

## **SOLAR COOKER ON URBAN ENVIRONMENT AS A COMPLEMENT FOR LIQUEFIED PETROLEUM GAS COOKING – CASE STUDY ON LAS TUNAS NEIGHBOURHOOD, BUENOS AIRES**

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**Abstract:** *The present study aims to design an urban solar kitchen as a complement to the use of LPG, adapted to the culinary practices of the families of the Las Tunas neighbourhood, in the Metropolitan Area of Buenos Aires. For this purpose, a field study was carried out, following the snowball method, through semi-structured interviews to obtain data related to 9 families in the neighbourhood. Starting from the social theory of practice, the different elements that make up the act of cooking were considered, and the interviews focused on the most relevant elements for a proposed alteration of the cooking equipment. The data gathered was codified through the R package, and the obtained results defined the design characteristics of the solar cooker. Considering parameters such as the need to cook inside the house and at night, during all months of the year, and to allow cooking any type of food, as well as the ability to adjust the dimensions of the components so that they adapt to each family, a solar cooker composed of a Scheffler disc and a thermal storage unit of saltpetre was proposed. The thermal behaviour of the solar cooker was studied, and the ability to cook all the year was demonstrated. The constructive parameters and the construction method were established. The construction of the solar kitchen should be made by a cooperative of resident workers of the neighbourhood, to increase the chances of adaptation, generate employment, and strengthen the community. Using data from the community to design a product adapted to the user's needs and existing practices, this study aims to contribute to the design and dissemination of urban solar kitchens throughout the world.*

**Keywords:** urban solar cooking, social theory of practice, users' needs, Buenos Aires, Thermal storage

## **1. INTRODUCTION**

Primary energy consumption is rising on a global level and 81,4% comes from fossil sources [1]. In the period from 1970 to 2010, 78% of the increment in greenhouse gas emissions was due to fossil fuel combustion and industrial processes, and the same can be said for the period from 2000 to 2010 [2]. Also at a global level, urban population, when the same definition of urban area is used, may account for 84% of total population [3]. Given the social, economic and ecological crisis the world is facing, is urgent to decrease consumption and production on a global level [4]. As an everyday practice, cooking is an external energy consumption activity that is unique in humans and mainly cultural [5]. Even though three million solar cookers are installed in the world [6] and solar thermal energy is the most abundant and easy to use renewable energy [7], they are not in use as they should. On Iessa et al [8] bibliography review is pointed that solar cooking promotes often don't take local problems and needs into account when drawing a project, existing practices are seen as obstacles instead of a research element, gender relations at a family level are not taken into account and there is a lack of studies regarding the impact of the use of solar cookers on people's lives. Social factors associated to the use and adoption of solar cookers are the crucial elements to look at when evaluating a project aiming to introduce this new technology [8]–[11].

The present work aims to study the users' needs and cooking practices of nine families from Las Tunas neighbourhood, in Buenos Aires Metropolitan Area, in order to design a solar cooker adapted to the data obtained on the field. Human-scale development and energetic sovereignty are the philosophical compass of all this work, while the social reality of the neighbourhood was the basis for all the decision-making process.

## **2. METHODOLOGY**

This work had two stages of research, being the first one related to the anthropological field study and the second to the technical study of the solar cooker.

### **2.1. Case study on Las Tunas neighborhood**

Cooking was studied as a practice, according to the definition of Reckwitz [12] and the empirical knowledge of Torkelli et al [13]. Solar cooking, and not the solar cooker, was also studied as an innovation following Rogers' process [14]. Nine semi structured interviews were created in order to study the relevant elements of practice, such as materials, procedures and competences, following the triangle of cooking practice proposed by Torkelli et al (Figure 1). Interviews, see APPENDIX 1 – INTERVIEW FORM FOR LAS TUNAS NEIGHBOURHOOD FAMILIES, were conducted following the snow-ball method, recorded on a cellphone, transcribed to Word, converted on .txt file and analysed with R package for qualitative analysis – RQDA.

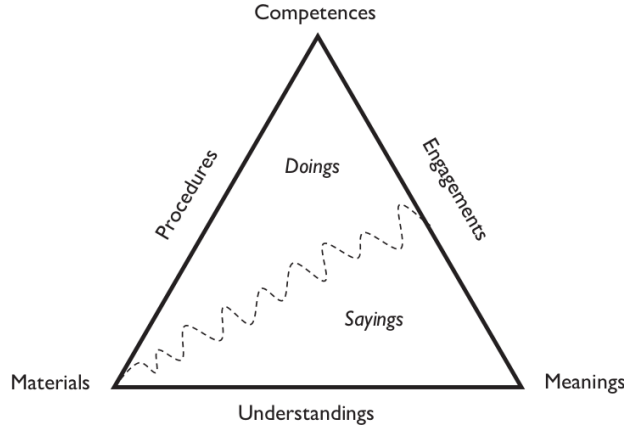


Figure 1: The triangle of elements of practice and their manifestations as doing and sayings in cooking.[13]

The raw data from the interviews was coded on RQDA and seventeen categories were created, inside which the codes were placed. The categories used were: functions of energy, types of energy, LGP supply, bottle brand, perceived problems, amount of cooking pots, amount of people to cook for, cooked food, cooking equipments, available space for solar cooker, functions of space, cooking schedule, reasons of interest on solar cooker, occupation, person in charged of cooking, cooking times, types of cooking.

Based on this categories, codes were created along with the analysis and raw data was divided into this codes. Finally codes and categories were sent to Excel to create graphs and better visualize obtained results. These results established the design parameters the

solar cooker must fulfil in order to be connected to the social reality and actual practice of the final users.

## 2.2. Solar cooker

The second part started as a bibliography revision of available solar cookers types and components that could meet the design parameters. A thermal study was conducted in order to verify the ability to melt the phase-change material (PCM) in the thermal storage unit (TSU). The analysis was focused on the TSU of saltpetre, using the thermal characteristics studied of Mussard et al [15], with a melting point of 220°C to allow all types of cooking [16]. The TSU is composed of a casing of aluminium filled with saltpetre. The distribution of temperatures inside the TSU is considered constant on its volume and that the temperature of the casing is the same as the saltpetre. The specific heat of aluminium is considered constant in time, the temperature of isolation varies linearly and the temperature in the outside of isolation is equal to ambient temperature, assuming is perfectly isolated.

The variation of internal energy of the TSU in kW is given by

$$\dot{Q} = \frac{m_{TSU} * C_p * \Delta T}{\Delta t} \quad (1)$$

Where  $m_{TSU}$  is the mass of the aluminium case and the salts in kg,  $C_p$  is the specific heat of both materials in kJ/(kg K),  $\Delta T$  is the temperature variation of the TSU in °C and  $\Delta t$  is the time interval in seconds.

The variation of internal energy, assuming that there is no work done by the system and no energy generated in the interior of the system, is equivalent to

$$\dot{Q} = \dot{Q}_{radiation} - \dot{Q}_{losses} \quad (2)$$

$\dot{Q}_{radiation}$  in kW is given by

$$\dot{Q}_{radiation} = \dot{Q}_{solar} * \alpha * R \quad (3)$$

where  $\dot{Q}_{solar}$  is the solar energy the Scheffler disc receives in kW,  $\alpha$  is the absorptivity of the surface of the TSU, dimensionless, and  $R$  is the reflectivity of the disc surface, dimensionless.

The solar energy received by the Scheffler disc, in kW, is given by

$$\dot{Q}_{solar} = q_{sun} * A * \cos(\theta_{ef}) \quad (4)$$

where  $q_{sun}$ , in kW/m<sup>2</sup>, is the solar flux,  $A$  is the effective area of the disc, in m<sup>2</sup>, and  $\theta_{ef}$  is the effective angle of the Scheffler disc, dimensionless, given by

$$\theta_{ef} = \theta_{sun} - \theta_{disc} \quad (5)$$

where  $\theta_{sun}$  is the sun angle, in degrees, and  $\theta_{disc}$  is the tilting angle of the disc.

In the system, there were energy transfers in the form of convection and conduction. Convection losses occurred in the aluminium plate that was receiving the solar radiation in the TSU, that was in contact with air. Conduction mechanisms were occurring on all the surface isolated with rock wool.

So,  $\dot{Q}_{losses}$ , in kW, is given by

$$\dot{Q}_{losses} = h_{air} * A_s * \Delta T_{conv} + (k_{isol}/e) * A_{isol} * \Delta T_{cond} \quad (6)$$

where  $h_{air}$  is the convection coefficient of air, in kW/m<sup>2</sup> K,  $A_s$  is the surface in contact with air, in m<sup>2</sup>,  $\Delta T_{conv}$  is the temperature difference between the surface and outside temperature, in K.  $k_{isol}$  is the conduction coefficient of rock wool, obtained on the manufacturers sheet, in kW/m K,  $e$  is the thickness of the isolation, in m,  $A_{isol}$  is the isolated surface, in m<sup>2</sup>, and  $\Delta T_{cond}$  is the temperature difference between the aluminium case and the outside temperature, in K.

The balance of energy on the TSU is finally given by

$$\frac{(m_{al} * Cp_{al} * [T_{TSU} - T_{\infty}] + m_{salts} * Cp_{salts} * [T_{TSU} - T_{\infty}])}{dt} = q_{sun} * A * \cos(\theta_{ef}) * \alpha * R \quad (7)$$

$$- (h_{air} * A_s * [T_{TSU} - T_{\infty}] + (\frac{k_{isol}}{e}) * A_{isol} * [T_{TSU} - T_{\infty}])$$

Solar flux in equation (4) was obtained from NASA Langley Research Project (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program, and a polynomial expression for each month of the year was generated using Excel.

$\Theta_{ef}$  in equation (5) was calculated modulating the disk inclination in SolidWorks.

Equation (7) was solved in Excel making an iteration of 0,1 hours,  $dt$ , in order to study the evolution of the system and obtain  $T_{TSU}$  on a 48 hour period. Three studies were made in order to see the effect of isolation on the metal plate in contact with air. A cooperative local construction method was proposed in order to involve and promote local employment, generate income and reduce waste.

### 3. RESULTS AND DISCUSSION

Results obtained from the case study and RQDA analysis defined the following design parameters:

- Ability to cook at lunch and dinner time, during the whole year;
- Have enough space to use two cooking devices;
- Aesthetically attractive, modern, with low maintenance required and autonomous functioning;
- Able to reach high temperatures to boil water fast;
- To be used as an oven;
- That allows to cook indoors;
- Ability to adapt its own dimensions to the routines and realities of each family, to use more or less pots, to have more or less power and to adapt the TSU.

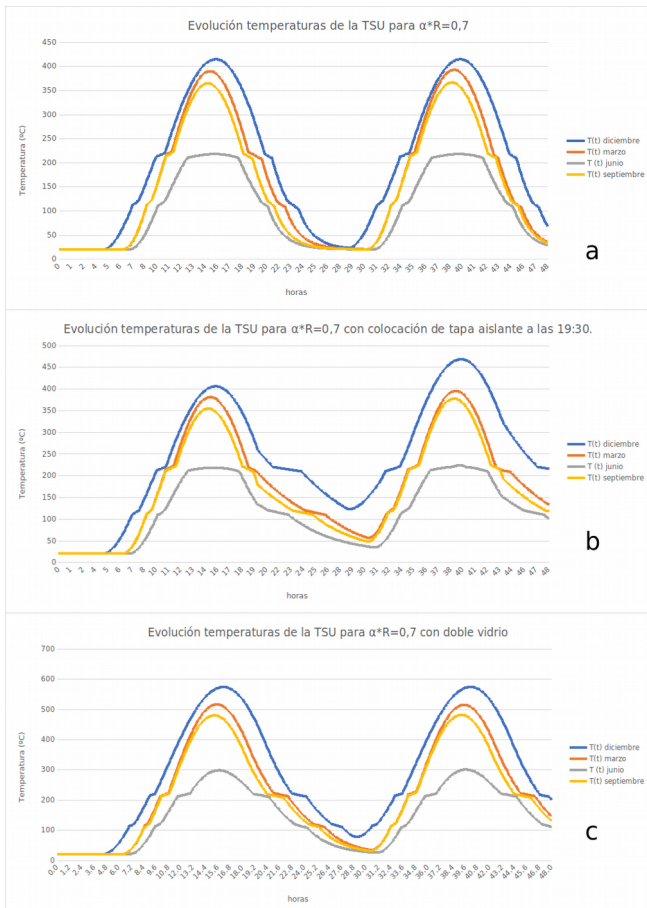


Figure 2:  $T_{TSU}$  for a period of 48 hours: a) without isolation on absorbing cavity; b) with isolated cover from 7:30pm to 8 am; c) with double glass on absorber cavity.

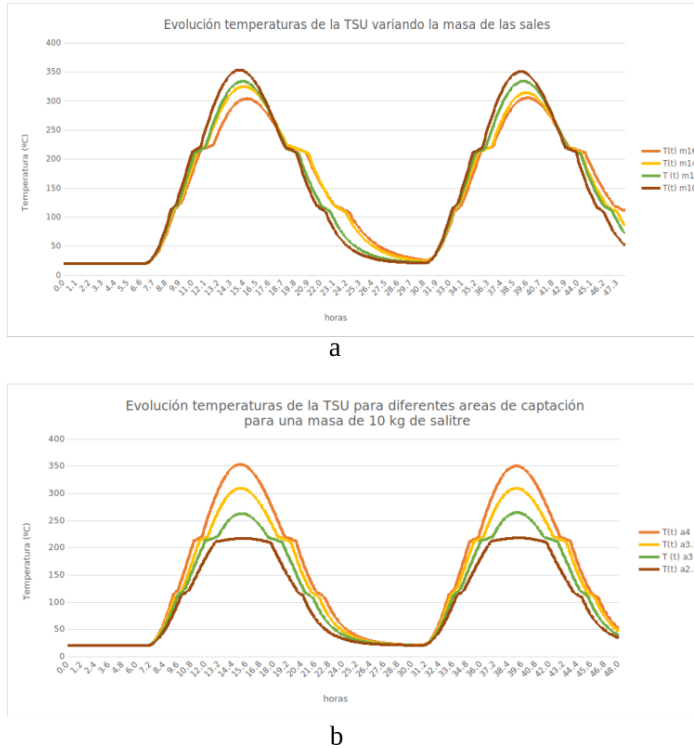


Figure 3:  $T_{TSU}$  evolution for a period of 48 hours: a) saltpetre mass variation; b) Scheffler disc area variation.

anyone to having to worry about inserting or removing the isolated cover, reducing the chances of error. For these reasons, two new studies were made in order to optimise the dimensions of the disc and the saltpetre for the double glass system, hence reduce material and economic resources. These studies were made for the month of June, since it's the one with lowest insulation (Figure 3).

Final dimensions for the disc and the TSU were 3 m<sup>2</sup> and 10 kg of saltpetre, respectively. The disc area captures enough energy to melt the saltpetre mass, the melting process is complete at 1pm and the solidification starts at 7 pm, which fulfil the requirement of day and night cooking.

The proposed method of construction was based on the process of building a boat, with small stripes of wood bended and fixed in order to make the shape of the disc, based on the experimental construction study of Sholes et al. [17]. Each of the parabolic structural stripes, that define the parabolic shape of the Scheffler, were approximated to a sphere, for easiness of construction. This approximation was studied by Reddy et al. [18] and the design charts were used to estimate the budget for the construction of the disc, considering that all the materials would be bought. The proposed daily

The system chosen was a Scheffler disc with a TSU that would be put inside the house, on the south façade and with the disc oriented towards north. Calculations were made for a 4 m<sup>2</sup> disc and 16 kg of saltpetre and 80 mm of rock wool and the  $\alpha \cdot R$  product used was 0,7 in order to take into account geometry and surface finishing imperfections on a real construction scenario. Three different scenarios were studied: one with the absorbing plate in contact with air (Figure 2 a), a second with an isolated cover inserted on the absorbing plate cavity at 7:30 pm and removed at 8 am (Figure 2 b), and a third one with a double glass on the absorbing plate cavity (Figure 2 c).

Results showed that with the isolated cover and the double glass, the saltpetre would melt on both equinoxes and solstices, which proved to be two possible systems. Nevertheless, temperatures reached with double glass on the absorber cavity were much higher, being the lowest difference on June, of 77 °C. Also, the double glass system would not need

tracking mechanism for the disc was based on the one built and tested by Mercer [19] that relies on 4 gears and follows a mechanical clock mechanism with one revolution per day.

#### 4. CONCLUSION

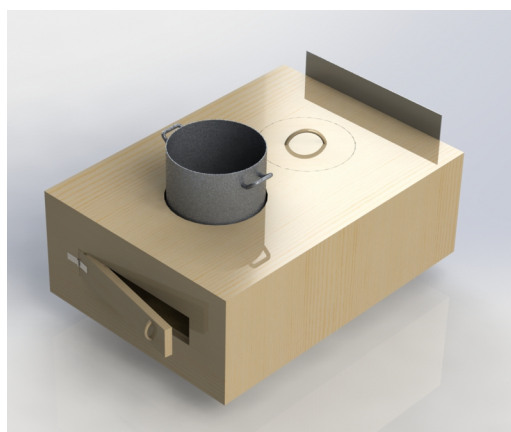


Figure 4: Render of the proposed TSU taken into consideration the ability to redimension to fit specific purposes. Made in SolidWorks.

The conducted field study led to important design parameters defined by the potential users, taking into account their own knowledge, cooking practices and daily routines. Nevertheless a pattern was not clearly identified in the families interviewed, and this was also taken into consideration. To increase the chances of adoption of a solar cooker, there was no assumption made regarding the characteristics of the system by the author. It was interesting to notice that, while conducting the interviews, people were very enthusiastic about the possibility of cooking with sun, but they were clear about not changing their routine. Also the performance and the need for a demonstration was highlighted.

A Scheffler disc with a TSU of saltpetre fulfilled the design parameters and also was adapted to the existing infrastructure of the neighbourhood. Low density blocks, with the majority of the houses having only ground floor and a lot of free space in the back and in the front of the house, allows the setup of the Scheffler and the TSU, assuming that people would have the kitchen or a covered space on the south façade to put the thermal storage unit. A 3 m<sup>2</sup> Scheffler and a 10 kg of saltpetre TSU (Figure 4) was the proposed system for a family of four members, and the thermal study shown it was viable.

A cooperative construction method was proposed in order to generate employment, increase the chances of adoption and the creation of a retrofitted mechanism to continuously adapt the system to the users' needs. Also all the materials proposed in the construction are widely available in the neighbourhood, or easily bought in Buenos Aires. The decision to propose a cooperative is due to the fact that human scale development needs and participatory design are at the core of all this work.

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## **APPENDIX 1 – INTERVIEW FORM FOR LAS TUNAS NEIGHBOURHOOD FAMILIES**

Interviews to families – Eating habits, cooking dynamics and use of GLP

Location: Las Tunas neighbourhood, Tigre, Buenos Aires

### **Data to retrieve**

Number of inhabitants:\_\_\_\_\_ Monthly income (total):\_\_\_\_\_

Annual GLP consumption:\_\_\_\_\_ Annual GLP expenses:\_\_\_\_\_

The house has space for a solar cooker (north façade, free space with sun):\_\_\_\_\_

### **Questions**

What type of food is more frequently consumed in your house?

How many food do you cook per day, and at what time? Who is the person responsible for cooking?

How do you normally cook the food?

How long does it take to cook for the whole family?

What are the daily work/study routines?

Do you identify any type of problem with the use of GLP bottle?

How do you use GLP at your place?

How do you obtain the GLP bottles?

Do you use any other fuel to replace or complement GLP?

(after a brief explanation of solar cooking, the inherent changes, the sun dependence)

Do you have any interest in using solar cooking as a complement to GLP bottle?

How much money would you be willing to spend on such a cooker?