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SOLAR OVEN MANUFACTURED FROM A EPS THERMAL BOX

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Abstract. *It presents a solar oven for baking food, manufactured from a thermal box of EPS. The solar oven proposed is a prototype of solar concentration for the operation of baking foods such as breads, cakes, pizza among others. The main innovation of the work is the use of EPS cooler, widely available, low cost and with a structure already defined and manufactured, avoiding the production of mold to get the box. It should be noted that the EPS thermal box is already a very efficient thermal insulator. This thermal property of the materials of the EPS box is important due to not require the use of insulating materials on the sides and bottom of the solar oven, to minimize heat losses. The inside of the box EPS enclosure baking oven, was coated on the bottom and side sheets by mirrors forming the profile which gives the greater concentration of solar radiation. Above the floor of the oven is system with plane mirror reflector, which moves according to the movement of the sun, directing the solar rays into the oven where the food displaced into the baking. We describe some aspects of construction and assembly of the solar oven proposed. Are presented results of tests that diagnose the viability of using the solar oven for several types of food. Compared are the times of baking food with those obtained for other types of solar ovens presented by solar literature, also as compared to gas conventional oven. Preliminary tests have shown the feasibility of using such solar oven, temperature levels being achieved adequate for the purpose proposed, affording the baking of various foods. The tests show that the solar oven reached the maximum temperature of 123.8°C and baking various foods such as pizza, lasagna, cake, bun, and other in an average time 50 minutes. Proved the feasibility of use of the oven proposed.*

Keywords: *solar, solar oven, EPS box, baking food, low cost.*

1. INTRODUCTION

The firewood is probably the oldest energy used by man and still has great Importance in the Brazilian energy matrix, participating with about 10% of primary energy production

About 40% of wood produced in Brazil is transformed into charcoal. The residential sector is the most expensive wood (29%). Usually it is for cooking food in rural areas. A family of eight requires Approximately 2.0 m³ of wood per month to prepare Their meals. The Industrial sector comes next with about 23% of consumption. The main industries that consume fuel in the country are food and beverages, ceramics and pulp and paper (National Energy Balance 2009 - www.mme.gov.br).

These data show the that massive use of wood, putting at risk the health of the planet, point to the need for a policy of mass use of solar cooker for cooking food as a way to preserve nature and Also to lessen the ecological imbalance the indiscriminate use of firewood, while Minimizing the emission of polluting gases into the atmosphere.

The use of solar energy for cooking and baking food is one of the oldest and spread this energy source, and its main characteristic its social function. It's wonderful to see that people in Africa use solar ovens and massively contributing to a policy of non-use of wood, Which Contributes to the environmental imbalance of our planet.

In the northeastern hinterland plagued by Droughts, the hinterland suffers from hunger and thirst due to inclement sunshine on Their barren lands. The use of solar ovens in the solar scrub promises to reverse or at least mitigate this situation by Allowing backcountry better living conditions.

It presents a solar oven for baking food, manufactured from a thermal box of EPS for the operation of baking foods such as breads, cakes, pizza among others. Are presented results of tests that diagnose the viability of using the oven / stove for several types of food.

2. REVIEW

The solar cooking food is one of the main research lines of the LMHES UFRN, having been the subject of numerous scientific papers published in various national and international conferences and eight Masters Dissertations. The following table shows the history of this line of research in LMHES.

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Souza in 1986 built a solar oven timber with four segments of steel together constituting the reflective surface that concentrated solar radiation and sent into the enclosure of the oven. It was demonstrated a low efficiency of the oven according to a level of absorptivity of stainless much larger than the mirror, despite its good reflectivity.

Souza, in 1994, built and studied two solar ovens with reflective surfaces of flat mirrors. The first solar oven was square with three sides in two segments of mirrors and the other was also square with three mirror segments, ranging from manual angle. The tests showed the viability of solar ovens for obtaining temperature levels absorbing surfaces of the ovens of above 130 ° C.

Melo, in 2008, presented Master's thesis, in PPGEM PPGEM-UFRN about a solar oven made from a conventional gas stove. The location of the burners, served as the venue for the oven and was covered by a glass slide for the generation of greenhouse gases and had his back and side isolated by a compound of plaster and Styrofoam. Plane mirrors was placed on the sides of the oven for the concentration of radiation and a parabolic reflector was introduced into the backing compartment for the use of the incident radiation reflected inside the oven. The absorption average temperature was about 150 ° C and the air in the interior in the oven was 120 ° C.

Souza et al., in 2008, presented in the VI CONEM a solar oven made from blocks of composite material. The oven was proposed with the bottom inside surface with a parabola shaped in manual process and mirrors coated in small pieces to increase its internal temperature. The blocks constituting the oven has low thermal conductivity, were lighter and showed good mechanical resistance. Above the furnace was located a parabolic reflector to concentrate the incident rays, sending them to the oven.

Gomes, in 2009, presented Master's thesis, in PPGEM PPGEM-UFRN about solar oven of low cost and easy operation for baking and cooking, built from a scrap tire. We studied three configurations, with two types of reflective parables. The supporting structure of the solar oven movements necessary to keep the apparent motion of the sun was made using a swivel chair scrap. There was obtained a maximum temperature at absorbent of around 160°C to about 120°C of internal temperature.

Souza et al., in 2009, presented at the 20th COBEM, a model of the solar oven for baking, constructed from the use of a composite material, which has in its composition the EPS ground. Were baked various foods, among them a cake, demonstrating the efficiency of the furnace proposed.

Souza et al., presented in 2011, at the 21th COBEM a model of the solar oven for baking, built from a scrap polyethylene drum. For presenting profile cylinder the focus of the parabolic reflecting was linear, allowing the use of up to three pans inside. The proposed solar oven was feasible for roasting operation, from 9:00 to 14:00 hours.

Souza et al., in 2011, presented at the 21th COBEM a solar oven for baking food, built from a box thermal EPS. The main innovation of this work was the use of Styrofoam cooler, widely-available, low cost and with a structure already defined and built, avoiding make a mold to obtain the box. The times for pizza and lasagna baking proved competitive with other models already tested and shown in the solar literature to food roasting.

Souza et al. in, 2012, presented at the VII CONEM a solar oven made from a scrap of freezer intended for baking foods such as pizzas, cakes, breads, lasagna and more. This oven provided the baking of various foods simultaneously. Were shown their thermal and economic viabilities, by getting of the cooking times competitive with other solar ovens already tested in the world, the high temperatures of the absorber and internal and its large area of reflection of solar radiation and consequent concentration.

Figure 1 shows the various types of solar ovens have already been manufactured and tested in LMHES / UFRN.

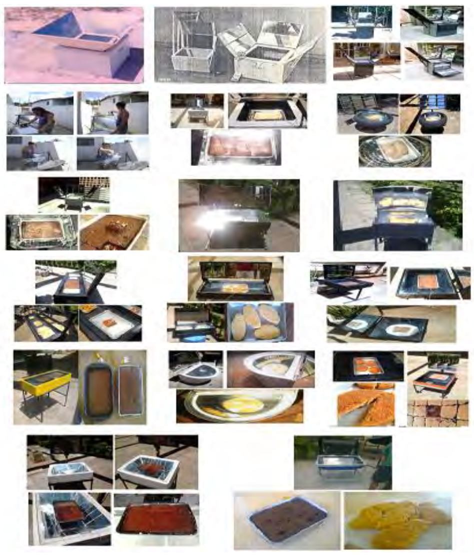

Figure 1. Solar ovens manufactured and tested in LMHES / UFRN.

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3. MATERIALS AND METHODS

The solar oven made from a scrap box EPS presented the following dimensions:
- external - Length: 0.74 m, width 0.56 m and height: 0.20 m;
- internal - length: 0.625 m, width: 0,44 m .

The outdoor area corresponded to 0.41 m² and the external volume 0,083 m³; internal area corresponded to 0.28 m². The area of the reflecting surface that lines the inner walls of the furnace corresponded to 0.36 m². The outer reflective surface presented a catchments area of solar radiation corresponding to 0.18 m². Figure 2 shows a schematic drawing of the solar oven, its components and their dimensions.

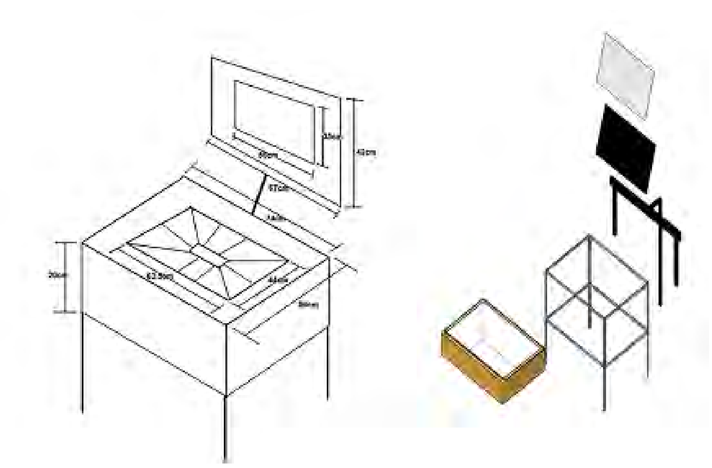

Figure 2. Schematic drawing of the solar oven, its components and its dimensions.

The enclosure of the oven was covered with a transparent flat glass of three mm thick. The glass is seated in the box and EPS moves to facilitate loading and unloading of food offered for cooking. The furnace structure was fabricated using angles and provides rotational movement to facilitate the handling of the oven.

Tests were performed without load for determining the temperature of the furnace box type solar studied. Temperatures were measured every five minutes or so. The tests were conducted for the period from 10:00 to 14:00 hours.

Tests were also performed to load the two baking pizza 400g, breaded chicken and 500g of a cake 700 g, determining the time required for this purpose. The same parameters were measured test without load for the same time interval. Were also measured temperatures inside the oven for evaluating the temperature difference between the base where is the food and the air around it. The temperatures of the internal air and base were measured with Chromel-alumel thermocouple Type K coupled to a digital thermometer.

The temperature data were measured with Chromel-alumel thermocouples, connected to a digital thermometer MINIPA MT-914 with read range from -70 ° C to 1200 ° C within 0,1 ° C and a maximum error in about 2.0%. The global solar radiation was measured by a solar station installed in LMHES UFRN. Figure 3 shows the solar oven in test.

Figure 3. Solar oven proposed in test in Solar Energy Laboratory UFRN.

3.1. Thermal balance of solar oven

The solar radiation incident enter in the solar oven in two ways: as global solar radiation incident on the glass cover and direct solar radiation reflected by the external mirrors. Much solar radiation as the direct solar radiation reflected by the mirrors external focus on the top of absorber shape and surface mirrored inside the oven The energy balance equations are presented below.

3.1.1 The energy that enters the solar oven (E_{ef})

The energy entering the solar oven in two forms: the solar radiation incident on the roof solar oven and solar radiation directly reflected in the outside mirrors located on top of the solar oven. Equation 1 shows the total energy entering the solar oven.

$$E_{ef} = E_g + \mathrm{E}_{\mathrm{re}} \tag{1}$$

E_{ef} = Energy that enters the solar oven (W); E_g = energy from the solar radiation that falls directly on the solar oven (W); = Energy of reflection of the mirrors of the upper solar oven (W).

To calculate the energy input in the solar oven using the equations 2 and 3 shown below.

$$E_g = I_g.\tau_v.A_v \tag{2}$$

$$E_{re} = I_d.\rho_e.\tau_v.A_v \tag{3}$$

I_g = instantaneous global radiation entering the solar oven = 1000 W/m²; I_d = instant direct radiation entering the solar oven = 800 W/m²; ρ_e = mirror reflectivity = 0.95, τ_v = glass transmissivity = 0, 85; Av = glass area = 00.28 m².

3.1.2. Energy lost by the side, bottom and the cover glass (E_{PF})

Considering the average temperature of the oven external surfaces was calculated convective heat loss from such surfaces and the ambient air. Ignored for radiation emitted to the external environment due to the low temperature gradient between the exchange surfaces. To calculate the convective exchange, used the equation 4. They performed several measurements in the temperature of the external surfaces for the period of highest incidence of solar radiation between 11 and 12 hours.

$$E_{pf} = Q_{convec} = h_c.A_{se}.(T_s - T_{amb}) \tag{4}$$

E_{PF} = Energy lost by the solar oven (W) h_c = transfer convective coefficient between the outer surfaces of the oven and air; A_{se} = area of the external surface of the oven temperature T_{se} =external surface of the solar oven; T_{amb} = ambient temperature.

3.1.3. Internal Efficiency solar oven (η_{if})

The internal efficiency solar oven will be calculated by the ratio between the energy absorbed and available inside the oven and the total energy entering the solar oven by equation 5.

$$\eta_{if} = (E_{abs} / E_{ef}) \tag{5}$$

Being:
η_{if} = internal efficiency of solar oven; E_{ef} = Energy that enters the solar oven (W); E_{abs} = Energy absorbed by the oven (W).

4. ANALYSIS OF RESULTS

Table 1 present the energetic contributions involved in the energy balance of the solar oven studied, and its thermal efficiency.

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Table1. Energies involved in the energy balance of the solar oven studied.

ENERGY	WATTS
Energy entering the furnace	418,9
Energy absorbed by solar oven	326,3
Energy lost by the solar oven	92,6
Internal Efficiency oven	77,9%

The efficiency of the solar oven studied was around 78%, since the energy lost corresponded to 22% of the energy that went into the baking enclosure of the oven. This efficiency demonstrates the wide feasibility study thermal solar oven, which resulted in the good efficiency of the insulation used. Subsequently, baking times proved also good thermal efficiency of the solar oven studied.

Table 2 shows the average results of the test evaluated the absorber temperature and the internal environment of the oven solar studied. The solar oven was placed on exposure to the sun 10:20 am. The average ambient temperature was 29 ° C and thermal sensation of 33°C during the test.

Table 2. Hourly average results of the test without load.

Time (hour)	**$T_{absorber}$ (°C)**	**$T_{internal}$ (°C)**	**I_g (W/m²)**	**I_d (W/m²)**
10:30	80	80	948	758,4
10:40	90	90	955	764
10:50	102	92	970	776
11:00	107	98	980	784
11:10	114	105	980	784
AVERAGE	**98,6**	**93**	**966,6**	**773,3**

The maximum temperatures in the absorber surface and internal air of solar oven corresponding to 114°C and 105° C, respectively, were significant and suitable to provide the baking of foods. The average temperatures for these parameters during the test duration, at around 102.4°C and 94.6 C, respectively, are also suitable for obtaining the desired end. The average ambient temperature was 29.5°C, the thermal sensation of 33.5°C, average humidity of 60%, the global solar radiation average of 966.6 W/m² and direct solar radiation average of 773.3 W/m².

Despite temperatures of the absorber surface and inside the oven being well below conventional gas oven with internal temperatures up to 250°C, solar ovens previously fabricated and tested reached levels similar to those achieved by the solar oven in the study and enabled the baking of foods.

Tests with box type solar cookers have already shown their greater viability for baking food. Then broke for testing for baking of some foods whose results are shown below.

A cake was baked and the results of the measured parameters in this test are shown in Table 3. The complete baking of the cake 700 was obtained in 45 minutes. The test was started at 11:15 hours. After placing the cake mixture in shaped the absorber temperature was of 40°C and the internal of the oven of 82°C. The environment temperature during the test was on average 30.5°C, the thermal sensation 35.3°C and relative humidity of 60%.

Table 3. Results of the measured parameters in the test to bake a cake.

Time (hour)	**$T_{absorber}$ (°C)**	**$T_{internal}$ (°C)**	**I_g (W/m²)**	**I_d (W/m²)**
11:15	40	82	980	784
11:20	50	85	980	784
11:25	57	77	980	784
11:30	66	86	977	781,6
11:35	57	76	960	768
11:40	80	69	940	752
11:45	84	75	920	736
11:50	85	72	880	704
11:55	88	82	880	704
12:00	83	74	880	704
AVERAGE	**69**	**77,8**	**937,7**	**750,16**

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Despite temperatures inside and base are well below the levels achieved in a conventional oven gas, again evidenced the viability thermal furnace proposed for obtaining the cake, baked in 45 minutes, long enough near the time needed to make the same food in a conventional oven. This is explained by the combination of energetic contributions of the greenhouse effect and concentration that leads to a condition suitable for obtaining the foods baking. Solar conditions were ideal for the use of prototype solar radiation global average around 940 W / m² and direct radiation average around 750W / m².

Other solar ovens tested had already baking time for the same cake found in the above mentioned experiment, similar to levels of radiation. It should be noted the cost-benefit study presented by the oven. Figure 4 shows the cake baked in the oven proposed.

Figure 4. Baking a cake in the oven solar study.

Another test conducted with the oven was baking a pizza. Table 4 shows the results of the temperatures inside the oven and the absorber, global and direct solar radiation. The test began at 12:10 hours. The temperature before placing the pizza were 41°C for the shaped temperature and 80 ° C to the air temperature inside the oven. The environment average temperature was around 30.8°C during the test, the thermal sensation of 36.4°C and relative humidity of 60%. The complete baking pizza happened in 15 minutes.

Table 4. Test results for baking a pizza in the oven solar proposed.

Time (hour)	**$T_{absorber}$ (°C)**	**$T_{internal}$ (°C)**	**I_g (W/m²)**	**I_d (W/m²)**
12:10	41	80	970	776
12:15	51	84	980	784
12:20	60	86	990	792
12:25	62	88	1000	800
AVERAGE	**66**	**84,5**	**985**	**788**

The internal temperature of the oven and of absorber were below achieved with a conventional oven gas. However, considering that the time of baking a pizza in a conventional oven gas happens in about 10 minutes, the solar oven built was feasible to bake this food, as provided in attached fifteen minutes of baking the pizza. In relation to that food was the oven that had the best results of all tested already in LMHES. It should be noted the excellent weather conditions for this test. Figure 5 shows the baking a pizza in the oven solar study.

Figure 5. Baking a pizza in the oven solar study.

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A third test was performed in the oven baking of chicken fingers, five units, each with a mass of 100g, 500g total. Table 5 shows the results of the temperatures inside the oven and absorber shaped. The test began at 12:30 hours. The temperatures of breaded before baking were 46°C for the absorber temperature and 71 ° C to the air temperature inside the oven. The average temperature was around 30.3° C during the test, the thermal sensation of 35.3°C and relative humidity of 60%. The complete baking the breaded happened in twenty-five minutes.

Table 5. Test results for baking fingers chicken in the oven proposed.

Time (hour)	**T** absorber **(°C)**	**T**internal **(°C)**	**I_g (W/m²)**	**I_d (W/m²)**
12:30	46	71	1009	807,2
12:35	56	73	990	792
12:40	61	75	980	784
12:45	65	77	970	776
12:55	70	79	960	768
AVERAGE	**59,6**	**75**	**981,8**	**785,4**

The internal temperature of solar oven and the absorber were once again well below achieved with a conventional oven gas. However, considering that the time of baking the batter in a conventional oven gas happens in about 15 minutes, the solar oven studied was feasible to bake this food, especially for its low cost. Solar radiation levels was of great magnitude, reaching maximum values for global and direct solar radiation above 1000e 800W / m², respectively. Figure 6 presents the breaded in the solar oven baking proposed.

Figure 6. Breaded chicken baking in the oven solar study.

For the diagnosis of thermal loss from the oven temperatures were measured from their outer surfaces. Figure 7 shows the mean values of temperatures measured during the test without load at 11 hours.

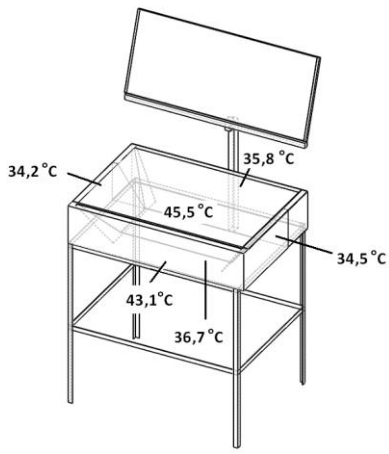

Figure 7. Temperatures on the external surfaces of the oven.

Levels of external temperature of the solar oven studied demonstrated its low thermal loss, as evidenced by low time for baking foods tested, competitive with solar ovens solar pointed out the literature for baking foods and even conventional ovens with gas.

Table 6 presents the average parameters of the oven for all foods tested.

Table 6. Average parameters measured in the tests for baking food.

FOOD	Mass (g)	Baking time (min)	T_{abs} (°C)	T_{int} (°C)	I_g (°C)	I_d (°C)
PIZZA	460	15	66	84,5	985	788
CAKE	700	45	69	77,8	937,7	750,16
STEAKS	500	25	59,6	75	981,8	785,4

The baking time for the oven studied obtained are inferior to all other versions already tested in LMHES / UFRN. The mirroring procedure with profiles stepped produced a higher concentration of rays inside the oven and being absorbed by the absorber shaped led to a higher rate of heating of food. It's baking time to solar conditions excellent were comparable to those obtained for the conventional oven gas, mainly for the cake. Table 7 presents the cooking time for some ovens and tested for the conventional oven gas and its values confirm the performance of the solar oven stud mainly by two factors greater concentration of radiation in the bottom of the absorber and a higher thermal insulation by your box is made of a material of very good thermal insulation.

Table 7. Average parameters measured in the tests chosen for baking food.

FOOD	Mass (g)	Baking time (min)	Baking time others ovens (min)	Baking time gas oven (min)	T_{int} (°C)	T_{abs} (°C)	I_G (°C)	I_D (°C)
PIZZA	460	20	15 a 30	10 a 15	78,9	90,6	841,4	673,12
CHEESE BREAD	400	80	60 a 80	30 a 40	85	84,7	773	618,4
NUGGETS	300	30	25 a 35	10 a 20	76,7	83,7	921	736,8
CAKE	700	50	60 a 80	40 a 45	90,4	91,4	928	742,4
KIBES	500	60	50 a 80	30 a 40	74	83,6	1006	804,8
STEAKS	500	35	30 a 40	20 a 25	67,6	65,9	841	672,8
LASAGNA	650	60	60 a 80	40 a 45	66,7	87	907	725,6

5. CONCLUSIONS AND SUGGESTIONS

1. The proposed solar oven itself proposed feasible to bake food from 9:00 am to 2:00 pm under solar conditions good;
2. The solar oven has become competitive with conventional gas oven;
3. The solar oven was studied that had easy assembly and manufacturing processes, manufacturing technology and can be passed on to needy communities;
4. The proposed solar oven has a good cost-benefit ratio for its low manufacturing cost;
5. The solar oven studied showed the best results for the baking of food among all solar ovens manufactured and studied in LMHES / UFRN;
6. The cooking times of foods tested are comparable with those presented in the literature for solar cooking food;
7. All food baked in the oven had proposed solar cooking times competitive with conventional oven and gas were lower than the time indicated by the literature for solar cooking food. The proposed solar oven was more competitive with conventional gas oven for baking a cake;
10. It is important to have another conventional source for cooking food to replace the proposed solar cooker on days with insufficient solar conditions for its use.

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