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SOLAR OVEN MANUFACTURED FROM A DRAWER SCRAP

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Abstract. *It is presented a box type solar oven made from a wardrobe drawer. The main characteristics of the manufactured oven are its low cost, the reuse of materials, easy manufacturing and assembly processes and, furthermore, simple operability. The knowledgment involving manufacturing and operation of the studied oven can be passed on to people of any social and intellectual levels. The optimal spacing between the absorber surface and the glass cover of the oven was studied, taking into account the convective and radiative coefficients, and the height that provided the better efficiency to the oven was determined. Spacings of 10, 9.0 and 8.0 cm were tested. Parameters such as internal and of the absorber temperatures, heat loss and efficiency were analyzed, using a 750 g cake for the intended diagnostic. It was shown that the optimal spacing corresponded to 7.0cm. The feasibility of using the oven to produce the baking of the tested foods has been demonstrated, being a cake baked in 45 minutes in excellent solar conditions, a time that is competitive with the one obtained in a conventional gas oven.*

Keywords: *solar energy, solar oven, box type, baking foods, low cost*

1. INTRODUCTION

About a third of the world population (more than two billion of people) relies on the use of the firewood to supplement their energy needs for cooking of food and heating. This result in a large-scale deforestation, generating desertification and ecological unbalance and causing hunger, poverty and social inequality in the poorest population.

It is unacceptable to continue using firewood when it has available the gas, which generates much less damage to the environment. But the poor population of underdeveloped countries and even developing not have the resources to buy canisters. This happens in the 21st century.

This energy has being named “energy of the poor”, because it’s an energy source of low cost, don’t need to be processed before use and also because it be significant part of the energetics base of the developing countries. It can represent up 95% of the energy in some countries. In industrialized countries, the firewood contribution reaches a maximum of 4%, except in Finland and Sweden where the share of biomass reaches 20.3% and 16.9% respectively (INTERNATIONAL ENERGY AGENCY-IEA, 2006a and 2006b). In the residential sector, half of the families in the world still use firewood or charcoal for cooking and heating. In 2004, this represented 825.72 Mtep, corresponding to 10.8% of total energy consumption, or the 78.8% of the consumption of renewable fuels and waste (INTERNATIONAL ENERGY AGENCY-IEA, 2006a).

These data show the large use of the firewood as a major environmental issue currently being evaluated, thus pointing to the need for a mass policy of using the solar oven for cooking foods.

In the last national energy balance it was found that Brazil consumes 12,989 x 103 tons of equivalent oil for the cooking of food, which in addition to natural gas and LPG are included firewood and charcoal, (Energy Research Company **-** EPE, 2014).

.Solar cooking is an alternative to alleviate these serious problems in the use of firewood and charcoal. The technology required for cooking of food by energy solar is already dominated for decades. It would be possible to extend it to all the poor of our country and from other underdeveloped or developing countries.

This paper presents a solar oven to produce the baking of foods that was made from the use of a wardrobe drawer in disuse. The transformation processes of the drawer in a solar oven will be described and the manufacturing and assembly processes of all its elements will be also described. Different heights between the absorber surface and the glass cover, correspondents to 80, 90 and 100 mm, will be studied in order to determine which height provides greater thermal efficiency.

The main characteristics of manufactured oven are its low cost, the reuse of materials, easy manufacturing and assembly processes and simple operability. The manufacturing and the operation of the studied ovens can be passed on to people of any social and intellectual levels.

The proposed oven is intended for domestic use in rural and urban areas, in the period 10h to 14h, for the operation of baking foods as breads, cakes, pizzas and more. The materials used in the solar oven are low cost, enabling its use by disadvantaged sections of the population, making it an element of social promotion and combating ecological imbalance. Technological transfer of manufacturing and assembly processes of such oven can be seen as an option to generate employment and income for poor communities, socializing the use of clean and renewable energy source.

2. MATERIALS AND METHODS

For the manufacture of the proposed oven was used a drawer of a wardrobe in disuse. Initially, the internal and external surface of the drawer was cleaned and sanded. Thereafter, its external surface was painted in order to protect it from inclement weather, and the internal part of the oven walls was coated with polystyrene (EPS). Subsequently, the absorbing surface of the oven was made using a painted aluminum sheet in black color. To complete the manufacture of the proposed equipment, the coverage was made using a transparent glass sheet that was placed on top of the drawer.

In order to direct the rays from direct solar radiation to the oven interior it was used a reflecting surface, mirror blade with 3mm thickness, located above the oven coupled to a support that, besides supporting the oven, it allows the mirror adjustment in the ideal inclination, leading the reflected rays into the oven, focusing on the food.

The manufacture of this solar oven was carried out, basically, in five steps: preparation of the oven, the thermal insulation installation, production of the absorbing surface, preparation of the glass cover and positioning of the oven on the support. The Figure shows some steps of the manufacture and assembly processes of the proposed solar oven.

Figure 1. Manufacture and assemble processes of the studied solar oven

2.1 Experimental Procedure

Tests performed with the oven in question occurred in days with similar solar conditions, so that the results could be compared. The tests were started around 10:00 am and ended around 12:20 pm.

On each day the oven was tested with a different configuration, by varying the distance between the absorbing surface and the glass cover. On the first day the oven was tested with a spacing of 100 mm between the absorbing surface and the glass cover. On the second day was placed an EPS board with a thickness of 10 mm between the oven bottom and the absorbing mold, with the intention of reducing to 90 mm, the distance between the absorber and the glass cover. On the last day of testing was conducted the same procedure, adding another 10 mm EPS board, reducing this dimension to 80 mm. These settings are shown in Figure 2.

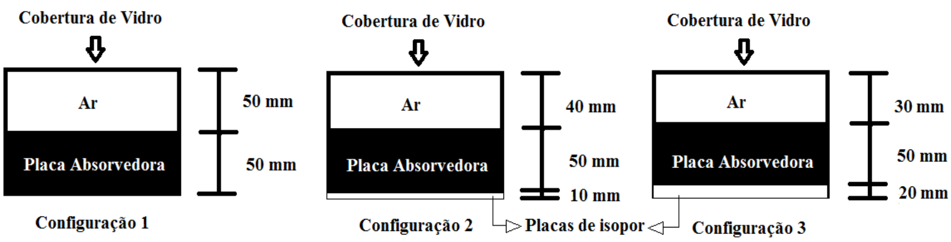

Figure 2. Configurations tested with the solar oven

The oven was initially tested without load, remaining exposed to sunlight for about a period of one hour. This was done so that there was enough time for the oven to come into steady state operation. During this period, the temperatures of the absorber and the air were measured and recorded.

When the oven has reached its maximum temperature and entered steady state operation, the load was added therein, which consisted of a cake of 750g for the three cases. During the time that the oven was tested with load, approximately 50 minutes, the temperatures of the absorbing surface and the air were also measured, with the same purpose of comparison of obtained data. In Fig. 3 it is possible to see the solar oven in operation for a test with and without load.

Figure 3. a) Test without load; b) Test with load.

The temperature of the absorbing surface and air within of the oven were recorded in five minute intervals. This was done using thermocouples of the type K (Chromel/Alumel) coupled to a digital thermometer of the ICEL brand, model TD-880 with reading range -100 to 1300ºC and precision of ± (0.7 ° C + 0.1% rdg). Besides these, were also measured the temperatures of the external surfaces of the laterals and cover of the oven in order to subsequently evaluate the thermal losses of the system to environment. These measurements were performed using a Infrared portable digital thermometer of the HIGHMED brand, HM-88C model, temperature range -50 ° C to + 550 ° C, 0.1 ° C resolution and precision of ± 2.

The data of global solar radiation were measured by a Davis - Envoy Weather Station installed on LMHES / UFRN. The equipment, which is installed in the laboratory roof, transfers the readings in 30-minute intervals to a receiver that is connected in a computer, making it possible to keep records of readings performed by the measuring instrument.

2.2 Thermal Balance of the Solar Oven

The incident solar radiations on the glass cover of the oven and on the mirrors of the support enter in the solar oven in two ways: as incident global solar radiation on the glass cover and reflected direct solar radiation by the mirror, as outlined in the Figure 4.

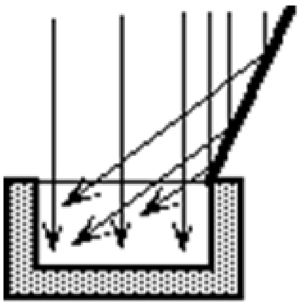

Figure 4. Solar radiation global and direct that focus on the glass cover of the solar oven.

The equations that were using in the energy balance performed on the equipment in question to determine their thermal efficiency will be presented.

2.2.1 Energy that enters in the Solar Oven (E_e)

The total energy that enters in the solar oven consists of the global solar radiation and reflected direct solar radiation by the mirror. This can be expressed by Eq. 1.

$$E_e = E_g + E_r \tag{1}$$

Where: $\boldsymbol{E_e}$ = energy that enter in the solar oven [W]; $\boldsymbol{E_g}$ = Energy from the direct global solar radiation incident on the oven [W]; $\boldsymbol{E_r}$ = Direct energy from of the mirror reflection [W].

The energy E_e and E_r are determined through the Eqs. 2 and 3.

$$E_g = I_g.\tau_v.A_{glass} \tag{2}$$

$$E_r = I_d.\rho_e.\tau_v.A_{mirror} \tag{3}$$

Where: $\boldsymbol{I_g}$ = Global instantaneous radiation that enters in the solar oven; $\boldsymbol{I_d}$ = Direct instant radiation that enters in the solar oven; $\boldsymbol{\rho_e}$ = Mirror reflectivity of the support; $\boldsymbol{\tau_v}$ = Glass transmissivity of the oven cover; $\boldsymbol{A_{glass}}$ = Glass area of the oven cover; $\boldsymbol{A_{mirrors}}$= Reflective surface area.

2.2.2 Energy Lost by Solar Oven (E_p)

Considering average temperatures on the external surfaces of the proposed solar oven, it is possible to measure the heat loss through these surfaces. Such losses are radiative and convective origin between oven cover glass surface and the environment air and only of convection origin between the external walls of the oven and environment air. In addition to these losses, there is also the loss through of the oven floor, but due to the fact that this surface is insulated with a thick layer of EPS, it is considered that this loss is negligible. Eq. 4 expresses the sum of losses related to glass and sides.

$$E_p = E_{pv} + E_{pl} \tag{4}$$

Where: $\boldsymbol{E_p}$ = Energy lost by solar oven [W]; $\boldsymbol{E_{pv}}$ = Energy lost by solar oven through the glass [W]; Epl = Energy lost by the solar oven through of the sides [W].

The energy lost through of the ($\boldsymbol{E_{pv}}$) and the energy lost through each one of the four sides of the solar oven ($\boldsymbol{E_{pl}}$) can be calculated through of the Eqs. 5 and 6, respectively.

$$E_{pv} = (h_{r(ve-a)} + h_{c(ve-a)}).A_{glass}.(T_{ve} - T_a) \tag{5}$$

$$E_{pl} = \sum_{n=1}^{4} h_{c(lat,n-a)} \cdot A_{lat,n} \cdot (T_{lat,n} - T_a) \tag{6}$$

Where: $\boldsymbol{h_{r(ve-a)}}$ = Heat transfer coefficient by radiation between the external surface of the glass and the environment air [W/m².K]; $\boldsymbol{h_{c(ve-a)}}$ = Heat transfer coefficient by convection between the external surface of the glass and the environment [W/m².K]; $\boldsymbol{h_{c(lat,n-a)}}$ = Heat transfer coefficient by convection between the nth side wall of the oven and environment [W/m².K]; $\boldsymbol{T_{ve}}$ = Average temperature of the glass external surface [K]; $\boldsymbol{T_a}$ = Environment temperature [K]; $\boldsymbol{A_{lat,n}}$ = Area of the nth side wall of the oven [m²]; $\boldsymbol{T_{average\ lat}}$ = Average temperature of the nth side wall of the oven [K].

The heat transfer coefficient by radiation between the external surface of the glass and the environment, according to Duffie & Beckman (1991), is a function of the climatic conditions of the location considered and can be determined through Equation. 3.7.

$$h_{r(ve-a)} = 5{,}16.10^{-8}\,\frac{(T_{ve}{}^4 - Tsky^4)}{(T_{ve} - T_a)} \tag{7}$$

Where: $\boldsymbol{T_{ve}}$ = Temperature of the glass external surface [K]; $\boldsymbol{T_{sky}}$ = Sky temperature [K]; $\boldsymbol{T_a}$ = Environment temperature [K].

The value of T_{sky} can be obtained from Ta, using Equation 8.

$$T_{sky} = 0{,}0552.T_a^{\;1{,}5} \tag{8}$$

Heat transfer coefficients by convection between the external surface of the glass, the oven sides and the ambient air can be calculated through various correlations present in the literature or numerically, using techniques such as Computational Fluid Dynamics (CFD).

2.2.3 Thermal Performance of the Solar Oven (η_t)

The thermal efficiency of the solar oven is calculated through of the ratio between the absorbed energy by the solar oven and the total energy that enters in it. Furthermore, the absorbed solar energy is obtained through of the difference between the energy that enters in the solar oven and the energy lost by it. Thus, the thermal efficiency of the solar oven (η_t) can be calculated by the Equation. 9.

$$\eta_{if} = \left(\frac{E_{abs}}{E_e}\right) = \left(\frac{E_e - E_p}{E_e}\right) \tag{9}$$

Where: $\boldsymbol{\eta t}$ = Thermal efficiency of the solar oven; $\boldsymbol{E_{abs}}$ = Absorbed energy by the solar oven [W].

3. RESULTS AND DISCUSSIONS

Below the results of the tests conducted with the solar oven, of the simulation and of the thermal balance and some discussion about them are presented.

3.1 Obtained data with the oven tests

The tests on the first day were performed between 10:00 am and 12:00 pm. The oven was exposed to the sun without load and at 11:10 am, the time that the oven temperature reached 130.3 °C and 99.3 °C in the absorber surface and the air, respectively, the load was added. The tests on the second day occurred between 10:45 am and 12:40 pm. Again the oven was exposed to the sun with no load and at 11:50 am, when the oven has reached temperatures of 125.3 °C and 107.3° C on the absorber surface and the air, respectively, the load was added. On the last day, the tests were performed between 10:00 am and 11:50 am. The same procedure of the preceding tests were performed and temperatures of 143.0 °C and 115.6 °C on the absorber surface and the air, respectively, were recorded immediately before adding the load to the oven.

Table 1 presents, in a more detailed way, the obtained parameters during the tests with and without load, such as the behavior assumed by these parameters.

Table 1. Obtained data of the tests with and without load.

Teste 1			Teste 2			Teste 3		
Hora	Tabs	Tint	Hora	Tabs	Tint	Hora	Tabs	Tint
10:00	-	-	10:45	-	-	10:00	-	-
10:05	96	70,8	10:50	88,7	68,4	10:05	75,6	60,7
10:10	106,5	80,5	10:55	105,5	84,2	10:10	102,6	81,6
10:15	111,9	84,5	11:00	114,5	94,3	10:15	120,0	98,0
10:20	116	88,4	11:05	-	-	10:20	129,8	105,7
10:25	106,5	86,8	11:10	126	107,3	10:25	135,8	116,4
10:30	119,6	93,9	11:15	127,6	107,9	10:30	137,3	117,9
10:35	122,4	96,4	11:20	124,6	103,3	10:35	141,4	113,3
10:40	122,6	96,2	11:25	127,7	105,7	10:40	142,2	112,3
10:45	125,8	100,9	11:30	129	107,4	10:45	141,8	113,0
10:50	126,8	99,7	11:35	126,2	105,2	10:50	142,4	114,7
10:55	127	96,2	11:40	126,4	105,0	10:55	143,0	115,8
11:00	120	91,7	11:45	126,7	106,2	11:00	143,1	115,1
11:05	126,4	97,1	11:50	125,3	107,3	11:05	143,0	115,6
11:10	130,3	99,3	-	-	-	-	-	-

Teste 1			Teste 2			Teste 3		
Hora	Tabs	Tint	Hora	Tabs	Tint	Hora	Tabs	Tint
11:10	84,7	74,8	11:50	52,5	71,5	11:05	60,6	83,5
11:15	66,8	69,7	11:55	51,9	68,2	11:10	65,5	83,7
11:20	67	71,2	12:00	59,3	65,7	11:15	69,7	81,3
11:25	68,9	69,1	12:05	70	63,5	11:20	75,3	85,4
11:30	73,7	71,5	12:10	74,1	68,5	11:25	79,8	86,2
11:35	76,2	73,3	12:15	74,6	73,8	11:30	84,1	89,6
11:40	78,7	76,8	12:20	79,4	75,8	11:35	88,2	90,1
11:45	81,9	83,2	12:25	83,2	78,8	11:40	90,1	90,3
11:50	84	85	12:30	84,5	82,5	11:45	93,8	91,5
11:55	85,3	86,1	12:35	86,9	81,6	11:50	94,3	93,5
12:00	85,4	83,9	12:40	83,8	78,6	-	-	-

The highlighted values are the temperatures in the absorber and in the air immediately before and after the addition of the load. It was observed in both types of tests that in some intervals of time the temperature decays instead of keep rising as expected. This can be explained by the fact that during the tests some clouds partially blocked the sun's rays, which reduced the energy received by the oven. It is also worth noting the load baking time, which was 45 minutes to setting 3 and 50 minutes to the settings 1 and 2. Thus, even before the thermal balances were held, there was already a suspicion that this would be the optimal configuration.

In addition to these temperature values, the temperatures at the four sides and at the oven glass cover at three points were also measured for each test. The mean values for each parameter were subsequently used for the computational analysis stage. Table 2 show average temperatures and areas for the solar oven surfaces

Table 2. Average temperatures and areas for the oven surfaces.

Temperaturas Médias [°C]				Área [m²]
	Teste 1	Teste 2	Teste 3	-
Vidro	70,29	83,87	74,3	0,31
Lateral Norte	50,13	44,9	44,9	0,12
Lateral Sul	57,47	57,4	46,9	0,13
Lateral Leste	46,57	44,7	44,5	0,10
Lateral Oeste	51,97	45,8	45,4	0,10

It was noticed that the day of testing with better solar conditions was the one for test 2. However, as has been said, the setting that took less time to bake the 750 grams cake was the third one. This suggests that, if the test 3 had been carried out under the same conditions as day 2, the baking time would be even lower, which increases the probability that this is the most efficient configuration. Table 3 show average meteorological parameters measured in each test.

Table 3. Average meteorological parameters measured in each test.

Teste 1			
Radiação	Umidade Relativa	Sensação Térmica	Temperatura Ambiente
588,18	65,09	35,17	30,56
Teste 2			
Radiação	Umidade Relativa	Sensação Térmica	Temperatura Ambiente
848,54	65,09	40,27	32,52
Teste 3			
Radiação	Umidade Relativa	Sensação Térmica	Temperatura Ambiente
653,6	62,86	37,24	31,66

3.2 Numeric Simulation

From the data collected with the tests, three computational analysis, one for each setting, were performed in order to obtain necessary parameters for the thermal balance of the proposed equipment. For this stage, Ansys CFX 14.0, a Computational Fluid Dynamics (CFD) commercial package was used. The main purpose of developing the mentioned computer simulations was to analyze the temperature profile that develops in the air present in the vicinity of the equipment in question and to obtain the actual values of convective heat transfer coefficients on the surfaces of the oven for each one of the tests. With these values of coefficients it was possible to calculate the convective heat losses through the sides and glass cover of the oven.

The first step was to design the proposed oven and a 5 m³ volume to represent the surrounding air in a CAD (*Computer Aided Design*) software. After that, the geometry was imported to Ansys CFX and was discretized in small volumetric elements to compose the computational mesh.

The next step was to set the initial and boundary conditions. This procedure was performed for each one of the three cases. The inferior face of the cubic volume, representing the floor, was treated as a no slip wall. The other surfaces were considered as openings. The adopted environment temperature was an average of the temperatures obtained with the meteorological station installed in LMHES/UFRN. The EPS bottom was treated as an adiabatic no slip wall. The oven sides and glass cover were considered as no slip walls with prescript temperatures. The imposed temperatures were an average of the temperatures that were measured in different points. As a first result of the computational simulations, the temperature profile of the air surrounding the oven is obtained. This profile is represented in Figure 6.

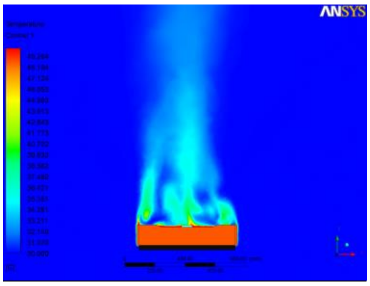

Figure 6. Temperature profile of the computational domain in a XY plane

It can be noted that the heat transfer phenomena that is present is the natural convection. When the surrounding air comes into contact with the heated walls of the oven, due to the conduction heat, exchanges heat with them, heats and tends to follow an ascending trajectory due to the decrease of its density.

In each one of the sides and the glass cover, this heat transfer process is associated with a different convective coefficient, since the heat loss is different. Through the Ansys CFX function calculator this coefficients could be obtained and are organized in Table 5.

Table 4. Convective coefficients of each one of the surfaces for the three performed tests

Coeficientes Convectivos [W/m².K]			
	Teste 1	Teste 2	Teste 3
Vidro	7,34	9,73	9,02
Lateral Norte	2,73	1,04	0,28
Lateral Sul	3,08	0,70	1,14
Lateral Leste	3,14	2,25	2,42
Lateral Oeste	3,67	2,68	3,05

3.3 Energetic Balance of the Oven

From the results obtained in the tests and computer simulations it was possible to use the presented equation to calculate the energies received and lost by the oven and its thermal efficiency on each test day. Table 5 shows the parameter values that were used for the heat balance and Table 6 the energies of the thermal balance and furnace efficiency for each configuration.

Table 5. Parameter used for the thermal balance calculation

	Teste 1	Teste 2	Teste 3
τv	0,85	0,85	0,85
ρe	0,95	0,95	0,95
Aesp [m²]	0,23	0,23	0,23
Ig [W/m²]	953	871	946
Id [W/m²]	762,4	696,8	756,8
hr(ve-a) [W/m².K]	8,61	8,72	8,66

Table 6. Energetic contributions and oven efficiency for the three tests

Teste 1	Energia [W]	Porcentagem [%]
Ee	392,71	100
Epv	196,44	50,02
Epl	30,08	7,66
Eabs	166,19	42,32
ηt	-	42,32
Teste 2	Energia [W]	Porcentagem [%]
Ee	358,92	100
Epv	293,7	81,83
Epl	10,11	2,82
Eabs	55,11	15,35
ηt	-	15,35
Teste 3	Energia [W]	Porcentagem [%]
Ee	389,83	100
Epv	206,08	52,86
Epl	9,24	2,37
Eabs	174,51	44,77
ηt	-	44,77

It was observed that the configuration that is more efficient was the third. It is worth noting that the majority of the thermal losses of the equipment occurred through the glass cover, because this component is separated from the absorber plate by small heights. This makes the convective and radiative exchanges intensify, raising the glass temperature. The heat loss occurring predominantly in the glass cover indicates that the insulation in the oven sides was effective.

4. CONCLUSIONS AND SUGGESTIONS

- ✓ The proposed solar oven was feasible to produce the baking of the tested food, being able to reduce fossil fuel costs and minimize damage to the environment;

- ✓ The optimal configuration was obtained with the spacing of 80 mm, for which the thermal efficiency was 44.77%;
- ✓ The oven is capable of baking from 10:00 am to 14:00 pm, under good solarimetric conditions;
- ✓ The food baking times were competitive with the ones of conventional gas ovens;
- ✓ The temperature levels obtained were consistent with those found in other solar ovens already studied and reached levels close to those obtained with conventional gas ovens (around 140 ° C);
- ✓ Test the oven with a larger load, in order to evaluate its performance;
- ✓ Keep a conventional source of baking to replace the proposed solar oven;
- ✓ Test other food types to expand the usability of the prototype.

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