

Design and Construction of a Solar Box Cooker as an Alternative in Nigerian Kitchens

**Gregory A. Alozie¹, I.M. Mejeha^{1, 2},
Oluwasogo A. Ogungbenro^{1*},
G. I. Nwandikom³ and Chidi Akujor^{1, 2}**

⁽¹⁾Department of Physics, Federal University of Technology Owerri, Imo State, Nigeria

⁽²⁾Information and Communication Technology Centre, Federal University of Technology Owerri, Imo State, Nigeria

⁽³⁾Department of Agricultural Engineering, Federal University of Technology Owerri, Imo State, Nigeria

*Corresponding Author: email:
sogogbenro@futo.edu.ng, alozgreg@yahoo.com

Phone number: +234 806 455 7474

Abstract

We have designed and constructed a "Heaven's flame" solar box cooker capable of boiling about 1.8 liters of water under the air temperature of 110°C in the oven box for 45 min. The solar box cooker was displayed in the sun for 3 days to test its workability as well as to check the effect of temperature from late hours of the early morning up to late in the evening with the aid of inserted thermometers (0°C - 360°C). The results show that the best time to cook with the solar box cooker is between the hours of 11.00 am and 4.00 pm (Nigerian time) on sunny days,

while the incorporation of heavy materials (such as pieces of stones) as heat storage materials inside the box cooker helps to maintain its heat for as long as 5.00 pm. The solar box cooker has been found to be environmentally acceptable and economically useful because it reduces household expenditure and improves the quality of food cooked.

Keywords: Heaven's Flame, Solar Box Cooker, Solar Energy, Quadrilateral Cone Concentrator, Heat Conservation Chamber, Sunlight Radiation, Extinct Coefficient, Oven Box.

1. Introduction

About 15% of the total world's population and over 50% of Nigerians rely on burning wood or dried dung for cooking their food. This is quite alarming considering the effect of inhaling polluted air and the environmental impact of deforestation; about 1.6 million people die annually as a result of air pollution in their houses [1]. More so, the time spent by people (mostly women and children) gathering sticks and dung for cooking and the effect of scarcity of paraffin oil (kerosene) in both the urban and rural areas is disheartening. Yet, most of these people live near the equator where sunshine is abundant and free.

The sun is the primary source of energy for our planet. Increased utilization of energy would result in an all-round benefit, both for individual users as well as the nation [2]. Use of solar energy would save a lot of time, money and life for the users, and could be effectively diverted for industrial use for

increased productivity and monetary gains, which means better living standard for our citizens. The sun is an inexhaustible source of renewable energy. The sun's surface temperature is 6000°C and on average, 2 calories of heat/cm²/min, (solar constant), are radiated. This abundant and clean solar energy could be utilized for many purposes such as cooking, heating, drying and generating electricity for our day to day consumption, (through the application of photo-voltaic technology). As a result of over centralization of power supply crises, coupled with the increasing need to get the rural dwellers electrified, it has become necessary to extend the list of technological alternatives for energy investment decision-makers to include decentralized sources of supply. Among the many available decentralized energy technology that could harness solar energy for home electrification and other energy sources, and also be well suited for remote locations is the solar photo-voltaic (PV) system [3]. The amount of energy radiated from the sun annually is estimated at 5.4 x 10²⁴ Joules per year which is equivalent

to at least 1000 times the amount of energy used presently in the whole world for the same period of time [4]. The annual total horizontal solar radiation in Nigeria as determined from mean annual sunshine hours varies from 5000 MJ/m² in the humid Niger- Delta to over 9400MJ/m² in the extreme north-east of Nigeria [5]. This energy from the sun is transmitted through space to the earth by means of electromagnetic radiation in form of heat and high energy at a relatively low intensity. Many researchers in Nigeria [5,6,7,8] have shown considerable interest in the sun and have used different methods in the attempt to harness the sun's energy for domestic purposes such as solar cooking, pumping of water and drying of food items in rural areas.

There are various types of solar energy cooker designs which utilized solar focusing collector designs in different forms and each is an attempt to improve the performance of solar cookers. These include rotatory paraboloid mirror, cylindrical parabolic mirror, spherical mirror, cone mirror and quadrilateral Fresnel Mirror [9]. Out of the various types of focusing collector mentioned, the quadrilaterally conical solar concentrator was chosen for this study. This is based on the fact that the geometry of the design is less complex than any other concentrator, the energy received by the absorber is greater than other concentrators or focusing collectors of equal aperture area and availability of local materials at relatively low cost of labor for the construction of the collector. This enabled us to achieve the goals of this work which includes

- i. To discuss the design and construction of an alternative cooking oven with solar radiation capable of cooking food in Nigerian environment where there is abundant solar energy.
- ii. To utilize the affordable sources from the sun and reduce too much dependence on fossil fuel electricity power supply in Nigeria which is grossly inadequate, unreliable and has become a major constraint to economic growth and development [10].

Solar Cooker Information

The dissemination of solar cooking information has been carried out for more than twenty years. The success has been less than satisfactory compared to efforts made [11]. Technical problems have often affected the success of solar cooking mandate. The earliest models have suffered from being ahead of the times, either because people had enough low cost or free fossil fuels to use. Socio-economic and cultural factors may have contributed or played a major role in this failure [12].

Solar cooking has been (or is currently being) introduced in 69 countries worldwide. The highest numbers of cookers are in India and China, approximately 34,000 in India, and 140,000 in China. In both countries, the solar cooking programs have been promoted by the government. Countries like Pakistan,

Kenya, South-Africa, the United States of America (USA) and Switzerland have less than 20,000 solar cookers in each of them [13]. These numbers of cookers in some of these countries can be counted in thousands and hundreds or not at all. In addition, the number of existing solar cookers in some of these countries may have gone out of active use.

The solar cooking dissemination project has been a part of India's national program for development and use of renewable energy sources since 1982. About 85% of mainly box type cookers have been distributed in six Indian states namely: Madhya Pradesh, Maharastra, Rajasthan, Ulter Predish, Gujarat and Dellin. The Indian government had offered a subsidy of 33% on the price of solar cookers for potential buyers. This has resulted in India being the largest marketer of solar cookers in the world. Nevertheless, comparing 34,000 solar cookers to about 800 million citizens, we can't say certainly that Indians patronizes solar cookers [11].

In China, the first solar cooker appeared almost 53 years ago in 1956. Before 1975, when the first China National Solar Energy Congress was held, only a few people researched on solar cooking. Forty-eight institutions presented more than a hundred models of solar cookers of which, eighty had been tested. By the end of 1983, records showed that fifty thousand (50,000) solar cookers were in use in China.

Estimated fuel saving potential of solar cookers is enormous. There are cheap (US \$ 5-10), expensive (US \$ 500-1000), small (cook for 3-4 persons) and bigger (cook for 30,000 persons) sizes, slow and fast cooking, portable hybrid etc. [14]. Solar energy is free, abundant and pollution free. In spite of these benefits, the cookers are not used on a massive scale (the total could be around 1.3-1.5 million solar cookers throughout the world). The world estimate concludes that the annual wood saving potential is 346 million tons of wood and the total market of solar cookers for domestic, small scale and large scale use will result in more than US Dollars 85 billion savings on fuel alone.

2. The Design Theory

Solar concentrators are types of focusing collectors which utilize optical system reflectors (mirrors or reflecting surfaces) or refractors (lenses) to increase the intensity of solar radiation on an energy absorbing surface for applications requiring high temperatures like the one required for refrigeration, power generation and space heating [8]. In focusing collectors the refracting or reflecting surfaces are used to channel natural concentration of solar energy falling on an area i.e., the focus of the system; consequently, the energy intensity at the focus is much greater than that of the environment. The area that receives this augmented insolation is called the 'Hot Spot', and this is situated at the spot where the cooking pot is placed for the solar box cooker.

The amount of heat, Q_c (in watts) needed to achieve cooking is

$$Q_c = MS \frac{\delta T}{\delta t}$$

Where M is the mass of the material to be cooked, S is its specific heat capacity in $\text{KJ/Kg } ^\circ\text{C}$, T is the temperature in $^\circ\text{C}$ and t is the time for cooking in seconds.

Though the box type solar cooker use both the diffuse and direct beam radiation, the major heat source is the direct beam radiation. The beam radiation H_{bm} for normal incident rays on a cooker is [15]

$$H_{bm} = A e^{-\beta/m \alpha}$$

where A is the apparent solar radiation at air mass w/m^2 , β is the atmospheric extinct coefficient and α is the solar altitude angle. The values of A and β can be obtained from standard Tables [16].

$$\alpha = \sin^{-1}(\sin \phi \sin \delta + \cos \phi \cos h)$$

and

h = hour angle, degree or radian

=1/4 (number of minute from local solar noon)

$$\delta = 23.45 \sin \left[\frac{360}{365} (248 + n) \right]$$

n is the n^{th} day of the year, ϕ is the latitude angle in degrees and δ is the solar declination.

The cross-sectional area AC of the cooker is given by

$$A_c = \frac{Q_c}{\eta_c H_b}$$

Where η_c is the efficiency of the cooker

$$H_b = H_{bm} \sin \alpha$$

And for square box

$$L = \left[\frac{Q_c}{\eta_c H_b} \right]^{1/2}$$

Which give dimension of the box.

A slight increase could be created on one of the axis to accommodate the handle of the cooking pot or the vessel being used. The focal length of the cooker was selected depending on the concentration ratio C_r , optimum cooking temperature, T_R and oven collector efficiency. This can be done iteratively. The concentration ratio depends on the dimension of the cooking vessel. The point of placement of cooking vessel which should be within the area of the focal point can then be established. If the area of cooking vessel position is AV , concentration ratio C_r is given by

$$C_r = \frac{A_c}{A_v}$$

2.1 Thermal Insulation

In a cooker, input power (i.e. the radiation entering and been stored in the collector) increases and the cooker gets hotter than the surrounding environment but heat power is lost due to temperature difference as heat will flow to the lesser potential. Cooking occurs faster or at higher temperature if the heat loss is reduced [12]. Wall heat loss represents heat transfer through a material by virtue of a temperature difference between the inside (Cooking Volume) and the outside (Surroundings). For the following discussions, the temperature difference is called ΔT and the rate of heat loss is Q_{loss} (e.g. watts). The cooker wall area contributing to heat loss is A_s .

The heat loss rate is simply described as

$$Q_{\text{loss}} = A_s \frac{\Delta T}{R} = UA_s \Delta T$$

The quantity R is thermal resistance ($^\circ\text{C per } w/m^2$), and its reciprocal $M = \frac{1}{R}$ is called the conductance ($w/m^2 \text{ per } ^\circ\text{C}$).

Thermal resistance may be thought of as the ratio of temperature difference across the wall to the heat flux (w/m^2) through the wall.

3. Design and Construction

The materials for the design were sourced locally; these include Cardboard sheets, Aluminum foil, Glue, Plastic or Glass plate and Plywood. The designed solar box cooker has four reflector sides which has the advantage of concentrating more sunlight radiation into the inner cooking pot. The heat storage boxes were constructed with plywood painted in black in the inside and rectangular in shape. The smaller sized box is the inner box that defines the cooking area and the power of the cooker. The dimensions of the inner box are 24.5 by 24 by 27 cm, and a volume of 15876 cm^3 . The outer heat conservation chamber also made of plywood and painted in black in the inside in a rectangular shape and has the dimensions of 33.5 by 32.6 by 23.5 cm with a volume of 25664.35 cm^3 .

Other materials used in the construction of the solar box cooker include;

- i. One sheet of glass, which has almost the dimension of the inner box in area with the edges slightly greater in size than the box, which takes care of handling of glass during opening. The glass was framed with aluminum frame to mask its sharp edges.
- ii. One small Can of black paint.
- iii. Two meter sheet of aluminum foil (2 mm thick) and one roll of duty aluminum kitchen foil.
- iv. A cooking pot with size to fit into the inner box.
- v. Thick Cardboard paper used for the construction of the solar collectors along with the aluminum sheet.

The gap between the inner box and the outer box as well as the base of the inner box was filled with heat absorbing

materials such as stone pieces and chippins to act as heat storage materials in the box.

3.1 The Collector Design

The collectors were drawn out as shown in *Figure 1.a*, on a four flat piece, using cardboard sheet. The protractor was also used for measuring the edges at Angle 80°. The edges were marked with blunt point tool and cut out. This was used to cut out the same shape of the 2 mm aluminum sheets, bent, glue dried. Aluminum foil was rolled over the collector faces, cut to sizes and glued to improve the reflectivity of the collector surface. Screw nails were used to hold the lower collector faces on the outer box to enable the collectors to be tied unto them to prevent wind effect on the collector.

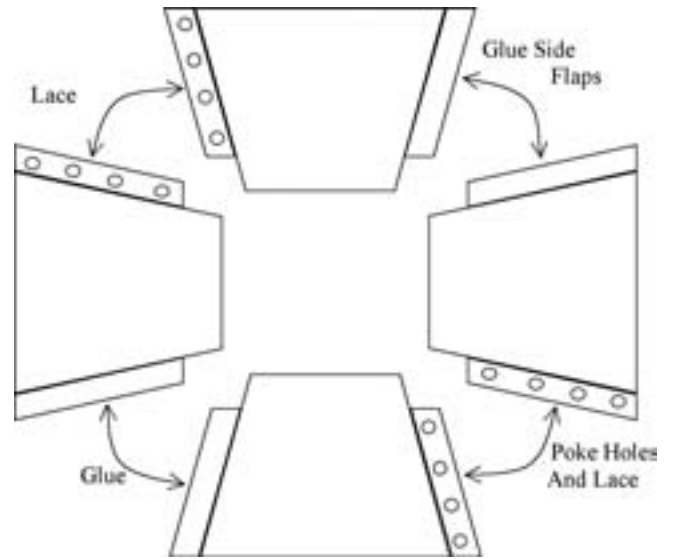


Figure 1.b: Collector Design and Construction.

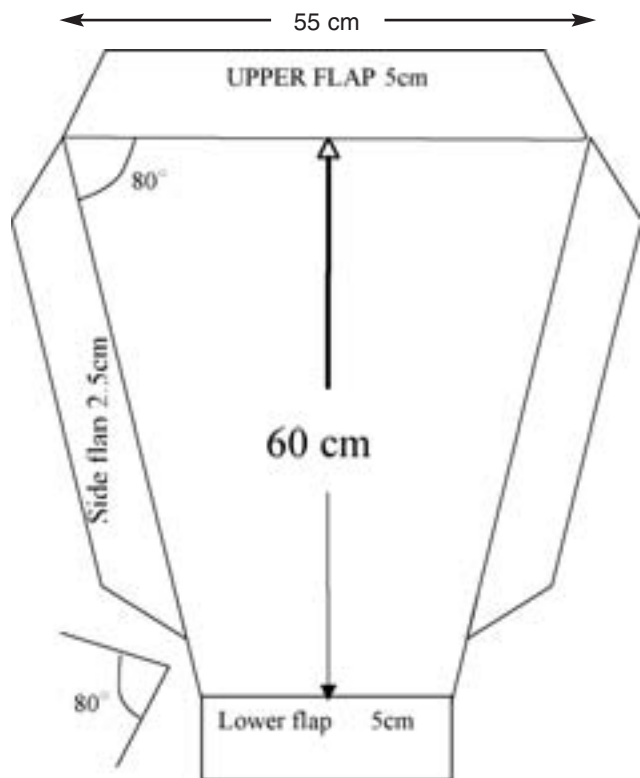


Figure 1.a: The pattern of the collector used in the design.

3.2 The Collectors Connection

The collectors were set out as they fit on the box and the side flaps glued together on two opposite corners until the glues dry. Holes were poked on the side flaps of the corners of the bent cardboard collectors and tied together with cotton cards. This makes the collectors detachable after use and could be safely folded together (see *Figure 1.b*). The solar box cooker designed to suit Nigerian and other countries is shown in *Figures 2.a* and *2.b* with detachable reflectors. One can cook a large number of food items such as rice, vegetable, soup, cereals etc., which are needed for our daily meals with the designed box cooker. It could be used to cook non-vegetable food items such as fish, chicken, meat etc.

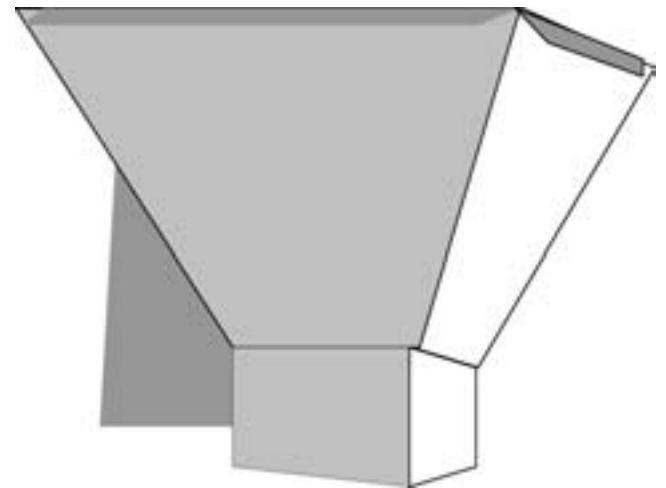


Figure 2.a: Side view of a Solar Box Cooker.

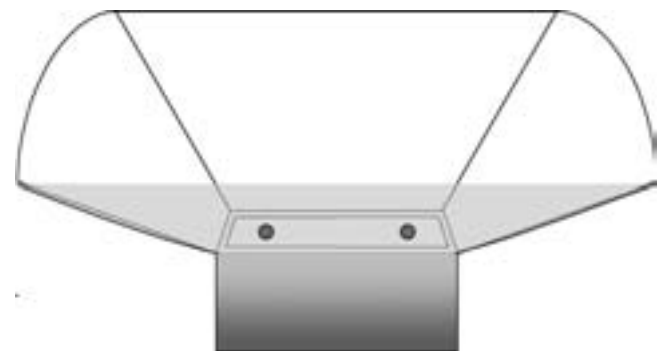


Figure 2.b: Inside view of Solar Box Cooker.

4. Results and Discussions

The Solar Box Cooker was displayed under the sun for three days to check its workability as well as check for the variation of temperature from late hours in the morning to late afternoon with the aid of inserted thermometer (0°C to 360 °C).

On the first day the box was displayed without solar collectors, and the differences in temperature observed inside the oven box were recorded. The second day witnessed the display of solar box with solar collectors, while on the third day the box cooker was displayed with both collectors and thermal mass heavy materials for heat storage. The observed different temperature ranges, along with time of the day were recorded. We present values of temperature and time obtained daily in **Table 1**.

TABLE 1. Table of values of temperature (degree Celsius) and time of observation in hours showing Day 1 without solar collectors, Day 2 with solar collectors only and Day 3 with both solar collectors and heat storage materials

S/N	Time in hours	Days of observation		
		Day 1 Without collectors and storage materials	Day 2 Without collectors only	Day 3 With both collectors and heat storage materials
		Temp°C	Temp°C	Temp°C
1.	8.00	40.0	45.0	40.0
2.	9.00	50.0	60.0	50.0
3.	10.00	60.0	70.0	60.0
4.	11.00	70.0	100.0	90.0
5.	12.00	75.0	110.0	100.0
6.	13.00	75.0	110.0	110.0
7.	14.00	75.0	110.0	110.0
8.	15.00	74.0	110.0	110.0
9.	16.00	74.0	110.0	110.0
10.	17.00	70.0	80.0	100.0
11.	18.00	55.0	70.0	90.0

From the data plotted, we observe that solar box cooker has limited temperature in the morning hours from 8.00 am to 10.00 am, of between 40°C and 70°C, which might not be good enough to boil water. However, the temperature begins to be enhanced from 11.00 am. It maintains slightly high temperature enough to cook food between the hours of 12.00 pm (noon) and 4.00 pm, up to 110°C before the heat starts to decrease due to sunset. This ensures that the best time to cook with the solar box cooker is between the hours of 11.00 am and 4.00 pm on sunny days (see **Figure 3**).

Results also show that addition of solar collectors to solar box cooker helped to intensify the heat and quickens the cooking rate. This is because the amount of the sun's radiation that would be collected with the help of the solar collector is greater than when it was exposed without the solar collector (see **Figure 3**, day 2 plot).

On the other hand, we observe that the solar box cooker maintains its heat for a longer period at the day's end, if heavy materials such as rocks, bricks etc are used as heat storage materials inside the box cooker (this is shown in **Figure 3**, day 3).

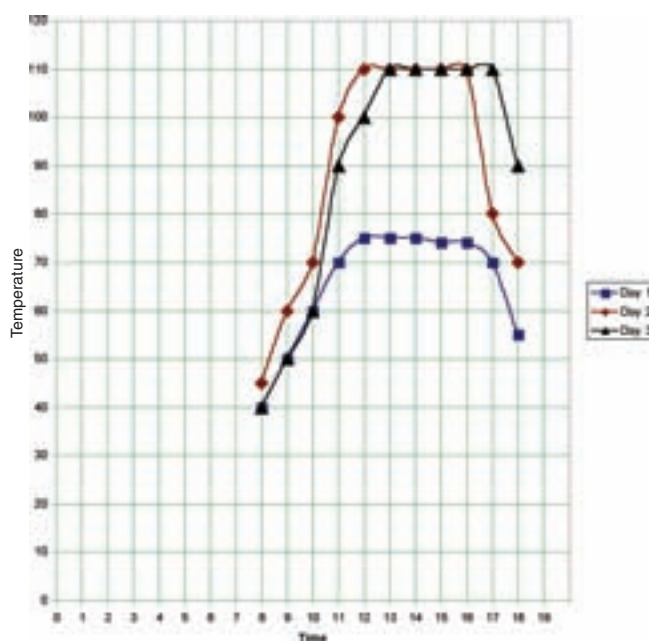


Figure 3. Cooking time versus Temperature of the box cooker
 a. Day 1, without solar collectors
 b. Day 2, with solar collectors only
 c. Day 3, with both solar collectors and heat storage materials

Conclusion

We have designed, constructed and tested a Heaven's Flame solar box cooker capable of cooking food in most tropical regions where the sun's radiation is abundant. Solar cooking enables individual families to do without commercially sold fuel and their cookers, as well as save money. Cooking with solar energy is clean, healthy and reduces the health hazards to which women are exposed to while cooking at a fire-place. Cooking with solar box cooker has to be done according to the sun's time (preferably 11.00 am - 4.00 pm), and is not possible on cloudy or rainy days or at night unless effective solar storage devices are incorporated.

Solar cooking is a delightful alternative to conventional cooking methods, hence, cooking is easy as there is no need to stir or watch over the food while it is cooked. However, developing countries such as Nigeria should borrow a leaf from the Indian and the Chinese governments and encourage alternative and renewable energy researches especially in the area of solar cooking as this also reduces fossil consumption for cooking purposes and help protect the environment. We should discourage sole dependency on petroleum products with its abundant green house gas emission into the air due to fossil fuel consumption.

References

- [1] Van Geel Pieter, "Energy for Development in the Real World", International Atomic Energy Agency Bulletin, 2005, 47 (1), 52-54.
- [2] Ashok Kundapur, India, webpage on solar cookers, http://ashokk_3.tripod.com.
- [3] Adeoti O., Oyewole B.A., Adegboyega T.D. "Solar photo-voltaic-based home electrification system for rural development in Nigeria". Domestic load assessment, Renewable energy, (2001), (241, 155-161). www.elsevier.nl/locate/renen.
- [4] Dixon A. E. and Lestie J. D. solar Energy Conversion. University of Waterloo. 1978.
- [5] Arinze E. A. and Obi S.E. solar Energy Availability; solar journal, 1984;3; 3-10.
- [6] Garba, B. Atiku, A. T and Sumbo, A. S. Comparative studies on journal of renewable energy, (1997), 5, 112-118.
- [7] Falade A., Talabi E. O, Akinsete V.A, Dasso F. F and Dejuwon A.A. A solar grain dryer for rural areas of Nigeria. Nigerian Journal of Solar Energy, (1985), 20-22.
- [8] I.O Popoola and J. D Ayanda. Design construction and study of performance of a conical solar concentrator. Nigerian Journal of Physics, (2005), Vol. 175, 275-284.
- [9] Ren H., Q.I.G Yang, T., Merg, L. and Zheng W. Solar Cooker. International Solar Energy Applications Training Workshop, GNERI, 1997; Lanzhon, China.
- [10] Chidi E. Akujor, Oluwasogo A. Ogungbenro, Gregory A. Alozie and Okey K. Nwafor. "A Nuclear Energy Option for Nigeria" Advances in Science and Technology, (2008), Vol.2, N° 2, 71-77.
- [11] Klaus Kuhnke, Marianne Reuben and Detlef Schwefel, Solar cookers in the third world, Friedr Veiweg and Sohn Braunsachweig/Wiesbaden, Germany, (1990), p. 228.
- [12] Pejack E. (Ed), Advances in Solar Cooking Proceedings at the first world conference on solar cooking, University of Pacific Stockton, California (1992).
- [13] Solar Cookers International U.S.A. Newsletter online, The Solar Cooking archives, (2004), www.solarcooking.org and www.solarcookers.org.
- [14] Shyam S. Nandwani (2005). My twenty five years of Experience with Solar Cooking in Costa-Rica - Satisfaction and Frustrations. Proceedings ISES, (2005). Solar World Congress, Orlando, U.S.A, p. 6.
- [15] ASHREA; Handbook of Fundamentals American Society of Heating Refrigeration and Air Conditioning Engineers. Inc, 1981, New York.
- [16] Hsieh, J. S. Solar Energy Engineering. Prentice Hall Inc. 1986; Englewood Cliffe, New Jersey.