughout the greater part of the day for the period tested. This indicates prospect for higher rate of moisture removal in solar dryer than open–air sun drying.

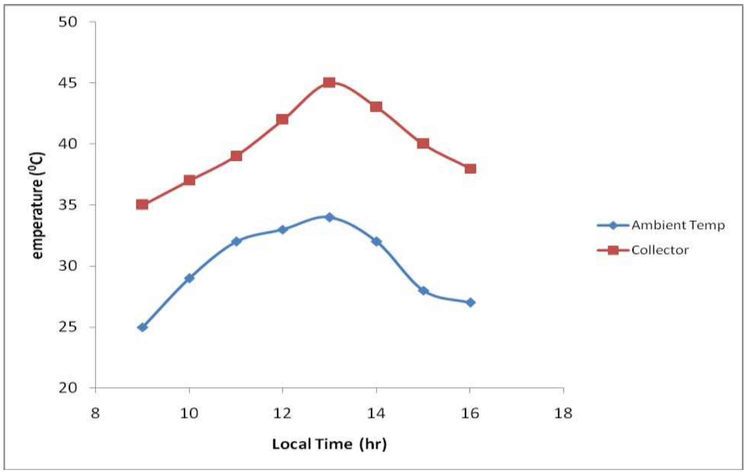

Fig.3: Average ambient and collector temperatures against local time for the month of April 2011

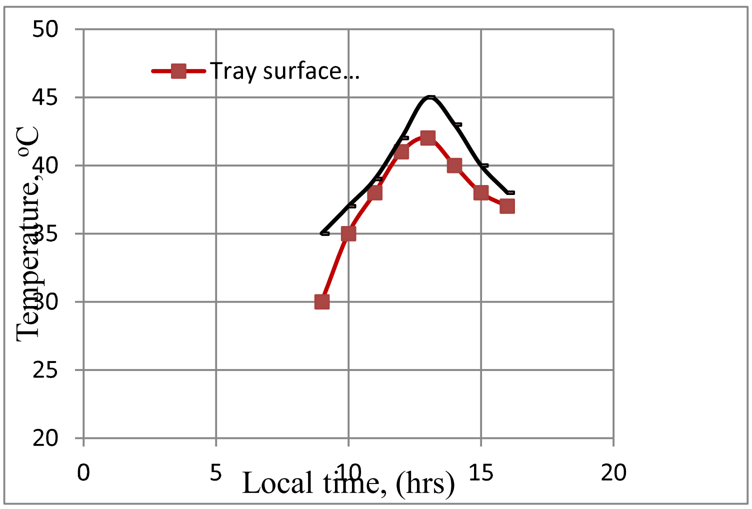

Fig.4: Average Tray temperatures against local time for the month of April 2011

The drying was quite slow in the morning as the drying chamber warmed up and the solar intensity low. The maximum drying occurred between 12.pm - 1.pm local time which corresponds with the period of highest temperature inside the dryer and high solar radiation intensity.

As the solar radiation increases, the temperature on the collector and inside the dryer increases. This logically indicates higher rate of moisture transport in solar dryer during the mid-day

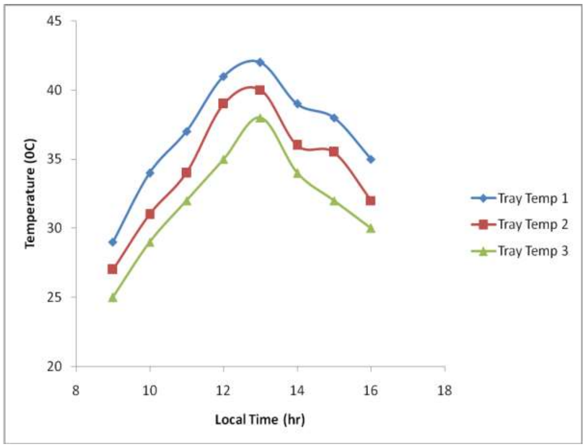

Fig 5: Average temperatures of the three drying trays against local time

Relative humidity was calculated with the values of wet bulb and dry bulb temperatures using the Vaisala sychrometric calculator. The results are presented in Tables1 to 3.

4. CONCLUSIONS

The rate of moisture removal from food items is a function of the temperature inside the dryer. Solar radiation can be effectively utilized for drying of agricultural product in Awka environment. Locally available materials were used in construction making it available and easy to maintain especially by peasant farmers. This will go a long way in reducing food wastage and consequently food hortages. This dryer can be used extensively for majority of the agricultural food crops. It protects the environment and saves cost and time spent on open sun drying of agricultural produce. The food items are also well protected in the solar dryer than in the open sun, thus minimizing the cases of pest, insect attack and contamination.

However, the performance of the solar food dryer can still be improved upon especially in aspect of reducing the drying time and probably storage of heat energy within the system.

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Appendix

Table 1: Summary of Design materials and parameters.

S/N	Parameters	Description
1	Location	Awkas, (lat 6.20 °'N)
2	Drying period	April- May, 2011
3	Solar irradiation, Awka (October/ November)	15.4 – 16.7 MJ/m^2/day
4	Average relative humidity	89%
5	Food products	Plantain and Cassava
6	Initial moisture content in yam	65-85%
7	Mode of heating	Indirect
8	Number of glazing	1
9	Glazing slope	17°
10	Glazing Materials	Glass
11	Loading provision	Door at back side of chamber
12	Number of trays	3
13	Air outlet provision	Vent at top of the chimney
14	Air circulation mode Forced convection	
15	Drying capacity	10kg
16	Thickness of plantain chips	3 mm
17	Construction materials	Wood, glass, mild steel sheet
18	Insulation used	Glass fibre
19	Thickness of glass	4.5 mm
20	Transmittance of glass	.81
21	Emissivity of cover	0.88

22	Emissivity of plate	0.98
23	Sky temperature	32 ºC
24	Air velocity at fan speed of 750 rpm	5 m/s
25	Dimension of collector	1.08 x 0.76 m2
26	Insulator thickness	0.0125 m
27	Pv module type and rating	55Wp (RSM 50, Solar smart switch)
28	Solar charge controller	SDRC- 10IP (12/24 V auto)
29	*Fan* rating	12 Volts
30	Fan speed	702 - 1012 rpm