SOLAR OVEN/COOKER MANUFACTURED FROM A BOX OF EPS (ISOPOR)

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Abstract. *It presents a solar oven / cooker for baking, and cooking, manufactured from a thermal box of EPS. The solar oven/cooker proposed is a solar prototype of concentration average for household in rural and urban, from 9:00 to 14:00 hours, mainly 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, because the conductivity of EPS correspond to 0.03 W/ m °C. This thermal property of the material of the EPS box is extremely important due to not require the use of insulating material on the sides and bottom of the solar oven / cooker, to minimize heat losses. Another innovation is the design and construction of a new system profile reflector to direct sunlight into the oven / stove. This system presents a profile that approximates a parabola, increasing the capitation and reflection area of radiation of rays into the oven / cooker. We describe some aspects of construction and assembly of the solar oven / cooker proposed, whose main characteristic of its low cost and is intended for low-income population, to avoid the use of firewood as damaging to the environment. Are presented results of tests that diagnose the viability of using the solar oven / cooker for several types of food. Are compared the times of cooking and baking food with those obtained for other types of solar ovens/cookers presented by solar literature.*

Keywords*: solar energy, solar oven / cooker, 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 (National Energy Balance, 2009 – www.mme.gov.br).

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.

These data show the 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, 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 significantly 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 oven/cooker in caatinga promises to reverse or at least mitigate this situation by allowing backcountry better living conditions.

This paper presents a model of a solar oven/cooker for food baking and cooking, building on the use of a EPS thermal box. The solar oven / cooker proposed is a prototype of solar concentration for the average household in rural and urban, from 9:00 to 14:00 hours, mainly for the operation of cooking foods such as breads, cakes, pizza among others.

The main innovation of the work is the use of Styrofoam cooler, widely available, low cost and with a structure already defined and built, avoiding the production of mold to get the box. It should be noted that the ice chest is already a very efficient thermal insulator, because the conductivity of EPS correspond to 0.03 W / m ° C. This thermal property of the material of the furnace is extremely important due to not require the use of insulating material on the sides and bottom of the solar oven / cooker, to minimize heat losses.

Another innovation is the design and construction of a new system profile reflector to direct sunlight into the solar oven /cooker. This system presents a profile that approximates a parabola, increasing the catchment area of radiation and reflection of rays into the solar oven / cooker.

2. REVIEW BIBLIOGRAFIC

Since ancient times people use the sun's energy to heat water, dry fruits and cooked vegetables. The first solar cooking with modern technology is attributed to Franco-Swiss Suassure of Horace, who built a small box solar energy, among other inventions related to this energy source. The solar kitchen Horace consisted of two boxes of pine wood, one inside the other, insulated with wool and had three cover glasses.

The British astronomer John Herschel used a solar kitchen of his invention during his trip to South Africa in 1830.

Also in the nineteenth century, Adams experimented with solar artifacts in India very successfully. By the year 1860, Mouchot, Algeria, cooked with a curved reflector, concentrating the sun's rays over a small saucepan.

In 1881 Samuel P. Langley used a solar cooking during the ascent to Mount Whitney in the United States.

Charles Abbot drew a mirror concentrator and achieved the same temperature around 200 ° C. Heated oil, retaining some of the heat for several hours after sunset, getting some food to cook at night.

With the arrival of the twentieth century the massive use of fossil fuels, but also the possibility of obtaining relatively cheap and abundant energy in almost all sections of the population, the industrialized world has forgotten the old, simple and natural techniques. Only in the last third of this century began to emerge when the problems resulting from the distribution of petroleum products and the increasing contamination of their products, solar energy was again being used albeit in incipient form.

In 1960 a UN study has been published to assess the real possibilities of implementation and development of solar kitchens in underdeveloped countries and developing countries. The conclusion of this publication was that the solar kitchens were viable and it just needed a change in customs for an adaptation to their widespread use.

In this quest to make the solar cooker a real option for primetime for the cooking of food can not fail to mention the efforts of engineer Maria Telkes that created numerous designs for solar kitchens, which were characterized by easy construction and low cost, viable therefore, to be used in poor countries.

China and India later this season has made efforts to distribute a large number of solar cooking to the population.

In 1970 Barbara Kerr and Sherry Cole developed in Arizona several models of solar cookers that have received wide acceptance because of their low prices. Meanwhile, Dan Halacy, a pioneer in the field of solar energy, solar cooking fabricated 30-60, so named because its construction was based on angles measured in degrees whose they were.

In the '80s there was the popularization of solar chef, Sam Erwin. It was the most efficient solar oven at home. Sunspot was the simplest of Bud Clevette, along with the Sun Oven, which has greater diffusion.

In 1992 the Solar Cookers International Association promoted the First World Conference on Solar Cooking, a historic event that brought together researchers and enthusiasts from 18 countries. This conference was repeated in 1995, 1997 and recently in 2006 in Spain.

In Brazil the study of solar cookers was a pioneer in Solar Energy Laboratory, Federal University of Paraiba, in the 80's through the teacher Arnaldo Moura Bezerra, who built several types of stoves to concentration, using various materials for the parabolic reflective surface.

In LMHES/UFRN this line of research has been highlighted as having been the five dissertations, several scientific works in progress and two other master theses. Several versions of solar cook concentration and box type have been built.

Facing the world scene that global warming is indeed due to continued emissions of carbon dioxide and methane in the atmosphere, many studies and debates have been conducted worldwide, aimed at mitigating the factors that influence the overall environmental impact.

In CONEM IV - National Congress of Mechanical Engineering held in Belem - PA, in 2004, Souza et.al., published a study on the use of a solar cooker modulated concentration for use in camping and rural communities, for the cooking of food .

In the 18th COBEM - International Congress of Mechanical Engineering, Ouro Preto - MG, 2005, Souza et. al., published an article under the title Project Optimization of the constructions and efficiency analysis of a solar cook food for cooking, where they studied a solar cooker for cooking the concentration of food.

In CONEM V - Mechanical Engineering Congress held in Recife - PE, in 2006, Souza et.al., published a study on the use of a solar cooker at a low cost alternative, the object of the present work, the operation of roasting .

In the 19th COBEM - International Congress of Mechanical Engineering, Brasilia-DF, 2007, Souza et. al., published an article under the title Bifocal concentration solar cook for direct cooking on the results of a study of two outbreaks of solar cooker for cooking, and compare their results with those obtained by conventional solar cookers concentration unifocal.

Internationally, the Asociación Española Solar Energy International Solar Energy Society and promoted in Vigo, Spain in June 2008, the XIV Congreso Ibérico y IX Congreso Iberoamericano de Energía Solar, in which researchers from around the world, presented the following papers Understanding on the use box type solar cooker: Analysis of reducing emissions of carbon dioxide from the substitution of firewood by the use of box type solar cooker (Neto, JGC et. al.) Designing the construction of an experimental school kitchen Solar Sergipe (Teixeira, OA, et. al.) low-cost solar oven using as a base element used tire (Souza, LGM et.al.); Solar Oven as a mechanism for ownership of more energy by low-income Brazil - Vital Brazil, OA et. al.) La cocina solar tolokatsins 3 - Ricon, EA; Lentz, EA, Cocinas solar models of transfer - Chile y Portugal (Serrano, RP; Auburn, AL).

In the 20th COBEM - International Congress of Mechanical Engineering, Gramado - RS Souza et. Al presented two studies on solar cookers, solar cooker with the concentration of urupema parabola reflector box type solar cooker and built in composite material. We demonstrated the feasibility of using these prototypes.

In Conem VI - National Congress of Mechanical Engineering in Campina Grande - PB, two papers on the use of solar cooker to concentration and solar oven/cooker for cooking and baking food. Both demonstrated viability to the end proposed, characterized by easy methods of fabrication and assembly and low cost.

Entities such as UNESCO and the International Solar Cooking appliances (SCI, an acronym in English) develop and finance projects aimed at using solar cookers in African countries like Zimbabwe and Kenya.

In Kenya, the International Solar Cooking Appliance (SCI) has funded a program that allowed the purchase of solar cookers for over 15,000 families living in refugee camps. A program of building solar cookers in the Peru office of a charity called Peru Children's Trust (Trust in Peruvian Children) uses the labor of 100 poor children by offering assistance to families in health and education.

Solar cookers are special devices through which sunlight are used for cooking food and other utilities. Classified into three basic types; kitchens of type box, to concentration and heated by flat plate collectors (Gomes, 2008).

The cooker box type can have different numbers of external reflectors, flat or slightly concave. It is characterized by allowing the attainment of temperatures below 150°C. It takes the heat and its operation is very simple. It has the advantage of being able to function with virtually no user intervention, keeping the food warm for a long time. It produces no harmful effects to the user or for contemplation or for reflection. Are stable and pose no risks for the production of flame, not generating, therefore, susceptibility to sunburn (Lion, 2007).

They are built with low cost materials, even if it is unlikely to use it for every day of the year. Ca is easy transport, lightweight and collapsible. This type of solar cooker finds wide application in the world, mainly in Africa and Asia, especially India and China as countries that have invested more in social programs that make the construction of low-cost solar cookers for a significant use by his people (Souza, 2009, 2007, Melo, 2008).

Below in Figure (1) are presented several models of solar ovens / cookers in use in the world.

Figure 1. Solar ovens / cookers in use worldwide.

3. MATERIALS AND METHODS

The insulate box that is the cooking enclosure of the solar oven / cooker has the following dimensions:
- Internal: L = 30cm C = 50cm, H = 20cm; Area = 0.15²; Volume = 0.03 m³ (30 liters);
- External: L = 36cm C = 56cm, H = 23cm; Area = 0.20²; Vext = 0.046 m³ (46 liters).

Every surface of the solar oven /cooker was covered with mirror sheets and was placed at the bottom segments of Styrofoam to give the same profile that allows a concentration of incident rays on it in the absorber surface where food was contained.

We used a plate covered with mirrors with parabolic profile with catchment area of 0.6 m², in a structure above of the insulate box to reflect the incident rays inside. The structure of these segments of mirrors has motion to allow the adjustment of them in the light of the sun's apparent motion.

The data were collected in the internal temperature of the insulate box and in the outer surface of the pan where food was placed. We measured also the temperature of the outer surface of the box insulate on all sides, the temperature of the bottom to quantify and evaluate the thermal losses and the ambient temperature.

There were certain times of the oven for lasagna and a pizza of 325g and its results were compared with times obtained with conventional gas ovens.

The temperature data were measured with thermocouples cromel-Alumel, coupled to a digital thermometer and a laser thermometer. The solar radiation was measured with a station installed on solarimetric LMHES UFRN. Figure 2 shows the solar oven/cooker under test.

Figure 2. Solar oven / cooker under test.

4. RESULTS AND DISCUSSION

Tables 1 and 2 present the results of tests conducted for the baking of a pizza (325)g in the solar oven/ cooker built.

Table 1. Temperatures inside of the solar oven/cooker and solar radiation during the test of pizza baking.

Time (Hours)	$T_{int.oven}$ (°C)	$T_{absorber}$ (°C)	Direct solar radiation (W/m²)
10:20	64,0	65,5	720,0
10:24	68,1	74,4	720,0
10:28	68,5	86,1	721,6
10:32	70,3	92,6	723,2
10:36	72,0	97,0	736,2
10:40	73,5	99,3	740,3

Despite the internal temperature of the absorber reach levels below those obtained with a gas conventional oven the viability thermal of the proposed solar oven /cooker was demonstrated by acquisition of pizza baked in 20 minutes. Compared to other solar ovens / stoves shown in the solar literature the time obtained proved to be competitive, being 33.3% lower than the best outcome.

Regarding the conventional oven, the time obtained was almost double, but it is worth mentioning the cost-benefit ratio for the solar oven / cooker and want to study in such a prototype solar would be used primarily by people with low incomes. Figure 3 shows the behavior assumed by the absorber and internal temperatures during testing of baking a pizza in the solar oven / cooker studied.

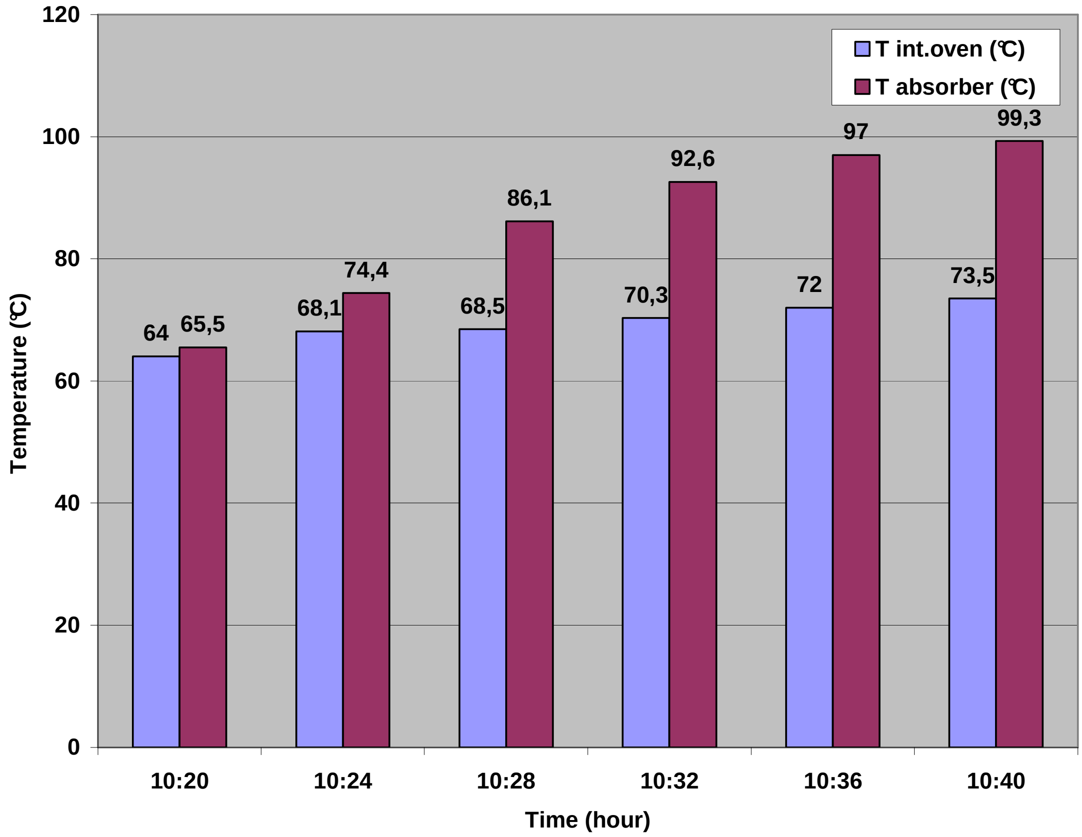

Figure 3. Behavior of the absorber and internal temperatures during testing of baking a pizza in the solar oven / cooker studied.

With regard to heat loss through walls and bottom of the box cooler, the Table 2 shows the temperature values measured during the test for baking pizza, according to the arrangement shown in Figure 4.

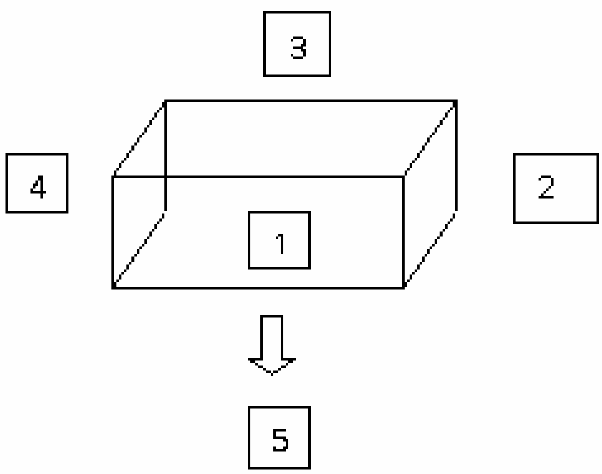

Figure 4. Arrangement of measuring points in the insulated box of the solar oven / cooker proposed

Table 2. Temperatures outside the oven during the baking test of a pizza, as provided in Figure 4.

Hour	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
10:15	51,2	37	37,7	44,2	45,0
10:20	52	37,8	38	44,4	45,5
10:25	52,8	38,2	38,4	44,6	45,6
10:30	53,1	38,5	38,6	44,8	45,8
Average	**52,3**	**37,9**	**38,2**	**44,5**	**45,5**

The highest temperature T_1 can be explained by the fact that this side is exposed to global solar radiation and be painted black, like all others. The lateral T_4 was also getting directly to solar radiation.

The lowest levels of T_2 and T_3 are explained by these is naturally protected from the sun and the average level of T_5 was due to the fact that the heat loss through the bottom. The ambient temperature during testing was approximately 30.5° C and wind chill around 35.3 ° C.

By obtaining a temperature gradient between the external surface of the bottom and the environment around 15°C, can increase the thickness of the EPS bottom to minimize heat loss by this surface. But even for such a gradient magnitude of the energy lost is insignificant. Figure 5 shows the behavior assumed by the temperatures of external surfaces of the solar oven /cooker in the process of pizza baking.

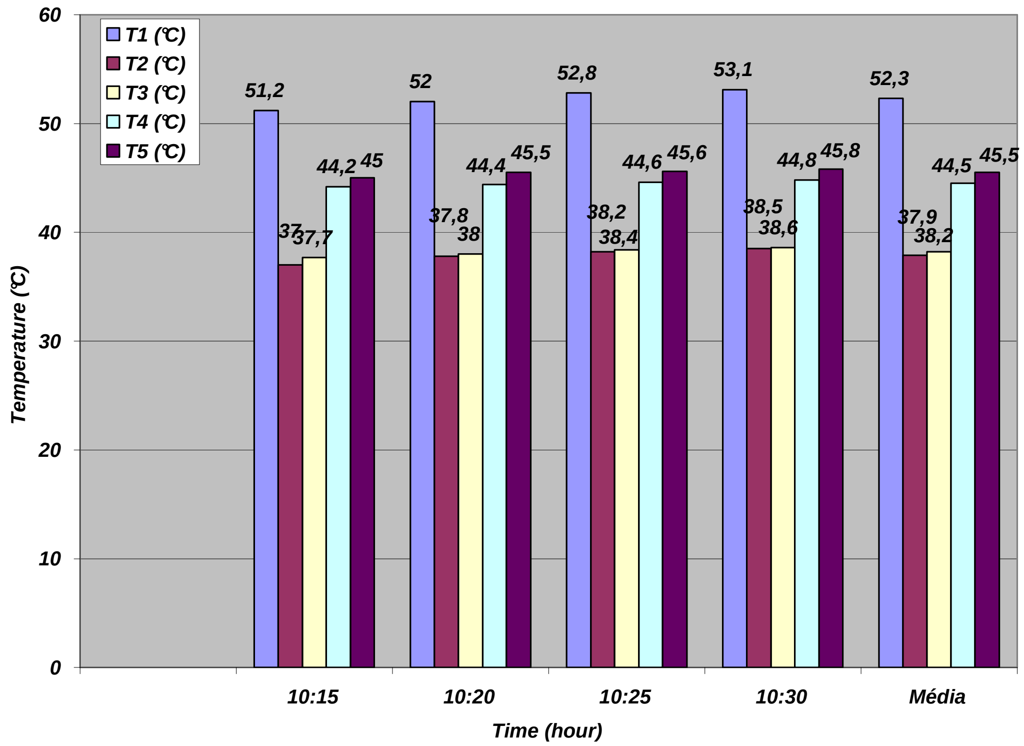

Figure 5. Behavior of the temperature of the external surfaces of the solar oven / cooker studied for the test of pizza baking.

Other test realized was the lasagna baking (650g). Table 3 shows the measured data for this operation.

Table 3. Thermal results of the test for lasagna baking (650g).

Time (Hours)	$T_{int.oven}$ (°C)	$T_{absorber}$ (°C)	I_d (W/m²)
11:10	86,2	63,2	768
11:15	87,1	75,4	770,4
11:20	87,7	88,5	774,4
11:25	88,0	90,3	760
11:30	88,2	92,5	792
11:35	88,3	93,4	778,4
11:40	88,5	94,3	772,0
11:45	89,0	95,9	760,0
11:50	90,1	97,4	764,8

The temperatures inside of the furnace and in the absorber were well below those achieved with a gas conventional oven. However, considering the time to bake lasagna in a gas conventional oven occurs in about 30 minutes, the solar oven/cooker built was feasible to cook that food, especially for its low cost. The time to cook the food tested was only 33.3% higher. Solar radiation levels were in great magnitude.

A measure that causes a significant improvement in the efficiency of the baking oven is to place in the sun long before the beginning of the process of placing the food to produce his pre-heating, which also occurs in conventional ovens, where this recommendation is suggested for a uniform temperature. Figure 6 shows the behavior assumed by the absorber and internal temperatures during testing of baking lasagna in the solar oven/cooker studied.

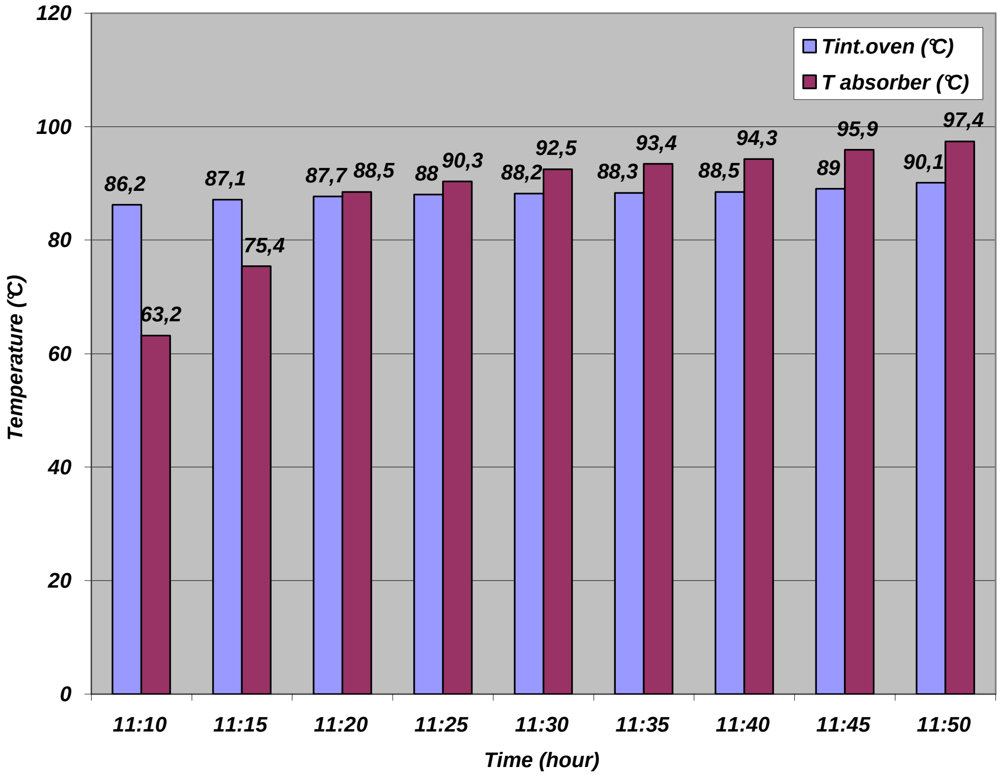

Figure 3. Behavior of the absorber and internal temperatures during testing of baking lasagna in the solar oven/cooker studied.

As regards the thermal losses through the walls and bottom of the box for the heat of baking lasagna Table 4 shows the temperature values measured during the test, following the provision already shown in Figure 2.

Table 4. Temperatures outside the oven during the baking test of lasagna.

Hour	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
11:10	53,5	39,3	39,5	40,3	43,5
11:20	53,8	39,4	40,1	41,1	45,3
11:30	54,5	40,5	40,8	42,5	45,5
11:40	55,5	41,5	41,5	43,2	46
11:50	55,8	41,6	41,7	43,5	46,2
Average	**54,6**	**40,5**	**40,7**	**42,1**	**45,3**

Temperature levels of the external surfaces were consistent with those of the previous test, for baking pizza.

The tests demonstrated the viability of using the solar oven/cooker proposed. Its mass use can be of great significance in social policy to generate employment and income for poor communities, which could produce baked at a low cost and using clean energy, environmentally friendly and promotes sustainable development, contributing to the reduction of use of firewood as an energy source.

The aim was to test the solar oven / cooker to produce the baking of cakes, breads, cheese and meat and also for the operation of cooking rice, noodles, cassava, potato, among others, but the conditions were not suitable solarimetric in our city in the first months of the year when the operation was necessary tests. Figure 7 shows the behavior assumed by the temperatures of external surfaces of the oven / cooker in the process of lasagna baking.

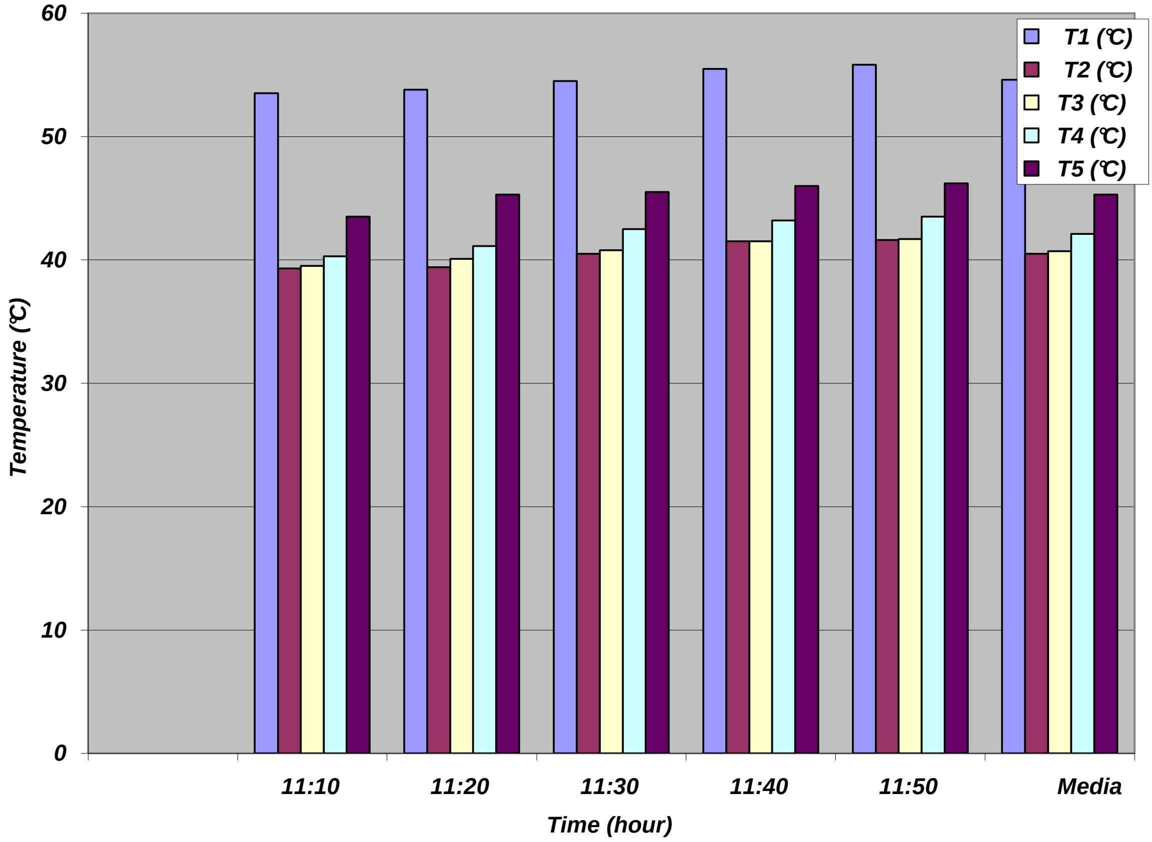

Figure 7. Behavior given by the temperature of the external surfaces of the oven / cooker studied for the test of baking lasagna

6. CONCLUSIONS

1. The oven / cooker proposed were feasible to bake food from 9:00 to 14:00 hours under good conditions solarimetric;
2. The oven / cooker have become competitive with conventional gas stove for baking food;
3. The oven / cooker has proposed cost-benefit ratio for its low cost manufacturing;
4. The operational and manufacturing processes and assembly of the oven / cooker proposed are simple and can easily be transferred to poor communities who might use it;
5. The time of baking of foods tested were higher than those obtained with conventional oven gas due to its lower internal temperature, but did not hamper the operations of roasting and baking foods;
6. The format of the mirrored surface inside the furnace led to a substantial increase in temperature of the base of the pan and a decrease in the time of baking or cooking food;
7. For the segments of mirrors placed on top of the furnace it was noted that the contribution of the same function to direct and concentrate the sun's rays inside the oven is extremely important, producing a better performance in roasting and baking foods by oven / cooker constructed;
8. The risks to the user of this type of stove are of low magnitude requiring only a few precautions that can be easily transmitted to its users;
9. The use of thermal box of EPS was found to be thermally efficient, minimizing heat losses without requiring thermal insulation;
10. It is intended to test the oven / cooker in the cooking operation of food.

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