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CIFP SOMESO, A CORUÑA, SPAIN

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XUNTA DE GALICIA | CENTRO INTEGRADO DE FORMACIÓN PROFESIONAL SOMESO

UAlg ISE UNIVERSIDADE DO ALGARVE INSTITUTO SUPERIOR DE ENGENHARIA

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Authors were invited to submit abstracts for consideration by the *Organizing Committee*. For each accepted abstract, the authors were invited to submit a full paper and a presentation file with audio recorded to be presented in CONSOLFOOD2023.
This document contains all of the *accepted* abstracts and full-length papers submitted for inclusion in CONSOLFOOD2023. It may be updated from time to time if papers are revised, or further full-length papers arising from submitted abstracts are received.
All of the submissions have been scrutinised by one or more members of the *Organizing and Scientific Committee*, but they have not necessarily been revised to accommodate suggestions made by the reviewers. Therefore, they should not necessarily be regarded as having been subjected to strict peer-review.

2-Getting further information

Authors may be contacted via the email address that appears under the title of each abstract or full-length paper. Where several email addresses appear, it is the convention that the name of the corresponding author bears an asterisk (*). If one name has an asterisk, please only contact that author.

3-Searching this document

All full papers and abstracts are listed in according to the programme of the conference sessions.

4-Copyright

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Session 1A

TRAINING PEOPLE IN SOLAR THERMAL FOOD PROCESSING FOR ENHANCING GREEN ECONOMYAND ECOLOGY

Janak Palta McGilligan

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In most of the rural and tribal areas across India like many parts of the developing world, the use of fuel wood is becoming increasingly unsustainable. Aside from the ever-increasing environmental damage, firewood is ever more expensive and scarcer, and wood smoke causes serious respiratory problems, particularly for women and children. Collecting fire-wood, is one of the major domestic chores, often a task performed exclusively by women and children. This was one of the most shocking experience in my early days as a Baha'i Pioneer in the capacity of Founding Director of Barli Development Institute for Rural women in Indore. During my year long stay in their homes for my voluntary service for eradicating guinea worms in 302 villages, I witnessed the vulnerable condition of women collecting firewood and cooking in smoke on the one hand and degrading deforestation and its impact on women, but was not aware of any solution. I found out solutions in Rio de Janeiro during the Earth Summit in 1992 when invited to receive UNEP Global 500 Roll of Honour for our Institute eradicating in Jhabua district. I am sharing my learning and experience that I mainly gained along with my husband late James (Jimmy) McGilligan O. B. E. the Manager of the Institute also fellow Baha'i Pioneer from U.K. Both of us served there until 2011, trained 6000 young illiterate, poor rural and tribal women empowered, graduated and returned to their own 500 villages from India. It was training with holistic approach integrating Literacy, Health Environment and income-generating skills in residential training programs. They demonstrated significant socio-economic positive changes in their knowledge, attitude and social practices about health and environment including use and promotion of solar cookers in their communities.

It took 10 years for both of us to start solar cooking training after we took up the Challenge of relieving women from smoke and risks of collecting fuel wood. We were seriously concerned about "Cooking in smoky kitchens is Violence Against Women." We made it a top priority to train women in solar cooking. We started with demonstration of solar box cookers in tribal villages but those were rejected by locals due to food timings and patterns. Jimmy manufactured and installed the first largest Solar Community Kitchen of Central India 1998 with large Scheffler dishes that still continues cooking two meals and breakfast everyday for its 100 inmates, stared saving one ton wood and reducing carbon dioxide emissions by 1.8 tons per year.

This solar kitchen motivated the trainees to enjoying smoke- free cooking for 6 months and they started asking about how they could have solar Cookers in their homes. We started exploring possibilities of facilitating the process of transferring solar Cookers for domestic cooking and got a charity offer from Gadhia Solar Valsad to help the rural poor women, funded by PLAGE, a NGO from Austria. The Institute decided to give the cookers mainly on two conditions firstly, the cookers were not just given away as charity but “by choice” only to those who will paid 10 % percent of the cost in advance, as 90 % was to be subsidized by PLAGE. Secondly, they had to be highly motivated graduates of the Institute who demonstrated a keen interest and willingness to take 8-10 days special training of potential users of SK 14.

A great deal of work went into learning about food habits and collecting information about indigenous recipes and user’s manual was written in simple understandable Hindi. Special training materials, were developed. They were trained solar cooking /baking, deep-frying and up keeping and maintaining the cookers clean.

This facilitated transferring 500 SK 14 Solar Cookers for domestic use to the trainees and their families. They gained more confidence and further learnt to use those cookers for their livelihood, started promoting solar energy by using these cookers for income generating like running tea stalls, making mid-day meal, cooking for their cattle-food, also used cookers for ironing clothes and textile printing. They started boiling water for drinking, increasing awareness, knowledge, initiation and execution of Solar Cooking of food for nutrition and health.

As the trainees demonstrated their enthusiasm, simultaneously Jimmy McGilligan trained the local staff and manufactured and installed 4 Large solar community kitchens in Private tribal School hostels. He kept on innovating and making solar solar bakery and dryers.

Having taken retirement after handing over the Institute to our successor in 2011, planed moving to a village and building our house in village Sanawadiya. Just before completing our house in village, Jimmy built hybrid Solar Wind powering 19 street lights for 50 tribal families. Just before almost completing the house both of us met with an accident and unfortunately, he passed away 17 days following the accident and I was left alone but completed the house and opened it for training people in simple sustainable living, growing organic food, using solar kitchen and solar dryers. I dedicated my work "Jimmy McGilligan Centre For Sustainable Development" People could see me changing my LPG Gas bottle in more than two and half years and learn solar cooking. By now, 160,000 persons have been trained educated (free of cost) including women, farmers, Self Help groups, students and faculties from various schools, professional institutions of science, engineering, management, hotel management, medicine, computers, information technology, home science, agriculture, communication and specially from Devi Ahilya University of Indore, Police Training Centre, IIT IIM who specially see it as a model of sustainable technologies and sustainable living. Have trained local women and youths with 13 different type of solar cookers. As a result, by now more than 1000 Solar Cookers including Prince 15 and Box cookers are in use after training them.

It has been well known to government / NGO/ educational Institutions, business and industry, political leadership and contributed to advancement of the Solar Cooking movement in India as well as international. Yet, there is no attention given by Government and we continue trying.

Socio Economic Impact on lives from Rural /Tribal Women Users of Solar Cookers after 10 years.

They found the solar cookers, smoke-free, hassle free, protect them from mental and physical abuse including rape, miscarriage during pregnancy caused by heavy load all faced during covering long distances to collect firewood. Cookers are the best for their health and environment, Clean Smart/Shining, save the trees, our eyes and lungs. According to them these are gender-friendly cookers because even they like to cook. It has raised the status of women in their families and communities. They are cooking for family and cattle feed, boiling drinking water, ironing clothes, textile printing. Many of them and Microcredit Groups are using these cookers for livelihood. Men also learn Solar cooking on women day. Even some men are also running solar tea stalls and food processing Units with solar dryers.

Training people in solar thermal food processing for enhancing green economy and ecology because solar cooking is a proven thermal process that uses appropriate technology to convert incoming sunlight light energy directly to heat (thermal energy) for cooking. It is a carbon-free/clean cooking solution. Goal 7 of the 17 SDGs aims at Universal access for affordable and clean energy for economic growth, social equity, and environmental sustainability by 2030. This calls for solar thermal cooking/food technologies solutions as one of the priorities in this SDG 5 is central to all the 17 SDGs.

For the last 5 years I have been mentoring start-ups. Some of the most successful economically and ecologically are:

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Other Links of Janak Palta McGilligan About Solar Cooking

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https://solarcooking.fandom.com/wiki/Janak_McGilligan

#RichaAnirudh #WorldEnvironmentDay2021 #IndianOil ZERO Waste Household | Dr. Janak Palta | Earth & Energy Heroes Ep 1 https://www.youtube.com/watch?v=aB_aMMGbI-s

Dr. Mrs. Janak Palta McGilligan at the UN ttps://www.youtube.com/watch?v=vRch0Lxq9ow

Janak Palta McGilligan Special Guest Speaker at COP27 https://www.youtube.com/watch?v=idsSTIpUXa8&list=PLYzG8cu3kR82NQdL_RUVKWeOUJIgjp-_y&index=1&t=11s

Inaugural Speech of Atul Bagai : UNEP India

https://www.youtube.com/watch?v=3mk6IqwF_00&list=PLYzG8cu3kR82NQdL_RUVKWeOUJIgjp-_y&index=7&t=14s

WHERE SHOULD WE BAKE BREAD?

Benjamin Pillot[a], Guillaume Guimbretière[b], Christophe Révillion[a], Corrie Mathiaka[a], Romain Authier[a]

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Abstract: In this paper, we analyze the potential organization of a network of solar craft bakeries for bread production at the regional scale. We apply our methodology to the Reunion island (2512 km2 – 860 000 hab in 2019), French overseas territory located in the Indian ocean and defined by a sub-tropical climate. We primarily address some basic questions: would solar-fueled bakeries match the requirements of the whole bread-supply chain as it is today? In other words, is the solar resource suited to both the work configuration of the baker and the dietary behavior of the community?

In first instance, we analyze how direct solar radiation could spatially replace electric ovens across Reunion for running bakeries, with respect to 1) the work timeline of the baker and 2) the bread quantity that actually feeds the local population. Accordingly, we propose a methodological concept to guide this analysis, depicted in the workflow of Figure 1. We apply DNI values to a model based on a solar thermal oven currently used by an artisan baker in Normandy, France, and compute the final outputs of the workflow through Python GIS. Then, in order to understand the full potential of solar baking in Reunion, we look at how a solar bakery could match its potential market, that is how likely bread and pastries produced through solar cooking are to be eventually sold. To do so, we propose a solar bread potential indicator, computed in every cell of a predefined geographical mesh. By combining population density, DNI potential (Figure 2) and probability of bread consumption, we retrieve solar bakery's viability throughout the territory, relying on the probability that bread production is eventually sold. Results are depicted in Figure 3: economic return gives both absolute and relative information about the viability of a solar bakery in Reunion.

In short, energy transition encompasses many possible social, cultural and technical changes towards sustainability. This study, by including baker's activity, community needs and practices, and a geographic approach to studying bakery transformation shows how this transition in the energy field must be apprehended holistically, beyond sole substitution of the supplying systems and resources.

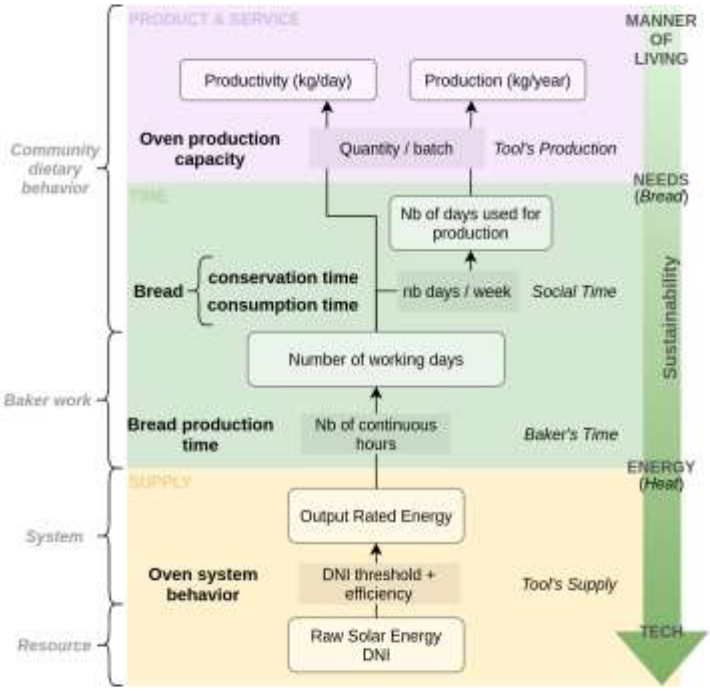

Figure 1: Research workflow. Tech used to harvest required energy addresses the population needs along a sustainable path.

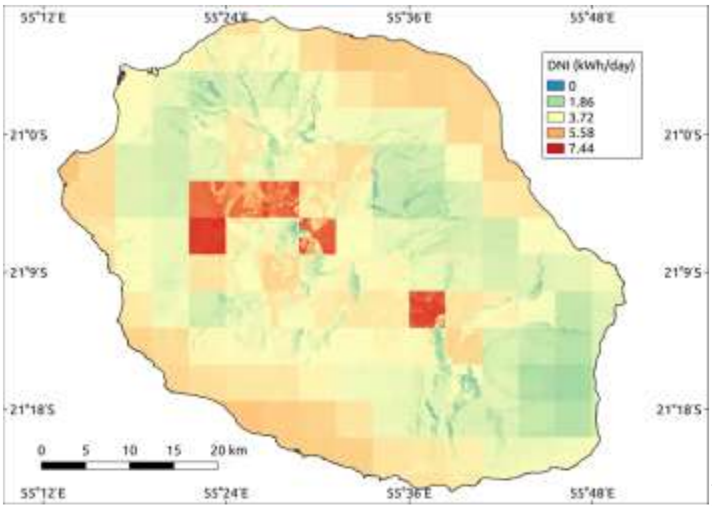

Figure 2: Daily mean DNI

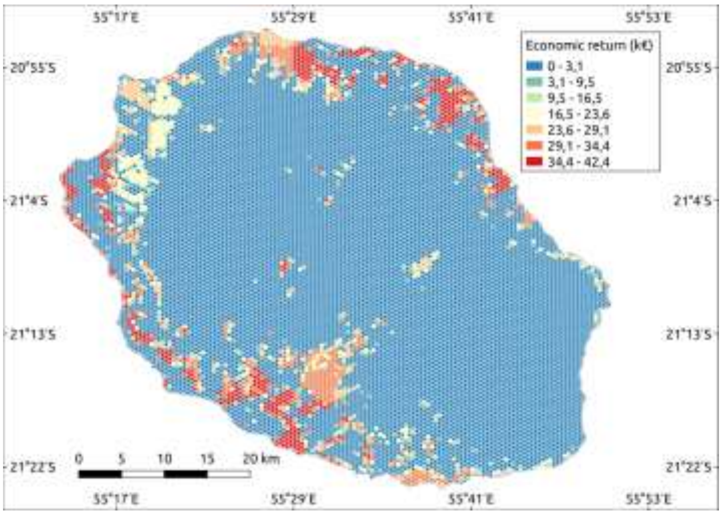

Figure 3: Solar bakery viability through forecast economic return in Reunion island

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A NEW FUNNEL SOLAR COOKER DESIGN: FUNNEL COOKER 041

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Abstract: A new design of funnel solar cooker named 041 is presented. This new design includes several improvements over the "classical" funnel solar cooker design. The reflector is built from a simple flat piece, without joints. It incorporates support elements against the wind. The front panel is designed to separate the pot from the reflector in the event of an accident due to wind. This design also makes it easy to track the sun in two axes. In case of water loss, the liquid falls to the ground and does not come into contact with the reflective panels. The performance of the funnel cooker 041 is characterized by means of experimental tests and numerical ray-tracing. Some practical cooking applications are presented.

Keywords: Solar funnel cooker, 041, new design, experimental tests, ray-tracing

A SOLAR COOKING CASE STUDY IN KAKUMA REFUGEE CAMP, KENYA

Bigelow, A.W., Hughes, C., Fox, M.

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Abstract: Solar Cookers International (SCI) is a non-profit organization with over 35 years of experience improving human health, economic well-being, women's empowerment, and the environment by promoting climate-friendly solar cooking for vulnerable populations worldwide. The challenges presented by approximately 2.4 billion people cooking over open fires with polluting fuels are great and SCI is addressing these challenges in collaboration with many organizations and partners. Building capacity with best practices: This presentation will highlight SCI's Kakuma Refugee Camp, Kenya, case study. SCI is leading a community-based solar cooking initiative in Kakuma Refugee Camp due to the dire needs of the refugees and the ideal solar cooking conditions there. Refugees often don't have enough food, funds, or fuel to feed their families. Working with Ecomandate, a registered community-based organization in Kenya with solar cooker expertise, over 1,900 refugees have been directly impacted and over 5,000 metric tons of carbon dioxide avoided with solar cooking in Kakuma. This initiative implements the best practices of solar cooker manufacturing in Kenya, by Kenyans, using materials available in Kenya, for cooking regional food in Kakuma. Local female solar cooking champions conduct training with ongoing monitoring and evaluation, along with follow-up and support to ensure the successful use of solar cookers. Families are saving money by purchasing less cooking fuel and saving time not collecting cooking fuel. The presentation will include both the practical challenges and solutions experienced in increasing the use of solar cooking in Kakuma. Worldwide, over 4 million solar cookers have been identified to date. These are estimated to have directly impacted over 14.3 million people and cooked over 7.7 billion meals. SCI estimates that if all the households in Kenya currently cooking with polluting fuels used solar cooking for meal preparation, over 19 million metric tons of CO_2 could be avoided annually. If the population cooking with polluting fuels switched to using solar cookers one-quarter of the time, Kenya could save over 2 billion dollars annually through avoided health and environmental costs. The economic opportunities with solar cookers are immense. Any country with adequate solar radiation can save millions, even billions of dollars annually with avoided health and environmental costs by reducing cooking over open fires and increasing solar cooking. It is estimated that if everyone currently cooking with polluting fuels used solar cookers ¼ of the time, over 1 trillion dollars could be saved annually across the globe.

Keywords: Solar thermal cooking, solar thermal cookers, humanitarian setting, refugee camp.

USING SOLAR COOKERS TO FEED 35 – 50 PEOPLE PER DAY AT THE TAMERA COMMUNITY

Hannah Larndorfer

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Abstract: The Tamera Community is an intentional community in southern Portugal. In our outdoor solar kitchen, we prepare meals for between 35 and 50 people each summer day. This is achieved with a range of solar cookers, and, on sunless days, locally produced biogas from our own kitchen waste. The qualities of each type of solar cookers like Scheffler Mirror, Tolokatzin, La Parabola, are described, and their contributions to a busy kitchen assessed.Daily decisions about what to cook, and the challenge of relying on the weather, are discussed.

Session 1B

PERFORMANCE EVALUATION OF A PROFESSIONAL COOKTOP POWERED BY A SCHEFFLER REFLECTOR

Gabriel Guillet, Thomas Fasquelle, Séverine Barbosa, Benjamin Kadoch

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Abstract: The objective of this study is to evaluate the performance of a special unit of Scheffler-type solar cooker offering an original cooking interface dedicated to restaurant cooks. This interface, called French cooktop, is well known and appreciated by chefs for its versatility and ergonomics. It consists of a cast iron plate, usually heated in its central part by a gas burner. In this case, a Scheffler collector coupled to a secondary flat mirror replaces this burner. This cooktop allows chefs to use it with various utensils that are placed at the right position of the temperature gradient on its surface. A similar example of this fixed-focus solar cooker is already used by the restaurant Le Presage in Marseille, France. Identifying the potential for improvement of the current system could lead to obtain more power for the same collecting area or a downsizing for the same power output. In addition, as French cooktop are often used as main cooking appliance, particular attention should be paid to matching the power requirements of the restaurant with the size of the system. This work aims to answer these two questions by experimentally measuring the performance of a system with an 8 m² Scheffler collector, a flat aluminium secondary reflector and a cast-iron plate. The seasonal adjustment is done manually whereas an electronic sun tracking system continuously rotates the reflector to follow the daily path of the sun. Tests take place in Marseille (5.4374°, 43.3449°), France. They follow the ASAE S580.1 Standard with little adaptation. The experimental procedure consists in heating water from ambient temperature to the local boiling point. Water temperature, ambient temperature, direct normal irradiance, and wind velocity are recorded along this heating phase. The cooling phase is also observed. The standard cooking power, obtained for a temperature difference of 50 °C between water and ambient air, allows the comparison of the current system with the literature. The results obtained help to identify the characteristics of the cooker and to show the parameters which should be considered with a greater attention in the future.

Keywords: standard performance assessment, Scheffler reflector, solar cooker design

DEVELOPMENT OF TABLE-TYPE SOLAR COOKER

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Abstract: While parabolic solar cookers offer several advantages, they also have safety concerns and folding difficulties. At low solar altitudes, the converging sunlight can also shine through the top of the cooking bowl, which can cause burns to the hands. In addition, assembling a parabolic mirror at the cooking site is time-consuming. On the other hand, when using a Table-type solar cooker shown in this paper, the cooking bowl is accessed from the backside of the parabolic mirror. This feature makes cooking as easy and safe as a kitchen stove. Thermal insulation can easily be added to the top and sides of the bowl since the concentrated sunlight only enters from its bottom side. In addition, the mirror has a woven structure made of thin and soft reflective material, making it suitable for folding. The solar tracking function using optical sensors and servo motors allows for high solar efficiency and avoids unexpected heating incidents. This paper presents the design, solar-tracking stability evaluation, thermal performance, cooking performance, and further plans for the Table-type solar cooker.

Keywords: Solar cooker, parabola, table-type, safety, foldable, woven structure, solar-tracking.

Experimental characterization of a foldable solar cooker with trapezium cooking chamber and adjustable reflectors

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Abstract: In this study, a portable and easy to construct solar cooker is presented as an alternative to traditional cooking methods to be used in humanitarian contexts, in order to face the issue of humanitarian goods transport and storage. The prototype consists of a trapezium-shaped cooking chamber and adjustable reflector panels made of inexpensive and readily available materials. The solar cooker was designed to be foldable and easily transportable by using lightweight materials. In fact, the folded prototype is compact having a lightweight of 7 kg. This allows to transport up to 124 units on a single pallet (Euro-pallet size) to the desired location. Several experimental tests without and with load (water and glycerin) were conducted using a black pot placed inside the cooking chamber, which has high area of clear glass, to evaluate its thermal and optical performances. During the tests without load, the highest temperature recorded for the studied prototype was 149.38 °C and the corresponding first figure of merit F_1 was 0.13 °C/(W/m²). The solar cooker loaded with 1 kg of water at 40 ºC took 115 minutes to reach 90 °C, being the average values of standardized cooking power and second figure of merit F_2 equal to 7.40 W and 0.18, respectively. The standardized cooking power was calculated using an equation derived from the Hottel-Whillier-Bliss formulation. Meanwhile, the prototype loaded with 1 kg of glycerin at 40 ºC took an average of 122 minutes to reach 105 °C, being the average standardized cooking power and average of second figure of merit F_2

equal to 13.19 W and 0.2, respectively.

Keywords: Solar cooker; Foldable; Adjustable reflectors; Experimental test; Humanitarian camps.

PERFORMANCE COMPARISON AND EXPERIMENTAL VALIDATION OF FOUR PROTOTYPES OF PANEL SOLAR COOKER AT HIGH TEMPERATURE

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Abstract: In this work, four solar panel cookers (i.e., Kimono, Funnel, Cookit and DSPC) were tested with silicone oil to evaluate their ability to overcome the boiling temperature of water. The outdoor experimental campaign was carried out during three different periods of the year, in the location of Ancona, Italy. The manufacturing steps of the panel prototypes were proposed in our recent paper [1] together with the results of no-load and load tests using water as test fluid.

Two cooker configurations, characterized by different aperture areas, were tested by inserting the same amount of silicone oil (1 kg) inside four receivers, one for each cooker. Preliminary results show that, as in the previous experimental campaign [1], the Kimono and Funnel devices perform better during all periods of the year analyzed. In fact, the maximum temperature reached by the silicone oil when tested with these two prototypes exceeded 145 °C for medium to high sun elevations. The Cookit also showed good performance while the Dual Setting proved to be the least performing device compared to the others.

[1] Aquilanti, A., Tomassetti, S., Coccia, G., Muccioli, M., & Di Nicola, G. (2023). Experimental characterization and performance comparison of four prototypes of panel solar cooker for low to high sun elevations. Journal of Cleaner Production, 136158.

Keywords: Panel cooker; Experimental test; Performance evaluation; High-temperature characterization.

THE TOLOKATSIN 2022, A SUSTAINABLE SOLAR OVEN

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Abstract: The first Tolokatsin solar ovens were designed and built more than 27 years ago. After so many years of successful experience in its operation, their application has evolved to be able to be applied as a solar sterilizer and other applications that require different temperatures and flux densities than those necessary for cooking. At CONSOLFOOD2022 Conference the constructal evolution of these solar ovens was presented, showing the changes made to reduce the losses by reflections, by changing the number of mirrors and the solar concentration, keeping only mirrors of simple curvature (very easy to manufacture).

In the search for greater sustainability, the most expensive materials used in these ovens were replaced to make them more affordable and easier to replicate in any small town with local materials. In particular, the stainless steel and aluminum containers were replaced with fired and cured clay, and the aluminum mirrors were replaced by inexpensive mylar films attached to a thin support, also, the number of these was likewise reduced.

The operational results of this new solar oven are presented, which are more than acceptable. The Tolokatsin 2022 is much affordable for everybody, although as expected, it still does not reach the extremely high performance of its predecessor model.

Keywords: Tolokatsin solar ovens, Nonimaging optics solar cookers.

CHARACTERIZATION OF AN EVACUATED TUBE DUPLEX SOLAR COOKER (ETDSC)

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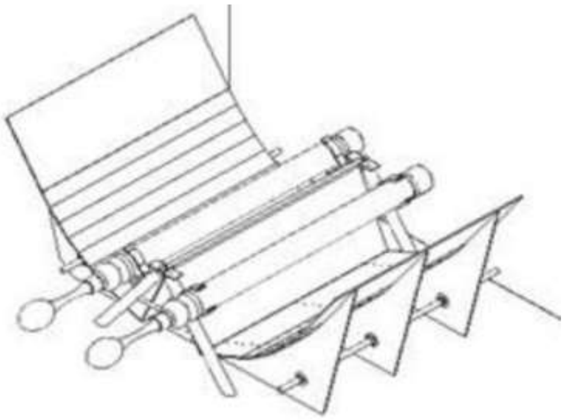
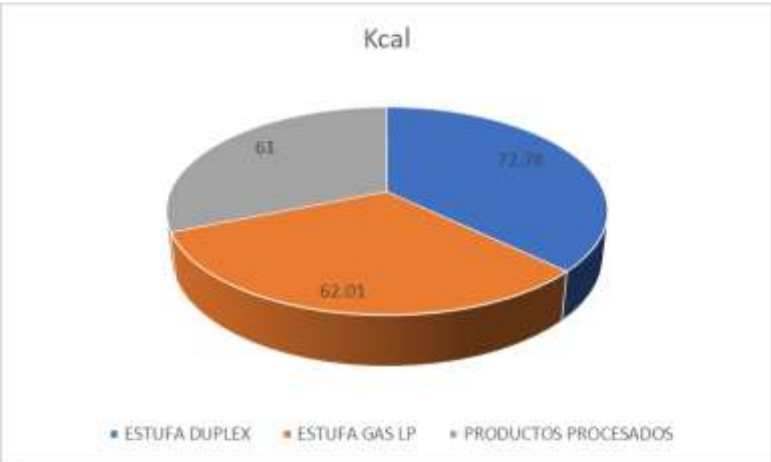
Abstract: The purpose of this study was to characterize an evacuated tube duplex solar cooker (ETDSC), the device is made up of two metal trays and a parabolic solar concentrator (PSC) and two evacuated tubes, in the metal trays the samples of the Food is introduced into each evacuated tube, cooking times are evaluated, considering weather variables, and the nutritional value of food prepared in the ETDSC and on a gas stove is limited. A 0.3 kg portion of chicken with vegetables is placed in tomato broth. For the measurement of solar irradiance, ambient temperature and relative humidity, a weather station was obtained. For the measurement of the wind speed, an anemometer was obtained, to measure the temperature inside the evacuation tube, type k thermocouples were used. To make the nutritional tables, methods described in the current regulations were used. A nutritional table of the prepared food was made, both in the ETDSC, as well as in the stove that works with LP gas. The food prepared in the ETDSC presented a variation greater than 15% in energy content with respect to the conventional stove and a variation greater than 16% with respect to the values of the nutritional tables reported for processed products. Derived from the results obtained in relation to energy content, it is established that the cooking method using the ETDSC is a viable alternative for food preparation. This proposal constitutes a promising option aimed at a sector of the population that lives in rural areas with difficult access to conventional fuels. Cooking food in two types of stoves: A conventional one, which works with LP gas, and a solar stove, with the following requirements respectively: Buying fuel for the gas stove, it increases constantly, for the ETDSC that has days with good solar irradiance, with ambient temperature higher than 23°C and wind speed less than 1 m/s. The preparation times may vary depending on the values of solar irradiance, in the same way it is necessary to train users in the use, management and maintenance of the ETDSC.



Diagrams of the evacuated tube duplex solar cooker are attached.



Values in kcal of the different cuisines.

REFLECTIONS ON OF ONE HUNDRED SOLAR COOKS FROM FOUR CONTINENTS

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Abstract: The Big Blue Sun Museum of Minneapolis Minnesota USA, is an collection of classic and contemporary solar cookers. The collection embodies a broad history of solar cooker fabrication and each cooker has inspired many to further the cause of promoting solar cooking.

The Museum launched an on-going video series in 2020 which documents the contemporary history of solar cooking, along with past history that otherwise has not been recorded. Over one hundred people were interviewed in person or online, from North America, Asia, Africa, and Europe. The video subjects represent a broad spectrum of experience with solar cookers, education, and promotional activity. We can learn much from them about how to motivate people to adopt and promote solar cookers in their communities and abroad.

The Museum asked open-ended questions: How did the interviewee(s) first become acquainted with solar cooking? How does the guest currently use and promote solar cookers? And what do they see as the most effective means of reaching those not familiar with solar cooking, and achieve a desired level of adoption?

Their responses also address some central questions: How will those in areas of deforestation, contaminated drinking water, and housing with the default appliance of an indoor wood or biomass stove accept solar cookers? Who best to market the appliance and practice so a cycle of dependency on outside agencies isn't established, and the region can become self-sufficient with integrated cooking methods? What external influences slow the progress of solar cooking?

Conclusions will be presented, including quotes and annotated video from the series. From these conversations, the Museum has launched or developed new volunteer-driven partnership projects developed to grow our network of the most active solar cooker proponents across the world.

Keywords: Solar Cooking, Solar Cookers, Solar Cooking Adoption, Solar Energy, Appropriate Technology

Session 2A

PHOTOVOLTAIC SOLAR COOKING WITH PTC CERAMIC HEATERS WITHOUT BATTERIES

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Abstract: Due to the continuous decrease in the price of photovoltaic solar panels, it is now possible to use them to produce heat, for example, for cooking, allowing indoor kitchens. But it is still necessary to have a regulated electrical current. We propose using PTC (Positive Thermal Coefficient) ceramic resistors, whose flexibility of operation adapts well to the variations of photovoltaic electricity and avoids overheating. In some PTCs, the resistance increases sharply above ≈200°C (Curie temperature); thus, the heat production stagnates. Therefore, there cannot be any burnout or overheating. A solar cooker has been conceived using them without them. This allows a solar cooker without electronics or batteries. The regulation of the cooker consists of putting into operation the appropriate number of ceramics according to the sunshine and the power required. This is feasible with the help of a Wattmeter, which guides the user in finding the best point of heat production. Since the temperature external to the resistors and pot is always below 200°C, it is possible to thermally insulate the cooker and the cooking vessel completely with ordinary materials. Thermal insulation significantly increases the installation's energy efficiency during the heating and slows the following cooling process in retained-heat slow cooking. The paper offers the design principles, implementation, and test results. It offers information to replicate and pave the way to improve this photovoltaic solar cooker.

Keywords: photovoltaic solar cooking, PTC ceramic heaters. Sustainable development. Energy poverty.

1.- Introduction

Let's take a quick historical look at the energy needed for cooking. Since the conquest of fire, wood has been the primary energy source. For *convenience,* it was gradually replaced by coal, wood charcoal, gas, or paraffin, whose heating capacity by weight and control are much more significant. Nowadays, wood is used in remote and isolated locations out of *necessity* as modern fuels are unreachable. Because wood sometimes does not renew itself at the same rate as it is harvested, it is necessary to find a new way of cooking, sustainable and renewable. Recently, electricity has been used for cooking when available and if affordable, but grid electricity does not reach the poorest remote locations. On top of this, wood fumes are toxic indoors the home and even outside of it, responsible for many diseases and premature deaths.

And now, there is a risk that fossil fuels will no longer be able to meet our needs, or they will be banned because of atmospheric pollution. In remote and isolated communities, fossil fuels become difficult to access for the poorest part of the population. Grid electricity, mainly fossil fuel-derived energy, seems even more inaccessible.

A solution is to use the mother of all renewable energies, the sun.

For several decades, a great deal of engineering and imagination has been devoted to solar thermal cooking; for example, Luther Krueger's "Museum of Solar Cookers" in Minneapolis, USA.

Meanwhile, emerging photovoltaic technology has made great strides. The exorbitant initial costs have followed a steady downward curve, which now crosses the rising curve of other energies, reaching below 1 €/kW of peak power.

What about using photovoltaic energy for cooking? Articles appeared on the subject around 2013. Since then, the price of photovoltaic collectors has continued to fall, e. g. [1]. The result is that solar cooking using photovoltaics now seems affordable. The low efficiency of PV panels compared with thermal solar cookers is overcome as described here.

Two obstacles must be surmounted, and this is what Section 2 of this article presents. The second obstacle leads to the proposed solution. Section 3 discusses the implementation of this solution. Section 4 deals with the regulation of the cooker. And Section 5 presents the thermal performance.

2.- Two obstacles and a solution.

The first obstacle.

To transform electricity into heat, it is customary to use nickel-chromium resistors (Ni-Cr), which can be found everywhere, e. g. electric radiators, toasters, and hair dryers. They withstand a specific power and even a little extra margin, but beyond a certain threshold, they burn out. Ni-Cr resistors, therefore, require voltage-regulated electricity to function normally. The now much-disseminated induction plate technology for cooking, which is a significant improvement, also requires an adequately regulated voltage.

The photovoltaic panel supplies electric power, primarily as an intensity I of electrons, coming from the absorption of photons, which is measured as solar irradiance W/m^2 (solar intensity G); actually, it is a collection of illuminated diodes connected in series and eventually in parallel that result in panel characteristic curves depending on the irradiance G, Figure 1. Because of that, the **operating voltage U must be selected**. The risk of resistor burnout is, therefore, permanent. A technique is necessary for ensuring a safe and efficient operation.

The second obstacle.

It is the **variable production of the photovoltaic panel**. The panel's electricity production depends on the amount of sunlight it receives. In a panel oriented to the sun, it is maximum under a clear sky at midday but decreases towards sunrise and sunset; it also decreases because of clouds and dust, either in the air or over the panel.

The characteristic line for the resistance
Let us connect with the preceding paragraph. The power P obtained is the result of matching the panel intensity I [Amperes] and the voltage U [Volts] with those of the load. The load is a resistance, which dissipates the resulting electrical power into heat; $P = I \times U$, expressed in Watts = Amperes × Volts.

The resistive load applied to a panel is characterized by R [Ohms]; according to the Ohm law, it is $U = I \times R$ [Volts], which is a straight line, depicted in Figure 1 whose steepness in the convenient U vs. I diagram is inversely proportional to the resistance R. The same Figure 1 shows three representative curves $U - I$ of the same PV panel illuminated by three values of G: $G_1, G_2,$ and G_3 although all intermediate values are possible.

When one connects a resistor R at the + and – terminal of the PV panel, the intensity across the resistance and the voltage must match the one delivered by the panel. Figure 1 shows the three crossing points, 1, 2, and 3, for three irradiances and the same R.

The characteristic curves of the PV panel

As Figure 1 shows, in a first approximation, intensity I [Amperes] delivered by the panel is proportional to the solar irradiance G (with a maximum of ≈1000 to 1100 Watts per square meter in the direction of the sun), which is on the plane of the panel(s) if oriented to the sun; $I \approx k \times A \times G$. k is a constant, and A is the surface area, typically around 2 m^2 for a single commercial panel. As a first approximation, for constant G, the panel intensity is almost insensitive to the voltage U for low voltages (near the short circuit, low R, delivering around 9 A for a commercial 2 m^2 panel). It falls abruptly when the voltage surpasses a definite value, reaching null Amperes when the circuit is open, $R = \infty$, as Figure 1 depicts, which is around 40 V for a commercial 2 m^2 panel. On the other hand, the resulting power $P = I \times U$ [W] increases almost linearly as U increases, up to a maximum $P_{máx}$, and for higher U it falls. Figure 1 shows the curve P for $G_2 = 500 \frac{\mathrm{W}}{\mathrm{m}^2}$. The resistor in Figure 1 has been selected for maximizing the power of irradiance, $G_2 = 500 \frac{\mathrm{W}}{\mathrm{m}^2}$. For different irradiances G, the $U - I$ combination resulting comes from the crossing of the straight line of R and the curve at the actual irradiance. The result is a fast drop in power for $G \neq G_2$ for the selected R.

A variable R is required

Thus, what determines the relation between U and I is R, as explained above, $U = I \times R$. Applying a fixed resistance R to a panel yields meager production under low solar irradiance, point 1. On the other hand, for $G_3 = 1000 \frac{\mathrm{W}}{\mathrm{m}^2}$, the power is also low, far from the maximum possible. Both points are indicated with bullets. Thus, there is a need for varying R to reach the maximum power for any G. The Maximum Power Point MPP is only reached at a specific voltage for any G, which is indicated with stars for the three values of G used. Fortunately, these optimum voltages do not mutually differ very much.

Because of these facts, many PV battery chargers and inverters incorporate an MPP Tracker (MPPT) that continuously searches for the adequate U for any G, as Fig. 1 shows with stars for the three cases considered so that maximum P is reached every time, $P_{máx}\langle G \rangle$. The variable R needed for the panel is achieved through electronics (e. g. Pulse Width Modulators PWM). In commercial devices, it is frequent that the MPPT automatically plays a dual role: optimizing the panel's production and, if applicable, also controlling the supply voltage, and very frequently, adjusting the charging process of a permanently connected battery. Avoiding battery damage requires limiting the intensity towards it, depending on the degree of charge and temperature. But also, the effective voltage applied must be slightly higher than the nominal voltage of the battery (12 V, 24 V, …) to transfer electric charge to the battery. Consequently, a charge controller is necessary to accommodate the delivery from the panel to the battery's requirements. Typically, it adapts the voltage and intensity to the battery needs, frequently losing part of the power available from the panel unless the electronics are pretty complex, i. e. using an automatic voltage converter (Buck-Boost converter). When discharging, disconnected from the PV panel, the battery offers an almost constant voltage, typically slightly below 12 or 24 V, down to the point near complete discharge when the voltage goes null. A voltage regulator must adjust the supply to 230 V AC independently of the selected panel voltage selected for supplying power to an AC grid.

Another issue is how the controller discerns to split the power from the panel(s) between charging the battery and supplying the connected load.

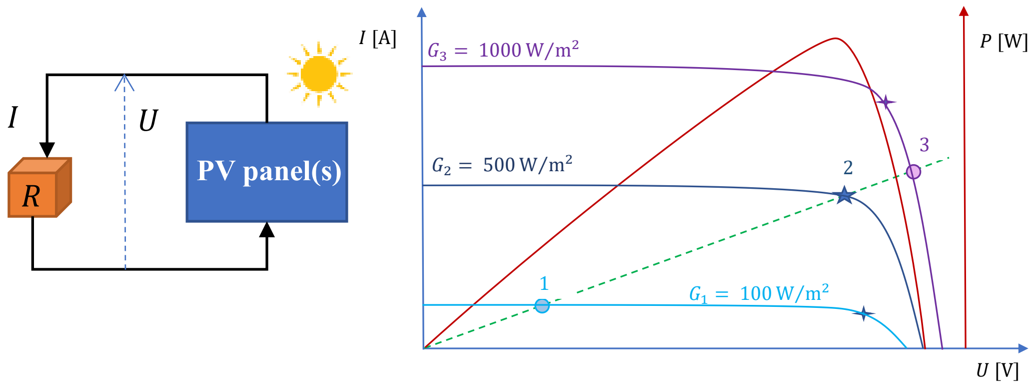


Figure 1.- Relations between voltage U and intensity I of a PV panel in good condition for three irradiances, the curve for a resistance R, and the power P delivered for only G_2 and R for MPP at G_2.

A solution, no battery

Technically, correctly interposing a battery with its regulator makes it possible to offer a complete and satisfactory system. The panel could be used near its optimum, the battery is charged according to the rules of the art, and the resistors of the cooker, of almost constant R, have a correctly regulated electric current as a result of an almost constant U. In addition, because the battery is an energy storage device, it is possible to cook off-sunshine. But this is not without its problems:

- Efficient panel/battery controllers with MPPT are expensive and typically are only available for large powers.
- The battery is expensive; although its price has decreased significantly, it is still the costliest component of a photovoltaic cooking system. It has a limited lifespan of about four years if correctly operating and much less in an extreme temperature environment or because of abuse.
- Frequent transport of batteries to remote locations is not easy.
- Finally, a battery is particularly polluting because of the metals from which it is constructed, Pb, Cd, Co, Ni, Li, etc.

On the subject of lithium batteries and according to many studies, e. g. [2], the question is, will there be enough left over for cookers in developing countries?

On the subject of rare and scarce metals, let us recall here that contrary to a current belief, there are no rare metals in photovoltaic panels [3]. The challenge is now to design a solar cooking device without a battery. Thermal Energy Storage TES can replace it.

As part of the solution, we propose the use of Positive Thermal Coefficient (PTC) ceramic resistors [4]. Like all resistors, a ceramic material produces heat when an electric current flows through it, independently of it being AC or DC. But as it heats up, its electrical resistance decreases, Figure 2. For the resistors of our interest, at ≈200 °C, the resistance is divided by around three compared to the ambient temperature, so its heating power is multiplied by three under a constant voltage. Then, beyond ≈200 °C, the resistance increases sharply, Figure 2. When it becomes remarkably high, the electric current can no longer flow, and heat production stagnates. This part is indicated with a dashed line in Figure 2.

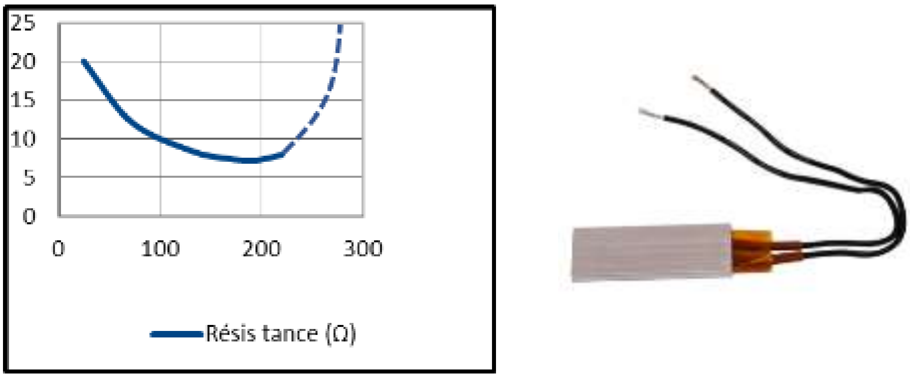


Figure 2.- Left) Example of the variation of the resistance R of a PTC element as a function of its temperature, obtained with the test bench herewith proposed. Right) example of a PTC heater element with a rated power of 35 to 80 W.

3.- PTC Ceramic Heaters

Although not widely known, ceramic heaters are pretty standard in everyday life. Small electric heaters, available in most household electrical goods stores and sold as auxiliary heaters, are a good example. Small and light, they are necessarily equipped with a fan that permanently drives out the heat produced by the ceramics, without which the heat production would stagnate. In cars, ceramic heaters are used to warm up the fuel and oil in winter without the risk of overheating.

Ceramic resistors can be found in DIY glue guns; the stagnation temperature corresponds to the melting heat of the glue, so there is no need for a thermostat (you don't hear a thermostat being triggered like with an iron).

The characteristics of the ceramic heating elements are interesting for our cooker:

- The heating elements do not burn out.
- The supply temperature of ≈200 °C is more than sufficient for cooking with water, such as braising, steaming, etc., except for frying in oil and grilling.
- The temperature of ≈200° is lower than the ignition temperature of cotton; it is, therefore, possible to insulate the entire cooker with cotton towels, for example. This insulation minimizes heat losses to ambient; thus, less power is needed to cook; also, insulation prolongs cooling with no power added.
- The commercial PTCs contain a ceramic wafer on which the electrical wires are soldered. A socket of Kapton® electrically insulates it pressed between two thin aluminum plates, Figure 2.

The only indication typically available from the buyer is the recommended voltage: 12, 24, 36, 48, 110, and 230 V, while a conventional resistor does not operate under a nominal voltage. In addition, the PTCs have a breakdown voltage limit not to reach. In principle, the manufacturer can indicate a maximum permissible power, which must not be exceeded. There is also a maximum temperature not to reach.

From common Chinese suppliers, usually, there is also no datasheet. The price varies from 0.40 € to 0.80 € for large quantities; it increases to around eight times higher for individual purchases.

As a main result, designing a cooker with ceramic heating elements is now possible as the Curie temperature can be as high as 250 °C. A small thermal resistance from the PTC to the pot is paramount. A layout can be as follows; several resistors are installed under a heating plate; the cooker user has two or three switches and a small Wattmeter, nowadays of such a low cost as 9 €. The user adapts the number of in-parallel resistors to the current sunshine, looking for the best operating point of the solar collector by reading the Wattmeter, or can reduce power if desired. In the case of constant sunshine, no monitoring is necessary. In case of a large increase in electrical power, the resistors are self-regulating and do not burn out.

There is the issue of starting with the PTC elements cold. Because of the high resistance, Fig. 2, they do not heat very much, especially if loading the panel with too high a resistance. Loading with a cold pot is recommended not to load until the plate has already heated itself.

The operation of the cooker can be automated, for example, using a microcontroller, e. g. of the Arduino® type. A cloudy passage could not affect the cooking process through its use, as MPPT will do the job.

The following section addresses the design of the cooker.

3.- Ceramic resistors and the cooker

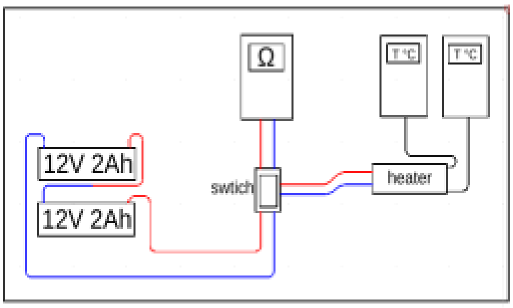
Almost all of the choices made below are not imperative, just the result of the research; many variants are available to the designer.

A first choice concerns the operating voltage of the installation. For reasons of user safety, exceeding a voltage of 40 V is not recommended, i. e. using a panel producing a voltage of ≈40 V in open-circuit, and therefore approximately 22 to 32 V in the usual operation.

Commercial resistors stamped as for 36 volts, of standard dimensions 35 x 21 x 5 mm, have been used successfully; 48 volts PTCs would also be suitable. Resistors stamped 24 volts were not used, as they have too low R.

The PTC test bench

Given the limited information provided by the manufacturer or seller, and also because of wide tolerances, it is essential to test the ceramics on a test bench, such as the one proposed here, Figure 3.



"36V" 35*21		
Température (° C)	Résistance (Ω)	P=U*U/R si U = 30V (W)
21	39	23
85	20,8	43
127	15	60
164	13	69
193	12,1	74
204	12	75
215	12,2	74
230	13,2	68

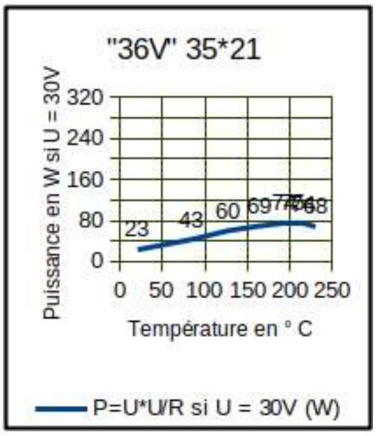


Figure 3.- Left) A simple test bench for PTCs. Center) A sample of results. Right) calculated power.

The resistor is held between two pieces of wood and instrumented by one or two wire thermocouples; type T or K are suitable and widely available in a ready-to-use configuration. A laboratory bench power supply of variable voltage up to 24 V DC is suitable; instead, two 12 Volt / 2 Ah batteries are suitable too, or a 24 V AC plug should also be suitable, with an autotransformer if reasonable control is desired. In the center of the circuit, there is a three-position switch, Figure 3. The operator powers the resistor while observing the temperatures, flipping the switch, and reading the Ohm value after the off-line temperature measurement somewhat stabilizes. Seven or eight measurements, spaced about 30 °C apart, are sufficient. Measurements for higher than the Curie temperature are difficult with this test bench unless extra power is available and/or extra thermal insulation is added.

A measurement example

The Figure 3 Center) offers the first two columns of some measurements. The third column shows the calculated power of the resistance, for an assumed voltage of 30 V, according to the formula $P = U^2/R$.

The graph on the Right) shows the power values. The operating temperature of the heating plate is estimated at 150 °C, as there is a temperature drop from the PTC to the hot plate, and there are heat losses. It varies according to the temperature of the cooking vessel, depending on whether it is being heated or maintained hot. The corresponding power is noted graphically, 65 W.

The arrangement of the resistors under the hotplate is carried out according to these elements.

The arrangement of the resistors:

For a 300 W peak panel, six identical ceramic resistors nominally declared for 36 V, with a calculated power of 65 W at 150 °C, were installed. They were arranged into three groups:

- A group of 3 resistors in parallel.
- A group of 2 resistors in parallel, actually a double-size PTC.
- A group of 1 resistor.

The user has three switches on this proposed cooker, allowing him to parallel set the power on 7 levels, including null. Thus, there is no electronic control at all.

Construction of the cooker

Below, in Figure 4, there is a one-piece cooker made from plywood, which an artisan can build. It is also possible to have the control unit separate from the heating element to facilitate cleaning and hygiene or to enclose it in a waterproof container. The heating plate is cut out of 5 mm sheet metal; aluminum is preferred. The insulation, which surrounds the heating block and the cooking vessel, is shown.

4.- The power control of the cooker

The role of approaching the MPP

At first sight, the regulation of the cooker consists of searching for the MPP with a couple of values (U, I); fortunately, U for maximum P does not vary very much when G is varied, Figure 1. MPP is achieved by putting the appropriate number of ceramics into operation, among the six ones installed under the cooker's heating plate. For that, the characteristic curve of the commercial PV panel(s) is consulted. If only a graph of intensity versus voltage for different Gs is provided, the power curves $P\langle U\rangle$ must be drawn and the maxima discovered so that the minimum PTC resistances (just indicative of the working point) are determined by calculation as $R_{mín} = U^2_{P_{máx}}/P_{máx}$. Alternatively, it is near the knee in the intensity versus voltage $I\langle U\rangle$ curve and $P_{máx} = U_{knee} \times I_{knee}$ so that it becomes $R_{mín} = U_{knee}/I_{knee}$.

The power of these ceramics installed varies according to their temperature, which varies with the temperature of the contents of the cooking vessel, but not so much according to their self-regulating nature. The temperature of the contents rises during the heating period and stagnates (steady-state) during the cooking process when input power equals the heat losses to the ambient, in addition to producing steam.

Manual control and automatic control

In the case of the manual regulation studied here, the user has six adjustment levels. The user makes a choice that can be verified with a Wattmeter. When the day is clear and sunny, the user can go about his cooking duties without worrying about the cooker.

An additional automatic control has been developed with a small microcontroller, for example, an Arduino®. The rudimentary algorithm is of the "Perturb and Observe" type. Two sensors for voltage and current transmit the information to the microcontroller. It calculates the instantaneous power. It then slightly modifies the number of ceramic resistors in operation, checks the effect on the instantaneous power, and confirms or denies the previous modification, repeating the process.

The automatic control tested had 13 levels, which is more precise than the manual control. A time delay is necessary to allow for the stabilization of temperatures.

In the event of a malfunction, there can be no damage. If the resistors are overloaded, the ceramic material plays its regulating role. If the resistors are underpowered, the cooking process continues like a "Norwegian pot", "heat bag", or residual heat cooking at low-temperature.

5.- Results obtained

Some examples of cooking.

They were carried out with a panel of 1.66 m², peak power 280 W MPP. Placed on Brittany, France, oriented to the South, and with an inclination angle of 50 degrees. No Sun tracking. Tested during summer on clear and sunny days at noon hours, Figure 4.

Figure 4.- Left) The developed prototype is shown under testing. The pot is insulated with cotton tissues [5].

Three examples and recipes:

- Plain rice: rice 300 g, water 500 g. Total cooking time: 55 min.
- Cooked vegetables: Onions 250 g, tomatoes 800 g. Total cooking time: 1 h 30 min
- Chicken casserole: 3 chicken thighs 680 g, onions 145 g, fennel 175 g, courgettes 270 g, red pepper 225 g, green pepper 215 g, crushed tomatoes 200 g. It is cooked in a Lagostina® pressure cooker of 3.5 liters capacity. The temperature reaches 110 °C after 1 hour, then cooked for 15 minutes.
- Chicken Basquaise: 4 chicken legs with drumstick and onions, to be browned. Addition of 200 g of tomatoes and 200 g of peppers. Heat up to 100 °C after 35 minutes; then cook from 100 to 115 °C for 20 minutes. Cooked in a Lagostina® pressure cooker of 3.5 liters capacity. Continuous irradiance measured on the plane of the panel $G = 930\ \mathrm{W/m^2}$, constant power of the cooker 220 W.

- Coral lentils dahl: browned onions 210 g, tomatoes 400 g, lentils 300 g, coconut milk 400 ml, stock 1/4 liters. Heating up to 100 °C after 3/4 hour. $G = 900$ to $960\ \mathrm{W/m^2}$, almost constant power of the cooker at 220 W. Then, cooking as a Norwegian pot for half an hour without any power supply; during this half hour, the temperature dropped from 100 °C to 90 °C with the insulation shown in Figure 4.

A method of measuring the performance of the panel plus cooker combination

The time taken to bring 1 liter of water to boil can be measured; this is already a good indication of this cooker prototype's performance. However, one may wish to be more precise in performing thermal calculations, in which case the notion of boiling could not be precise enough. The proposed methodology is to measure the starting temperature, then measure the time needed to reach the water temperature of 97 °C inside the pot, just before boiling at sea level. In an experiment with a starting temperature of 25 °C, it reached 97 °C in 40 minutes. The specific heat of the water is 4.18 $\mathrm{J/(g\ °C)}$. The amount of energy is (97-25) °C ×4.18 $\mathrm{J/(g\ °C)}$ ×1,000 g= 301 kJ. Duration of the operation: 40 min×60 s/min = 2,400 s. The average net power of the cooker is 301,000 J/2,400 s ≈ 125 W. As the average electrical power of the cooker has been measured as 220 W, this implies an average electricity-to-heat efficiency of 57%. The average sun-to-electricity PV efficiency is ≈ 20%, with a resulting overall efficiency of ≈15%.

6.- Some additional notes

Heat storage

In the case of a cooker without a battery, a substitute would be the storage of thermal energy for a few hours, for example, with a phase change material, such as erythritol [6], [7], [8], [9], and [10] among others. This, with good insulation, makes it possible to heat the breakfast the following day or to prepare hot sanitary water for a baby just with the residual heat. It should also be noted that the ceramic cooker can operate perfectly well on a previously charged battery.

Lighting and telephony

Without a battery, these devices can be recharged with a DC/DC USB converter worth only a few euros. When connected to the panel, it charges mobiles and lanterns via a small solar-integrated "USB Power Bank".

Quality of the switches

The quality of the switches, known as "rocker switches", is crucial. In the present case, the voltage is low, but the current is high, and DC. After closing the switch, the inner contact blades will heat up if they are loosely in contact with each other. This is a lost energy for cooking and is also a risk of an accident if overheating. Manufacturers of suitable quality switches state a maximum contact resistance of 50 milliohms in their data sheets. Do not hesitate to check this value with an ohmmeter after delivery. Last but not least, a peculiarity of direct current DC is that it causes arcing when the switch is opened, resulting in abnormal wear of the contacts. Reducing arcing with additional electronic elements is possible.

A small and bizarre phenomenon

Let's say a cooker is in operation. When removing the cooking vessel, the hot plate rises in temperature to the point of stagnation, then the Wattmeter indicates almost no power, even though it is sunny, but there is no malfunction. Putting a container back on the plate filled with cold water brings power back.

7.- Conclusions

The paper offers the possibility of constructing a PV-based solar cooker with no battery and no electronics, thus, suitable for sustainable developments for energy-vulnerable communities.

It can be manufactured on-site in many locations.

The paper offers the basics and practicalities particularized to a small power prototype, which has been tested for thermal performance and under real cooking. Escalation to higher powers is straightforward with the information offered.

Information on the construction and use of a cooker with ceramic heaters can be found at photovoltaic-solar-cooking.org. The contents are free of rights. From this basic model, a multitude of different cookers can be designed.

In this heating device, instead of adapting the electricity to the resistors, the resistors adapt to the available one. There is only not to exceed the limits of the device: maximum power, maximum temperature, and maximum voltage. The proposed design offers a high simplicity and a low cost.

8.- Acknowledgments

Jean Boubour founded photovoltaic-solar-cooking.org, which gathers some retired people in the industry informally in Brest (Brittany), France. Their help is deeply recognized. This activity progresses without any economic aim on devices of electro-solar cooking and incidentally for producing sanitary hot water. The prototype described here was constructed within this group by Mr. Jean Boubour. It is now under testing, mathematical modeling, and additional development at UC3M.

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Heat storage for cooking: A summary of experiences with direct and indirect solar energy concepts

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Abstract

The thermal energy demand of households accounts for more than half the total energy needs, depending on geographical location. For the case of Sub-Saharan countries, the dominating energy source for food preparation is biomass. With a growing population, the increased pressure on the biomass resources leads to deforestation and the subsequent environmental degradation. The objectives of a long term collaboration between African universities and NTNU have been to develop solar energy alternatives to wood-fuel for food preparation. As the sunshine is intermittent, the main focus has been on developing heat storage solutions which can be simple, robust, affordable and be produced and maintained with local resources.

An overview of different types of storage concepts which have been tested is given, together with the experiences related to solar charging and discharging for cooking. The storage concepts include Phase Change Materials, thermal oils with forced and natural thermal stratification and both air and oil based rock beds. The energy collection concepts include concentrators (troughs, parabolic dishes, Compound Parabolic Concentrators) and Photo Voltaics (PV). The heat transfer concepts include forced and natural circulation (thermosyphons), heat pipes and thermal conduction.

As the costs of PV has been steadily decreasing, the further work on heat storage for cooking is based on PV for the energy source, in the form of stand alone system or as heat batteries connected to PV power systems.

EXPERIMENTAL PERFORMANCE OF A FINNED SOLAR COOKING STORAGE POT

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Abstract: Thermal energy storage (TES) in solar cooking pots enables cooking during off-sunshine periods to enhance the usefulness of these pots during non-sunshine hours. A finned type solar cooking storage pot is designed and evaluated experimentally. The storage cooking pot is designed with a finned storage cavity to store heat during sunshine cooking periods. 5 litres of Sunflower oil are used as the storage material inside the cavity. The solar cooking pot is heated up during solar cooking periods with a 1.8 m parabolic dish concentrator. During storage cooking periods, the pot is placed in a wonderbag insulating cooker to investigate the storage performance. For both solar and storage cooking periods, 1 kg of water is used as the load. The solar and storage cooking periods are both 3 hours. 1 kg of water is boiled in around 30 minutes, and all the in water is the pot is fully evaporated after around 2.5 hours. The maximum temperature achieved by Sunflower oil in the storage cavity is about 134 ºC during the solar cooking period. For the storage cooking period, water in the pot achieves a maximum temperature of around 84 ºC in about 30 minutes. The load temperature is around 70 ºC at the end of the storage cooking period which is drop of 14 ºC from the maximum load temperature during storage cooking.

Keywords: Experimental thermal performance; Finned storage cooking pot; Solar and storage cooking.

ARE STAINLESS STEEL POTS SUITABLE FOR SOLAR COOKING?

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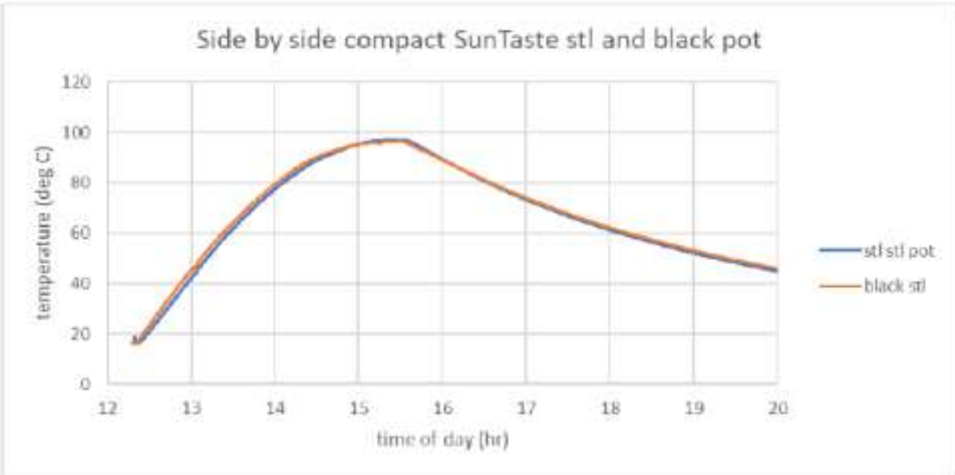
Abstract: People new to solar cooking have asked me many times as to what makes a good pot for solar cooking, specifically for box cookers. My standard answer was that a black or at least dark colored pot would be best as it absorbs solar radiation well. However, most people have stainless steel vessels for cooking at home, and it is an extra expense to buy black cooking pots. The question arose how important the color really was. Thus, a test was devised to check that out. Two identical box cookers were used side by side together with two identical stainless steel pots with glass covers, one of which was spray-painted black, each filled with 1.5 liters of water. The temperatures were measured as the water was heating up, please see attached figure. The ambient temperature hovered around 20 ºC, while solar radiation measured between 900 and 920 W/m2. Surprisingly, the time to reach 95 ºC was indistinguishable for both cases. The cooker with the black pot appeared to be heating up slightly faster. This sounds like a contradiction (if it heats up faster, it should reach the maximum temperature sooner), but it can be explained that although the black color absorbs solar radiation better than the unpainted one, the black pot loses heat by radiation faster than the stainless steel one as the thermal emissivity of the steel is significantly lower than that of the black paint, and at higher temperatures the thermal radiation heat losses become more dominant. In conclusion, it appears quite possible to use stainless steel pots for solar cooking – at least in the kind of box cookers that were used. It remains to be seen if the result is similar for panel or funnel cookers as this work differently from the box cookers.


Side by side compact SunTaste stl and black pot
temperature (deg C)
0
20
40
60
80
100
120
12
13
14
15
16
17
18
19
20
time of day (hr)
stl stl pot
black stl

STANDARDISED POWER VALUES OF SOME TESTED SOLAR COOKERS FOLLOWING THE LINEAR REGRESSION OF ASAE S580.1 STANDARD PROTOCOL AND THE LINEAR REGRESSION ASSOCIATED WITH THE HOTTEL-WHILLIER-BLISS FORMULATION

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Abstract: In the present work, two linear regressions of standardised power values of some tested solar cookers apparently very close are compared. One regression, largely used by testers and by some research teams, is based on the ASAE S580.1 Standard protocol and the other regression is based on the Hottel-Whillier-Bliss formulation, which has been largely adopted mainly to report performance of solar collectors for heating water at steady state but also to report performance of solar cookers by some research teams.

The procedure supporting the ASAE S580.1 cooking power of a solar cooker seems at a first view to follow the Hottel-Whillier-Bliss formulation but due to a small minor difference in the procedure of manipulating the experimental data when plotting the linear regression, the derived standardized power value is physically inconsistent because it does not represent the performance of the cooker when solar irradiance of 700 Wm^{-2}. When using the approach based in the Hottel-Whillier-Bliss formulation, the reported standardised power is physically consistent because it includes the influence of solar irradiance on the difference between the load temperature and the ambient air temperature. The differences between standardized power values produced by the two approaches depends on i) the slope of the linear regression of tested cooker, which depends on the thermal resistances to the heat transfer from the receiver to the surrounding ambient and ii) on the ratio between the solar irradiance registered during the experiments and the solar irradiance of 700 Wm^{-2}.

Keywords: Solar cooker, performance, cooking power, standardized cooking power.

OPTICAL RAY-TRACING ANALYSIS OF GEOMETRICAL VARIATIONS OF A FUNNEL SOLAR COOKER

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Abstract: Funnel solar cookers are simple, effective and have multiple advantages in practical use. The typology is wide but a large part of the existing designs are based on a 3D funnel-shaped concentrator assembled from a series of flat reflective panels. The optical performance of a funnel cooker design of this category has already been studied in a previous work. However, there are some interesting geometric aspects that have never been investigated before. The typical funnel geometry has two degrees of freedom to define its shape. This generates a family of variations from the base geometry. The influence of these variations on the cooker optical performance is unknown. This work uses the open source Soltrace ray-tracing tool to improve the understanding of these aspects. This knowledge may be of interest to designers and also to practical users of the funnel solar cooker.

Keywords: Solar funnel cooker, geometric variations, optical, raytracing, Soltrace

EXPERIMENTAL METHOD TO STUDY THE EVOLUTION OF THE PERFORMANCE OF SOLAR COOKERS AS A FUNCTION OF SOLAR ALTITUDE

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Abstract: The performance of solar cookers, mainly box cookers and panel cookers, depends on the solar altitude. To study the effect of solar altitude, using the ASAE S580.1 standard or another method that uses liquids. Many tests are required, at different times of the year (different solar altitudes). For this reason, a study method was developed that does not use liquids as study fluid. Leaving only the pot full of air.

When the pot is without liquid inside, the pot is operating with small inertia because the measure air temperature achieves much higher values, with short delay, than the ones obtained with liquids. Moreover, the registered evolutions can represent also how the stagnation temperature depends on the solar altitude angle. Thus, the plots provide valuable information about what is the most suitable ranges of solar altitude angle for each solar cooker. This method has been validated and has been improved with several experimental tests in different solar cookers.

Keywords: Solar cooker, solar altitude, Experimental method, box cookers, panels cookers.

COMMUNITY SOLAR COOKER USING LINEAR FRESNEL COLLECTOR

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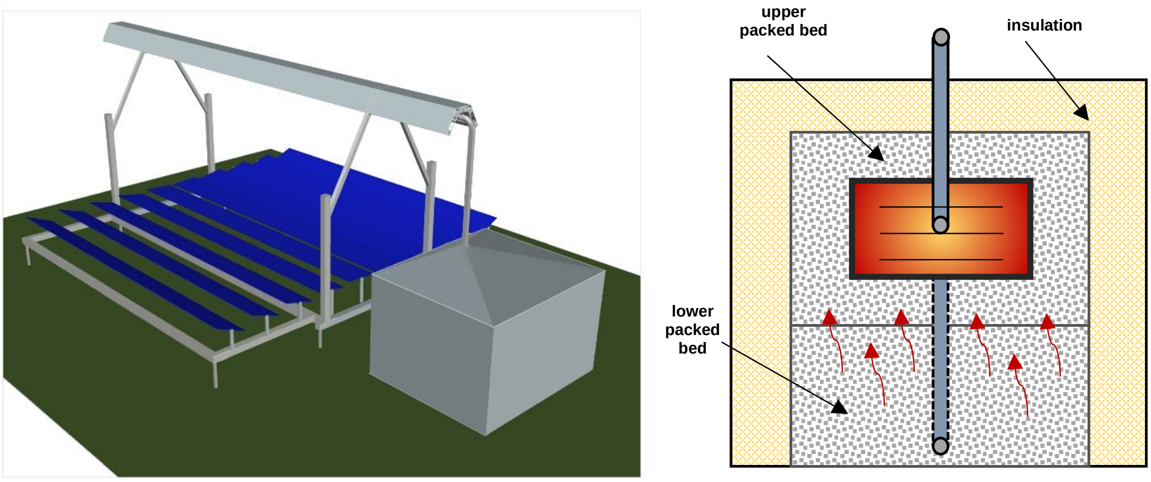
Abstract: Solar cooking is receiving increasing attention for its application in different contexts. In remote or rural areas, where the conventional energy source, either electricity or fuel is not available, it can represent an alternative to conventional cooking. Among different techniques, the concentrating solar cookers use a reflector properly shaped to refocus the incident sunlight on a focal point where the cooking object, a pot or an oven, is located. Parabolic dish is the most common type, although models based on linear parabolic reflector are emerging. Scheffler type solar cookers is used either for small cooker or community cooker.

In this study a community scale cooker is designed based on an original set up. A Linear Fresnel collector is used as concentrating technology. The sun light is not concentrated directly on the cooking object, instead it heats up a heat transfer fluid flowing inside the linear receiver, which then delivers heat to an oven placed close by. This configures an indirect concentrating solar cooker, with a fixed cooking point. In general terms the increased complexity of an indirect cooker limits its feasibility and increase the costs. The innovation here proposed is based on the use of air as heat transfer fluid which simplify the hydraulic equipment. Ambient air is blown through the receiver of Linear Fresnel collectors and is heated up to the desired temperature before to be introduced directly into the oven. Solar hot air can preheat the oven and the food as well as maintaining the required temperature during the cooking time. The design obtained is derived adapting existing commercial linear Fresnel collector for the purpose, for a peak power thermal of 15 kW. The oven is embedded into a packed bed of rocks, well insulated from the ambient. It increases the thermal inertia of the oven and acts as thermal storage, allowing to keep the required cooking temperature during short cloudy periods. Moreover, additional heat storage can be added below the oven as additional packed bed volume of rocks. When the oven is already hot, the excess of hot air is sent to the lower packed bed which heats up. During evening /night heat is transferred to upper part by air natural convection, allowing cooking without sun.

Keywords: Solar, Linear Fresnel collector, solar oven, thermal storage, hot air.



(a) (b)

Fig.1. Community solar cooker using Linear Fresnel collector (a); oven with packed bed of rocks (b).

SOLAR COOKING IN THE RURAL ZONES OF MÉXICO

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Abstract: In Mexico, 79% of the population lives in urban locations and 21% in rural areas, for cooking, the rural population uses coal, wood, plastics, or garbage, among other materials, most of which, when burned, produce polluting gases for the environment, in addition to contaminating food. There are other fuels but for their use conventional stoves are required and this entails a high cost for the communities. Mexico is located between 15° and 35° latitude, considered one of the most favored regions in solar resources in the world, and it was the intention of the author to demonstrate the feasibility of solar cooking in rural areas of Mexico and demonstrate to the Mexican population the power of the sun. An irradiation value of 5.5 KWh/m^2 was obtained, this was measured and documented. In the State of Mexico, solar cookers of various geometries were manufactured by engineering students, some with cardboard and aluminum, others with metal sheets, of which they were shown to people in rural areas of Toluca, demonstrating the cooking of some foods such as, meats, eggs, heating water for coffee, cooking some vegetables, among others. The solar concentrators were assembled locally and used on many occasions, these ultimately remained with the families for future use. These Solar concentrators are cheap to manufacture, when cooking food there was no contamination of food or the environment, these concentrators were of great help to families.

Keywords: solar cooking sun environment Mexico

Session 2B

THERMAL EVALUATION OF A MIXED TUNNEL TYPE SOLAR DEHYDRATOR UNDER DIFFERENT OPERATING CONDITIONS

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Abstract: The objective of this work is the thermal evaluation of a tunnel-type mixed solar dehydrator. The solar dryer receives heat through direct radiation that falls on the transparent surface of the tunnel walls and through the air that is heated with direct solar radiation through an air heating system, which consists of four flat plate solar collectors connected in series to a fan that directs hot air into the tunnel. The solar dehydrator can dry different agricultural products and has 40 trays with a total area of 10.8 m^2 where the products to be dehydrated can be placed.

The tunnel-type solar dehydrator measures 5.5 m long by 0.5 m wide with an average height of 0.53 m. For its evaluation, it was instrumented to monitor the following variables inside and outside of the tunnel: solar radiation, temperature, relative humidity, and volumetric flow rate. The evaluation tests in the tunnel-type mixed solar dehydrator obtained internal temperatures between 50 °C and 75 °C with average radiation of 914 W/m^2 and a mass flow of air of 0.053 kg/s. In addition, the thermal performance with or without load will be evaluated. The experimental results with load were using water to be evaporated to maintain the same experimental conditions.

This dehydrator can carry out the drying process since it operates within the range of temperatures recommended for drying agricultural products. It is worth mentioning that the coupling of forced convection solar heaters for air heating substantially increases the energy inside the tunnel, improving its performance and capacity.

CFD MODELING AND THE PERFORMANCE EVALUATION OF A MIXED-MODE FORCED CONVECTION SOLAR TUNNEL DRYER FOR CURRY AND CORIANDER LEAVES

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Abstract: One of the earliest unit techniques used to preserve agricultural products is drying, a complicated process that involves simultaneous heat and mass transfers. Final quality of product in drying process significantly depends on the flow behavior of drying air. The non-uniform temperature distribution and, air flow inside the drying chamber are the most significant drawbacks of conventional sun dryers. The employing of mathematical modelling methods, such as computational fluid dynamics (CFD), has great promise for determining the optimum solar drying conditions and dryer design that can maintain the desired product quality.

In this study, a low-cost, user-friendly mixed-mode forced convection solar tunnel dryer (MFCSTD) consisting solar air heater and dryer section has been desined and fabricated. The performance of the dryer was simulated using the Computational Fluid Dynamics (CFD) approach and validated by experimental obtained data. The simulation is carried out for an unsteady state condition and the $k - \varepsilon$ model is used to represent the turbulence model. At a constant airflow velocity of 0.6 m/s, CFD modelling and experimental research were carried out using 0.7 kg of curry leaf and 1 kg of coriander sample. In an experiment, the moisture content of curry leaves and coriander leaves in the MFCSTD decreased from 63.39% to 4.82% during 3 hours and from 89.59% to 6.59% within 4 hours, respectively. The average instantaneous drying rate obtained by experimental investigation and CFD simulation for curry leaves at the typical time was 0.002325 kg/min and 0.002565 kg/min while for coriander leaves 0.00442 kg/min and 0.00416 kg/min respectively. The average percentage deviation between predicted and experimental moisture content and drying rate for curry leaves were 6.904%, and 19.345 kg/min respectively and for coriander leaves was 7.09%, and 18.73 kg/min respectively. The average instantaneous drying efficiency values obtained for curry and coriander leaves were 22.95% and 30.70% respectively.

The experimental investigation and CFD analysis of curry and coriander leave in a solar tunnel drier are equivalent. With a variance of between 5 and 15%, the simulated results are in fair agreement with the experimental data. Nutrient concentrations were higher in dried samples, according to nutritional analysis studies. Since dried veggies have a low moisture content, they can be stored for a longer time.

Keywords: Curry leaves, Coriander leaves, Drying efficiency, Leafy vegetables, Mixed-mode forced convection solar tunnel dryer, Nutritional analysis, Solar drying.

A CASE FOR INCLUDING SOLAR DEHYDRATORS IN FOOD PROCESSING

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Abstract: The access of small-scale food producers and big agro-industry players to equipment is abyssal. The latter have access to well-developed and appropriate technology. In this article, one proposes a novel design for food dehydration equipment to serve small-scale producers, reducing their technological gap regarding dehydration. Equipment that dries more than 1000 kg daily is costly and consumes much energy. Lower capacity machines, up to 100 kg per day, are often one-off handcrafted projects built with reused materials without dimensioning supporting the design. They are usually not easily transportable and underperform: the drying chamber tends to overheat; the solar collector's area is usually 50% inferior to the required product quantity. One proposes a mobile dehydrator with a solar collector area 7 times larger than average, promoting moisture removal by naturally convected airflow at lower temperatures, reaching up to 4,5 m/s and 44,3 °C inside the entrance of the drying chamber. Under these flow conditions, the food's organoleptic properties are preserved compared to the often high-temperature drying handspun machines continually adopted by small-scale producers. The internal layout of the drying chamber was also changed to promote the increase of turbulence and reduce the existence of recirculation areas, thus facilitating the transfer of moisture from the food to the airflow. The expected result from implementing this novel design is avoiding food losses due to natural degradation by increasing the product's shelf life before transport and transformation. Solar equipment has zero operational costs, and all these advantages are expected to encourage small-scale dehydration technology.

DEHYDRATED FISH WASTE FOR BIOFERTILIZERS

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Abstract: Fish contains various nutrients necessary for health. However, most fish, such as the bones, the entrails, or the head, is discarded. These wastes have a high content of sodium, calcium, magnesium, and potassium, which enrich agricultural soils and provide crops with the necessary nutrients for their development. Therefore, these wastes present a viable alternative for creating economical and sustainable biofertilizers to empower the small farmer and increase the fishermen's income. In this work, dogfish and tilapia waste were dried in a direct solar dryer made of polycarbonate. The initial moisture content of dogfish was 77.3 g water/100 g ss bh, and the Tilapia was 73.3 g water/g ss (bh). However, if we compare with its moisture content after the drying process, it was observed that the skin of the dogfish species lost a higher moisture content than the bone and clearly than the heads of the Tilapia species, reaching 12.2 g water/100 g ss, also in bh. Furthermore, drying times were shorter for the skin (280 min) compared to tilapia heads (up to 660 min), while drying rates ranged from 0.035 to 3.84 g water/g ss hour for the heads and skin, respectively. The dried waste was ground to obtain fish flour which was analyzed by flamometry, obtaining 699 mg Na/100 gr, 395 mg K/100 gr, and 45,500 ppm of calcium. This flour mixed with soil allowed cucumber seeds to germinate, which did not germinate in not enriched soil.

Keywords: Solar Drying, biofertilizers, fish waste.

DESIGN AND CONSTRUCTION OF A SOLAR DRYER WITH HYBRIDIZATION OF SOLAR TECHNOLOGIES FOR DRYING FISH

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Abstract: Food drying requires high energy consumption due to the latent heat of phase change required to evaporate the water contained in the products and the low efficiency of current industrial dryers. Mexico has a significant solar resource, making developing solar dryers for dehydrating food products attractive, which would benefit the industrial sector. The design and construction of a solar dryer for drying fish are presented, which can dry between 30 kg and 40 kg of product. The dryer work with three solar energy technologies: a bank of solar collectors for water heating, a bank of solar collectors for air heating, and a bank of photovoltaic solar panels so that the dryer can operate continuously during hours of insolation and up to 6 hours of operation without solar radiation or in periods nocturnal. Once the solar dryer for fishery products was built and assembled, with all its components and auxiliary systems, an experimental evaluation was carried out to evaluate the dryer's operation. The experimental tests were carried out in the Solar Food Drying Laboratory of the Faculty of Engineering of the Universidad Autónoma de Campeche, in Campeche, Campeche, Mexico, located at the geographic coordinates 18°50′11″N 90°24′12″W. When operating the solar dryer with the solar thermal water heating system with storage, average temperatures inside the drying chamber were 52°C, 57°C, and 64°C. When operating the solar dryer with the solar air heating system, the average temperatures obtained inside the drying chamber from 54.2 °C to 61.5 °C, in both cases with an average air velocity of 2.4 m/s to 10 m/s, which is acceptable since for the drying of fishery products average temperatures of 55 °C are required with average flow rates of 2.5 m/s inside the dryer. With the results obtained, it can be deduced that the tunnel-type solar dryer for 40 kg of fish products meets the necessary parameters for the drying process.

Keywords: Tunnel-type solar dryer, Hybridization of technologies, Solar irradiation, Thermal storage, Heat exchanger.

THERMOFLUIDS' ISSUES OF MODELING A FLAT PLATE SOLAR AIR HEATING COLLECTOR (SAHC) WITH SENSIBLE THERMAL ENERGY STORAGE (TES) FOR DRYING IN AN ENERGY-VULNERABLE ENVIRONMENT

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Abstract: Drying food and other goods is of paramount importance for remote and isolated communities when the supply of energy is scarce, unreliable, or too expensive. Using the sun, with an enclosed cabinet for heating air to dry, is non-energy consuming as well as the dried goods are non-consuming when stored. The materials for the solar drier must be easily obtained. The construction and maintenance must be feasible and reachable in a remote and isolated location.

For the indirect type of drier, the solar collector is a very important part. This paper models its behavior affordably using average temperatures so that the different designs can be evaluated, and the performances predicted.

The design is based on storing heat in a plane layout of commercial beverage cans that act as solar receiver. This way drying is extended during the night and temperature peaks are shaved during the day.

Different basic designs are considered, and the effect of the design parameters is offered in a simplified manner considering laminar flow.

A second-generation prototype has been constructed. Materials have been chosen to allow remote construction. Computer monitoring has been applied using a special anemometer to measure very low velocities.

The results show the effect of layout and other main parameters on air velocity and temperature increase.

The experimental results show that water contained in commercial cans is an effective and affordable way of heat storage. The experiments show a substantially long cooling time during the night and a high sensitivity to wind.

Keywords: Solar passive dryer, natural convection, modeling.

7-Abstracts and full length papers (cont.)

Session 3A

FROM SMALL SK14 PARABOLIC SOLAR CONCENTRATOR TO 500 m^2 DUAL AXIS DISH SOLAR CONCENTRATOR

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Abstract: Solar concentrators are ideal for developing higher temperatures and in India solar concentrators were introduced for cooking by introducing SK1-14 Parabolic Concentrators developed by Dr Dieter Seifert of Germany. We with his support and technology transfer introduced and manufactured and commercialised the same in India and they were in two sizes SK 10 to cook for 4-5 people and SK 14 to cook for 10-15 people, i.e., domestic cooking. Through Dr Dieter Seifert we got to know Mr. Wolfgang Scheffler and with his support we transferred the technology Scheffler concentrators to India and introduced them as community cookers as they enabled cooking in the comfort of kitchen. For institutional cooking we with help of Germany company HTT GmbH and funding from GTZ Germany in co-operation with Brahma Kumaris developed the world first solar steam cooking system for Mt. ABU, Rajasthan to cook 1200 meals. Its success led to many more solar steam cooking system coming up in India including the world's largest at Shridi Temple that cooks 50,000 meals per day. It consisted of 73 Scheffler concentrators of 16 m^2 each.

Now to overcome the problems of space it required and also to increase the efficiency BIGDISH concentrator from Sunrise CSP Australia - 500 m^2 Dual Axis Dish has been built and under commissioning at Muni Seva Ashram. Once successfully tested a project with 2 BIGDISH of 500 m^2 each will be installed at Tirupati Temple that will cook for 80,000 meals per day.

Experience and success of BIGDISH is being shared - a technology that is not just ideal for cooking but also for dehydration (solar drying), desalination, solar air-conditioning and co-generation and tri-generation.

Keywords: Solar cookers, domestic solar cooking, community solar cookers, institutional solar cookers, BIGDISH concentrator, world's largest and most efficient dish, co-generation, tri-generation, transforming rural economy, combating climate change, carbon neutrality, net zero.

LICURI PULP PROCESSING USING SOLAR COOKING AS AN ALTERNATIVE TO CONVENTIONAL FUELS

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Abstract: The objective of this is to analyze the quality of food produced from a native fruit of the Caatinga biome, using solar cooking, aiming to adopt the method as an alternative to conventional fuels. The pulp of the ripe fruit of licuri (*Syagrus coronata* (Martius) Beccari) was used for the production of a mass candy using four different types of cooking: firewood, cooking gas, electricity, and solar cooking through a Scheffler-type solar concentrator of 2.7m². The sweets were characterized through microbiological, physicochemical, and sensory analysis. The results of the analyses were submitted to statistical analysis and Tukey's test with a 5% significance level. The time, temperature, and costs for the production of 1kg were also measured. Wood cooking had the shortest time at 82 min, followed by electric cooking at 148 min, LPG at 186 min, and solar cooking at 212 min. Concerning the maximum temperature in each cooking were: firewood 119°C, LPG 84°C, electricity 92°C and solar 91°C. The thermal energy costs for each type of cooking were: firewood 0.19US$, LPG 1.34US$, electricity 0.95US$, and solar 0.0US$. Regarding the microbiological analyses, all the sweets were within the standard required by Anvisa Normative Instruction No. 161/2022. The candy produced with firewood obtained lower humidity (8.57%) and higher TSS (63.68°Brix) due to the high cooking temperature. The total acidity (TTA) and pH were similar among the sweets, varying between 1.43 and 1.68% for TTA, and 4.02 and 4.09 for pH. The candy produced with electricity obtained the highest value for vitamin C (4.82mg/100ml). Regarding the sensory analysis, all the sweets obtained the majority of responses in the region of acceptance ("I liked it" and "I liked it a lot"), especially the sweets produced with electricity and gas, followed by firewood and solar. The formulation of the mature licuri mass candy produced in this work is protected by the Process number: BR 10 2022 022582 6 from INPI.

Keywords: *Syagrus coronata* L.; Caatinga; Renewable energy; Sustainable development.

Introduction

The Caatinga biome is home to a native palm tree (*Syagrus coronata* (Martius Beccari), known locally as liculizeiro, whose processing is responsible for a wide variety of products. From its fruit, the licuri, foods are obtained, such as: oil, cookies, cocada, paçoca, granola, caramelized licuri, candy, toasted licuri, liqueur and beer. These products, in addition to having high nutritional value, are allies in the fight against hunger, misery and malnutrition.[1,2,3,4] Other products made with licuri or parts of the tree are: soap, handicrafts, bags, hats, brooms, wax used in the manufacture of carbon paper, shoe polish, furniture, car paint, cosmetics, biodiesel and use of leaves and seed husks as a source of thermal energy to replace firewood.[5,6,7] The processing of licuri is, therefore, a viable way to increase the income and quality of life of the population of the northeastern semi-arid region.[2] Beyond the socioeconomic aspects, licuri is the main food of the Lear's Macaw (*Anodorhynchus leari*), an endemic species of the Raso da Catarina/BA region (Brazil), in addition to being a source of food for another 13 vertebrates and 5 invertebrate species.[1,5,7]

Little innovation has been observed in the processing of licuri, among them the use of a machine that helps break the fruit skin, reducing manual work.[2] But regarding the use of heat for toasting the almond, historically, this step has been carried out using thermal energy from firewood burning. In general, the use of firewood as an energy source contributes to the degradation of the caatinga, which also has been degraded due to inadequate agricultural techniques, indiscriminate suppression of native vegetation, overgrazing and removal of firewood for energy purposes.[1,8] The licuri tree also suffers from this degradation, so federal and municipal regulations were drawn up, such as Ibama Normative Instruction n° 191, of September 24, 2008[9], and Law n° 13908 of January 29, 2018, which establishes the licuri species as biocultural heritage[10], prohibiting cutting.

The other energy sources, also available for roasting almonds, such as LPG (liquefied petroleum gas, better known as cooking gas) and electricity are expensive and also have environmental costs. Solar energy is an abundant resource in the northeastern semi-arid region and has the potential to generate the heat needed to carry out industrial processes, including cooking food. The use of renewable energy sources is in line with the 17 SDGs (Sustainable Development Goals).[11]

There are some equipments that can be used to generate heat from solar radiation in different temperature ranges. Below 100°C, the solar desalinator transforms brackish water into potable water, the solar dryer dehydrates food, the box-type solar cooker performs slow cooking of food and the LCHS (low-cost solar heater) heats water for bathing; these are viable social technologies for the northeastern semi-arid region.[12] Between 100 and 150°C the evacuated tube solar heater heats fluids for industrial processes and the parabolic cooker can fry food. Above 150°C, solar concentrators can generate electricity and process food more quickly. The Scheffler-type solar concentrator has already been used for extracting essential oils[13], bread production[14], and water distillation[15], and it has a differential concerning other models of solar concentrators since it produces a focus parallel to the ground, allowing the cook to stay in the shade during the cooking process.

To evaluate the technical and financial feasibility of using solar cooking, this work aimed to process the licuri pulp using a Scheffler-type solar concentrator as an alternative to conventional fuels. The prototype was built in the city of Paulo Afonso (Bahia - Brazil). The food from licuri pulp was produced with four different sources of heat: firewood, electricity, LPG, and solar energy. Samples were characterized based on microbiological, physical-chemical, and sensory analyses. The financial costs related to the consumption of thermal energy for each type of cooking was also evaluated.

Materials and Methods

The construction of the Scheffler-type solar concentrator was carried out in the city of Paulo Afonso (Bahia - Brazil) (-9.389595, -38.217266) belonging to the territory of Itaparica identity, which is composed of the municipalities: Abaré, Chorrochó, Glória, Macururé, Paulo Afonso and Rodelas. These municipalities have similarities in climate, soil, fauna, flora and mainly because they have a strong relationship with the São Francisco River and all the interventions that occurred due to the construction of hydroelectric plants. The most present economic activities in this territory include ecotourism, hydroelectric production, and fish farming. Ecotourism is stimulated by the beautiful natural scenery inspired by the São Francisco canyons and the presence of archaeological sites. The original peoples are formed by indigenous people and quilombolas. According to CRESESB's SunData program, the average solar radiation throughout the year in Paulo Afonso is 5.37 kWh/m²/day. Specifically for May, period of the experiment, the average is 5.2 kWh/m²/day.[16]

Design and construction of heating system using solar energy

The Scheffler-type solar concentrator used in this work was designed based on the Solare-Bruecke manual, developed by the inventor of this model, the physicist Wolfgang Scheffler[17], and on the first solar concentrator of this type manufactured in Brazil.[18] This project was tailored to the latitude of the city of Paulo Afonso. Also, a secondary reflector was designed to receive the focus produced by the concentrator and to redirect it toward the bottom of a pan. All drawings were made using a computational graphic tool, the sketchup® software.

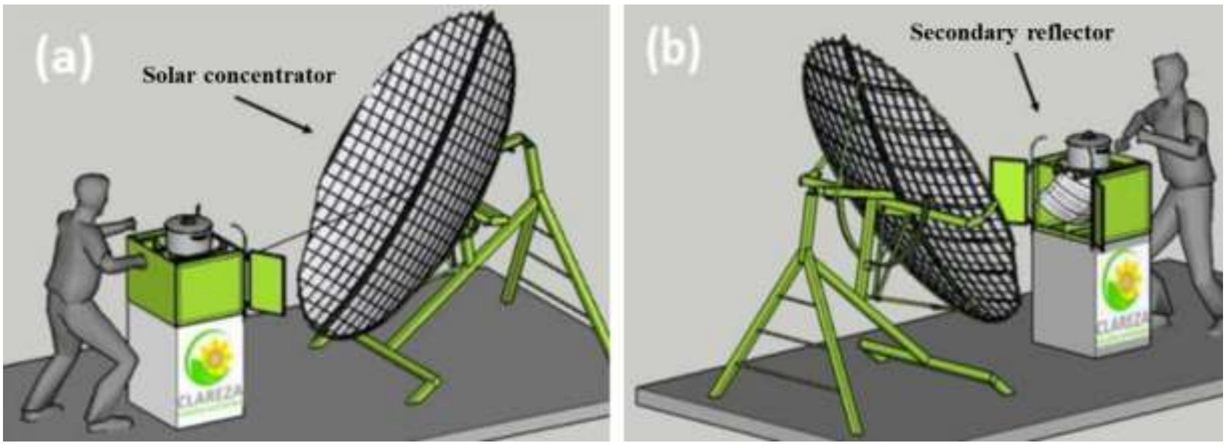

Figure 1. Perspective of the heating system with detail for the reflective material of the solar concentrator (a) and the secondary reflector (b).

Figure 1a shows the operation of the solar concentrator/secondary reflector system focusing on the reflective material of the solar concentrator, while in Figure 1b details the secondary reflector. It is important to point out that the operator can remain in the shade (Figure 2a) without harming food processing. Nevertheless, it is essencial using PPE (Personal Protective Equipment), for example clothes with UV protection, sunscreen, sunglasses, and cloth/silicone gloves.

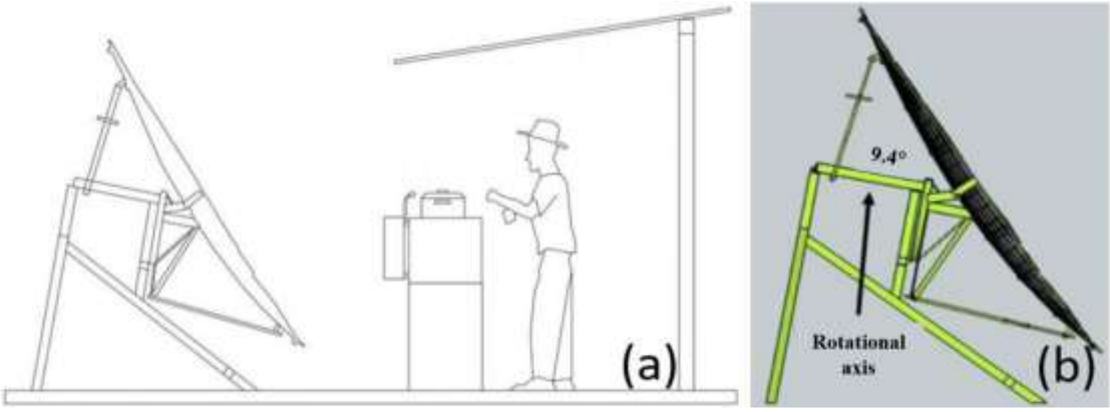

Figure 2. Side view of the solar concentrator with cover (a) and rotation axis adjusted to the latitude of Paulo Afonso - Brazil (b).

Figure 2b shows a side view of the solar concentrator with detail for the 9.4° inclination of the rotational axis. This inclination is identical to the latitude of Paulo Afonso and aims to maximize the use of solar radiation. The focus produced by the reflection of solar radiation is projected onto a secondary reflector, as shown in Figure 3T he black arrow (horizontal) represents the focus coming from the solar concentrator and the red arrow (vertical) represents the focus being deviated in 90° directly to the bottom of a pan. The structure was built with steel and glass strips were used as reflective material.

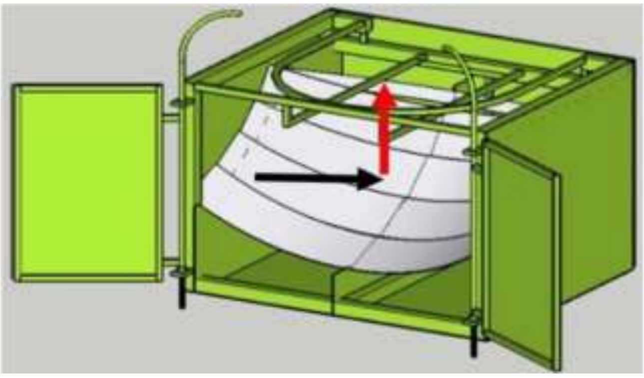

Figure 3. Secondary reflector design.

Figure 4 shows the solar concentrator in the final assembly phase. The mirrors were fixed on vertically positioned aluminum rods, using double-sided tape, which speeds up the installation process of the mirrors and reduces the spacing between them, increasing efficiency in capturing sunlight.

Figure 4. The final manufacturing process of the solar concentrator: installation of reflective material.

Food processing and characterization

The recipe for the ripe licuri mass candy was reproduced with different heat sources: firewood, LPG, electricity and solar. Following a randomized block design (RBD), five replications of each treatment were carried out to perform the physical-chemical and microbiological analyses. Cooking with solar energy was performed using a 2.7 m^2 Scheffler solar concentrator and a secondary reflector. The focus produced by the concentrator was reflected by the secondary reflector directly to the bottom of a black aluminum pan with 25 cm in diameter and 10 cm in height.

Since licuri is a plant native to the Caatinga biome, this work was registered in the Brazilian National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen), under n° A0AEBC9 as provided in Law n° 13123, of May 20, 2015, that provides access to genetic heritage, protection and access to associated traditional knowledge and sharing benefits for the conservation and sustainable use of biodiversity.[19]

Figure 5. Fruit gathering (a), and ripe licuri used for cooking processes (b).

Figure 6. Cooking methods: firewood (a), LPG (b), electricity (c), and solar energy (d).

Figure 5 exhibits the fruit gathering, and Figure 6 the different cooking methods. For all processes, the same pan, recipe, and ingredients were used, allowing the exclusive observation of the effects of each source of thermal energy used and its influence on the final quality of the licuri candy. To monitor the four cooking methods, a digital chronometer and an infrared thermometer for high temperature (model GM-300 / Brand B-MAX) were used. Every 60 seconds, temperature readings were taken on the surface of the candy and the side of the pan.

The formulation of the ripe licuri candy produced in this work is protected by the process n° BR1020220225826 of Brazilian National Institute of Industrial Property (INPI). The entire production process followed the methodology described in detail by Torrezan, summarized in the flowchart in Figure 7.[20]

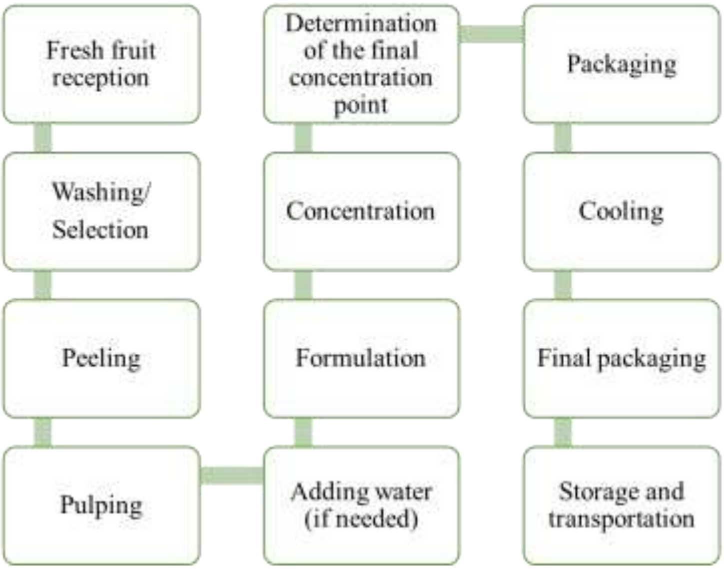

Figure 7. Flowchart of the candy manufacturing process.

The microbiological analyses performed were *Salmonella*, *Enterobacteriaceae*, and Molds and yeasts following the Brazilian normative instruction n. 161, of July 1, 2022, which establishes the list of microbiological standards for foods.[21] The physical-chemical analyzes performed were: humidity, vitamin C, pH, total acidity, and soluble solids.[22]

Because this research involved human beings, this work was submitted to the Ethics and Research Committee (CEP) of UNEB and was approved through the process n° 5185600. The participants signed the Free and Informed Consent Form, a document that aims to legally protect them and that informs all the necessary procedures for the sensory analysis. Sensory analysis performed at the Agricultural Family School in Itiúba (Bahia - Brazil) (10°50'47.5"S 39°43'01.9"W). Among the 32 participants were students from local communities and employees according to the inclusion and exclusion criteria submitted to the CEP.

The tasters tried samples with 12g of candy that was served at room temperature in 50ml disposable cups coded with three random digits. A 9-point Hedonic Scale (9 = liked very much, 5 = neither liked nor disliked; 1 = disliked very much) was used to evaluate the ripe licuri candy. The analyzed attributes were: aroma, flavor, texture, and global acceptance.

Concerning statistical analysis, the design used was randomized blocks (DBC) and the physical-chemical and sensory results were submitted to analysis of variance and the differences between means compared by Tukey's test with a 5% level of significance, using the AgroEstat software.[23]

The financial analysis was performed for each type of cooking (firewood, electricity, LPG and solar). In this work, the calculation was restricted to the costs related to the use of thermal energy for cooking the jam, without considering, therefore, the costs of labor, acquisition and maintenance of equipment. The solar concentrator used is not yet manufactured on an industrial scale and does not have technical standards in Brazil for its construction. The cost of LPG was calculated by Equation 1.

$$Consuption\ (R\$) = \frac{t \cdot C \cdot P}{60 \cdot m} \quad (1)$$

where t is the time in minutes, C is the gas consumption (kg/h), m is the capacity of the gas cylinder (kg), and P is the price of the cylinder (R$).

Results and discussion

Prototype construction and production of ripe licuri candy

The construction of the solar concentrator was concluded and the prototype is ready for operation. The reflector area of the concentrator measures 2.7 m, and it was covered with 10 cm x 10 cm mirrors, totaling around 300 mirrors, each 3 mm thick. The entire structure was made of steel and painted to prevent corrosion. This type of concentrator needs to track the Sun throughout the day. The focal length is 1.13 m and the focus height from the ground is 0.88 m, as seen in Figure 8a.

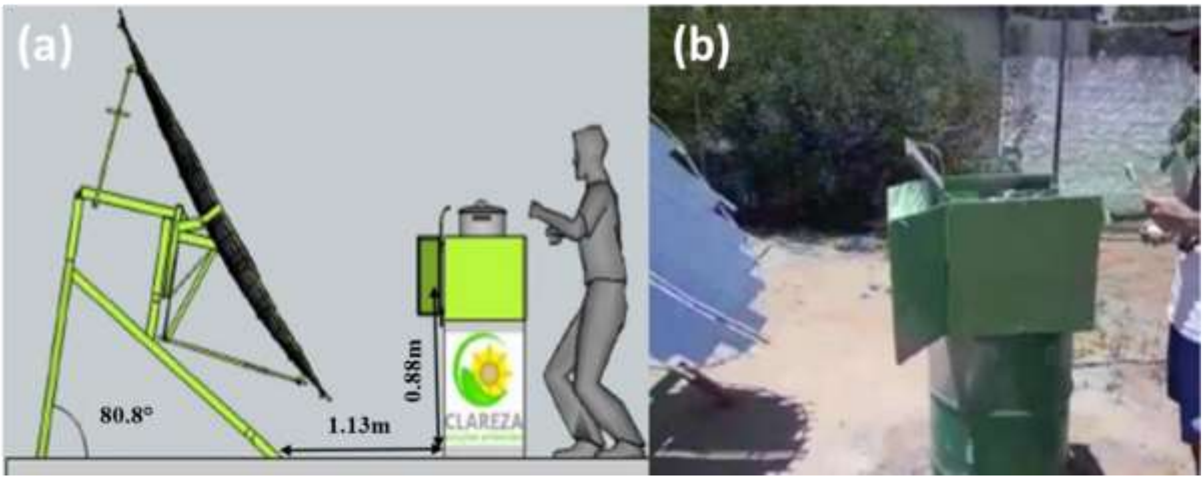

Figure 8. Side view of the project (a); side view of the prototype built in this work (b).

Processing and characterization of ripe licuri candy

The total preparation time of the ripe licuri mass candy was different for each type of heating; with wood cooking having the shortest time 82 min (1h22 min), followed by electricity cooking 148 min (2h28 min), LPG 186 min (3h06 min), and solar 212 min (3h32 min). The solar cooking time is inversely proportional to the reflective area of the solar concentrator used to capture solar energy and produce the concentrated focus. Therefore, it is possible to increase the catchment area and make the solar cooking time compatible with cooking using conventional fuels. Also, it can be observed that in the wood and electricity heating sources, in which the cooking temperature was higher, the cooking time was shorter; and in the LPG and solar heating sources, in which the temperatures were lower, the sweet cooking time was longer.

According to Torrezan, the cooking time can interfere with several final aspects of the candy, such as the darkening of the product due to sugar caramelization, excessive inversion of sucrose, loss of aroma, loss of pectin in case of very long cooking time, and problems with quality concerning its consistency due to little or no inversion of sucrose in case of very short cooking time.[20] Table 1 presents the total time, room temperature, and maximum temperature for each type of cooking.

Table 1. Cooking parameters for each type of energy source used.

Source of energy	Cooking time (min)	Room temperature (°C)	Maximum temperature on the candy surface (°C)
Firewood	82	28	119
LPG	186	21	84
Electricity	148	21	92
Solar energy	212	30	91

The graph in Figure 9 shows the temperature changes over the total cooking time for each process, with temperature readings every 60 seconds. Figure 10 shows the final appearance of the ripe licuri mass candy.

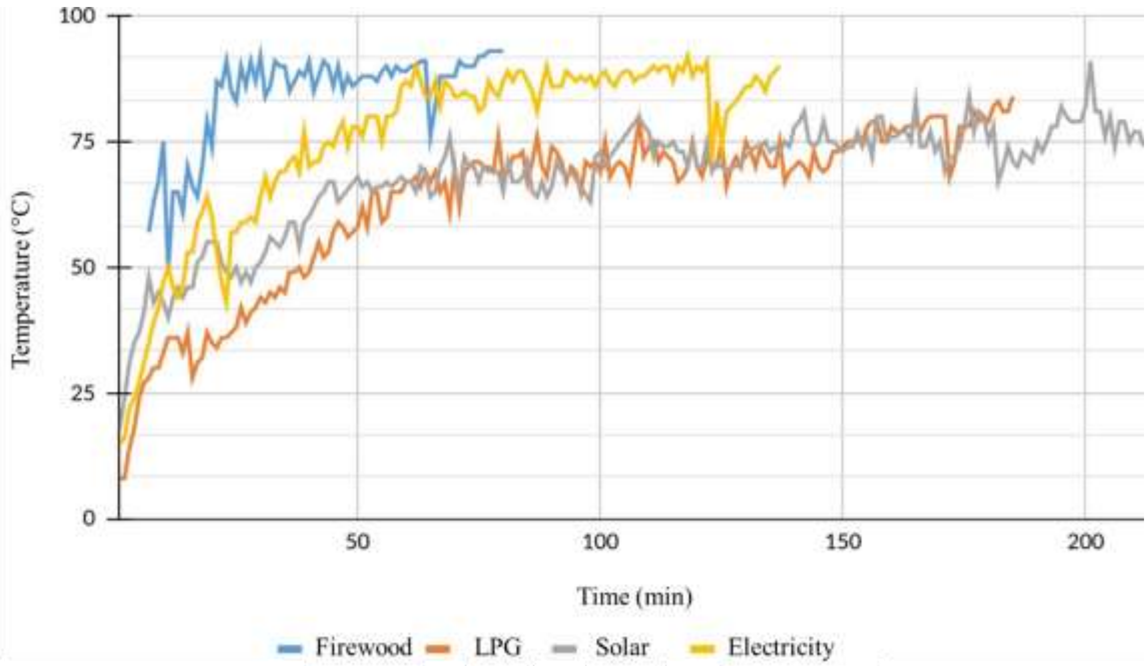

Figure 9. Temperature profile over the total cooking time for each process, with readings every 60s.

Figure 10. Final appearance of the ripe licuri candy.

The microbiological analyzes (Table 2) were in accordance with the microbiological standards for foods in the category "sweets in paste or mass and similar, including jellies and sweets in syrup" of Brazilian Normative Instruction n° 161, of July 1, 2022, which establishes the lists of microbiological standards for foods.[21]

Table 2. Results of the microbiological analysis of licuri candy prepared in different types of cooking.

Microbiological analysis	**Cooking process**			
	Solar	**Electricity**	**Firewood**	**LPG**
Salmonella/25g	Absence	Absence	Absence	Absence
Enterobacteriaceae (CFU/g)	<10	<10	<10	<10
Molds and yeasts (CFU/g)	60	<10	240	60

Regarding the results of the physical-chemical analyzes (Table 3), the treatment with firewood had the lowest moisture content (8.57%), while the LPG treatment had the highest moisture content (15.91%). This was due to the temperature reached in each treatment: in the case of firewood, which obtained a higher temperature (119°C), there was a greater loss of moisture, while in the LPG, with a lower temperature (84°C), there was greater difficulty in remove it. With lower humidity, the treatment with firewood obtained a higher total solids content, 63.68 TSS (°Brix).

Table 3. Results of the physicochemical analysis of licuri candy prepared in different types of cooking.

Physicochemical analysis	Cooking process			
	Solar	**Electricity**	**Firewood**	**LPG**
Moisture (%)	14.54^{b}	12.77^{c}	8.57^{d}	15.91^{a}
TSS (°Brix)	55.43^{c}	60.32^{b}	63.68^{a}	56.32^{c}
TTA (%)	1.68^{a}	1.49^{ab}	1.64^{ab}	1.43^{b}
pH	4.04^{bc}	4.07^{ab}	4.09^{a}	4.02^{c}
Vitamin C (mg/100ml)	3.29^{c}	4.82^{a}	4.38^{b}	3.50^{c}

*Means followed by the same superscript letter do not differ statistically ($p < 0.05$) according to Tukey's test.

As seen in Table 3, the cooking process with solar energy obtained the higher total titratable acidity (1.68), and the pH of ripe licuri mass candies ranged from 4.02 to 4.09 between treatments. According to Ribeiro *et al.* the pH is important to obtain a stable gel, in which a very low pH can cause the breakage of the gel, and consequently the loss of water; while a very high pH does not allow the formation of the gel. Additionaly, the pH and total titratable acidity can influence the product shelf life as they reduce the microorganisms deteriorating actions.[24]

Thus, the vitamin C of ripe licuri mass candy in the solar and LPG processes were statistically similar, while the cooking with firewood and electricity differed among all treatments. According to the Brazilian National Health Surveillance Agency through resolution nº 269, the (RDI) Recommended Daily Intake of vitamin C for adults is 45 mg.[24] Therefore, in all processes, the sweet is able to supply this nutritional demand in small quantities of the product.

Table 4 presents the physicochemical characteristics of other sweets found in the literature. Analyzing the characteristics of these sweets, it is possible to notice similarities with the licuri sweet produced in this work, in relation to pH (mango and guava sweets) and total soluble solids (guava, mango and juçara sweets).

Table 4. Physicochemical characteristics of other sweets found in the literature.

Authors	Creamy sweets	Formulation/ Concentrations	Physicochemical parameters		
			TTA (%)	pH	TSS (°Brix)
Freire et al. (2009)	Guava	40 °Brix	0.39	3.89	40.00
		45 °Brix	0.39	3.87	45.00
		50 °Brix	0.47	3.86	50.00
Leite Júnior et al. (2013)	Mango with okara flour	Control	0.32	4.02	63.00
		1% okara	0.33	4.08	63.50
		3% okara	0.31	4.26	65.50
Moura et al. (2014)	Guava	Brand A	0.47	4.16	50.70
		Brand B	0.56	3.79	53.30
		Brand C	0.46	3.88	56.60
Silva et al. (2016)	Juçara	with pineapple	0.86	3.94	61.93
		with banana	0.48	4.33	61.93
Bolzan e Pereira (2017)	Persimmon with Araucaria seed	with 0% pine nuts	0.82	3.65	69.63
		with 5% pine nuts	0.80	3.68	70.52
		with 10% pine nuts	0.79	3.70	71.00

*Adapted from SOUZA, OLIVEIRA and FEITOSA (2018).[25]

The hedonic values applied for sensorial analysis were: 1) I disliked it very much; 2) I disliked it a lot; 3) I disliked it; 4) I disliked it a little; 5) I neither liked nor disliked it; 6) I like it a little; 7) I liked it; 8) I liked it a lot; 9) I liked it very much. In general, the four cooking processes obtained a higher frequency of evaluation in the region of acceptance, including responses such as: “I liked it”, “I liked it a lot” and “I liked it very much” in all criteria (global, aroma, flavor, and texture acceptance). Figure 11 shows graphs of frequency containing the results obtained with the sensory analysis.

All samples were accepted by the majority of participants, in all evaluated attributes, as seen in Table 5. In the criterion “Global Acceptance”, the cooking with electricity and LPG obtained the best results, without statistical difference. However, evaluating acceptance above 7 (I liked it), the electrical cooking method was superior in all criteria, except texture, where cooking with LPG received the best grades (Figure 11).

Table 5. Results obtained from the sensory analysis of licuri mass candy with the four cooking methods.

Microbiological analysis	Cooking process			
	Electricity	LPG	Firewood	Solar
Global acceptance	7.2a	7.1ab	6.5ab	6.1b
Aroma acceptance	6.8a	6.5ab	6.3ab	5.6b
Flavor acceptance	7.2a	7.1a	6.7ab	5.8b
Texture acceptance	6.4ab	7.3a	55b	6.6a

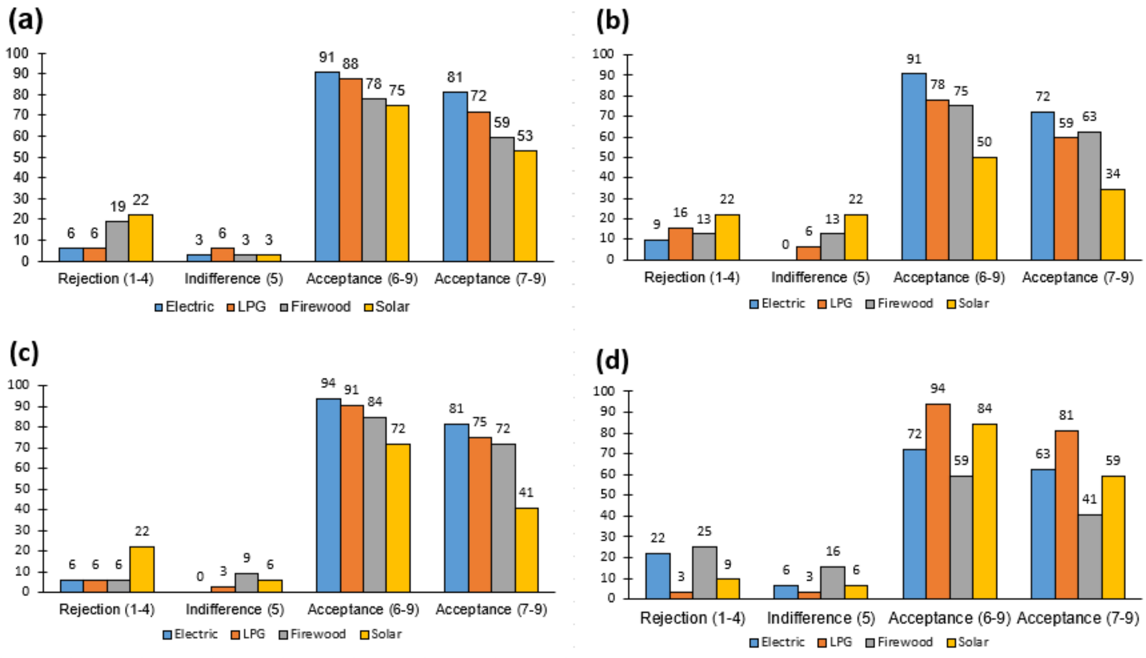

Figure 11. Graphs of frequency of sensory evaluation of licuri candy regarding: global acceptance (a), aroma acceptance (b), flavor acceptance (c), and texture acceptance (d).

The sensory analysis results for the ripe licuri mass candy produced with solar energy showed a disadvantage, being the last place in global acceptance, with 75%. These results can be explained by the oscillation in the supply of thermal energy during cooking due to the passage of clouds, which could have influenced the final physical and chemical characteristics of the candy.

Cost analysis

In the cost analysis of the process using LPG, the cooking time was 3h20min, the gas consumption was 0.225 kg/h, and the cylinder used (13 kg) cost R$120.00, during the trial period. Thus, the cost of the process was approximately R$7.00. For cooking with electricity, a 2000W electric stove was used. Considering that the process lasted 2h30min and the price per kwh was R$1.00 (with taxes and fees), the cooking cost was R$5.00.

For the experiment with firewood, certified firewood was used, costing R$50.00 per m^3.[26] Considering that $1m^3$ weighs an average of 500kg and around 10kg were used, the cost was approximately R$1.00. The cooking of the licuri mass using the solar concentrator did not generate costs specifically associated with the consumption of thermal energy.

Conclusion

The use of the Scheffler type solar concentrator proved to be technically and financially viable for applications in the northeastern semi-arid region, having the potential to reduce dependence on fossil fuels, electricity and firewood for the cooking process, generating cost reductions in line with the premises of sustainable development. The four cooking methods provided a food within Anvisa standards and obtained satisfactory performance in the sensory analysis, showing that the food produced with a solar concentrator has similar characteristics to the food produced with conventional heat sources. The greater the reflective area of the solar concentrator, the faster the cooking will be. The use of sunlight as an energy source allows cooking to be a clean process with no costs associated with energy consumption. Furthermore, it is expected that the industry will be able to reduce the manufacturing costs of the Scheffler-type solar concentrator, matching it to the price of conventional equipment used for cooking food.

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GENERAL SOCIAL ATTITUDE TOWARDS SOLAR THERMAL FOOD PROCESSING IN NORTH RAJASTHAN

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Abstract: The purpose of this study was to statistically analyze the overall attitude of the public towards solar thermal food processing in 10 cluster villages near Achrol in Jaipur District in Rajasthan, as well as 3 cities including Jaipur, Ajmer, and Jhunjhunu. A secondary purpose of this study was also to provide equitable access for training to build own solar cookers to genuinely interested people in need. A survey for a total of 150 people from varying households and three major socio-economic backgrounds (poor, fair, affluent) were asked a select number of questions including their current primary cooking or food processing method, in what form they were using solar energy directly and/or indirectly to process or cook their food, for domestic or commercial purposes. Additionally, they were shown visuals of some solar cookers cooking, baking and drying food and were asked about their level of familiarity with the technology and its access. This survey was carried out over 4 months (November '22 to February'23), and based on the overall score, 'Genuine Interest' and 'Need Assessment' factors were determined for select responders. These selected responders were then offered the opportunity to learn to make their own solar cookers and driers at Vatsalya Campus in Achrol, Jaipur, where an intensive use of solar thermal food processing can be seen via various categories of solar cookers including paraboloid reflectors, funnel cookers, evacuated tube cookers, solar driers etc.

From the current data, it was found that more than 75% of respondents from the rural areas were using solar thermal food processing already, primarily via basic passive technologies for drying. At the same time, it was found that only about 20% of urban respondents were using solar energy for any food processing at all, despite abundant sunlight. It was also found that the need assessment score and genuine interest score often coincided, making it easier to target financially disadvantaged people to switch to solar food processing, or learning how to make their own equipment with hands-on work. It was also found that only 5% of 'poor' category, 12% of 'fair' category, and 10% of 'affluent' category persons knew about the existence of major solar thermal food processing technologies, and no one in any category was aware about solar water distillation. This study has many positive implications as it provides data for carrying out the future pathway for access to solar thermal technology and its knowledge among the masses of northern Rajasthan, an area which receives a very high amount of sunlight hours per year. It definitively narrates what approaches may be considered to spread mass awareness and access to training about solar cooking, drying and water distillation.

Keywords: Solar Thermal Food Processing, Genuine Interest Responders, North Rajasthan, Solar Thermal Technology Penetration, Mass Solar Cooking.

PHOTOVOLTAIC DIRECT (NO BATTERY) COOKING

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Abstract: This paper describes a PV direct (no batteries) solar cooking system. It incorporates retained heat cooking so food can be prepared during the day and consumed late into the night.

The power system is simple and consists of 200 to 400 watt PV module and a maximum point tracker. The power system can power any 120 Volt AC cooking appliance containing a resistance heater. Resistive heaters work on both DC and AC. For many of the appliances powered additional Insulation was added for increased efficiency. We have powered hot plates, rice cookers, ovens, waffle makers etc.

For boil and simmer cooking we use what we call retained heat cooking 2.0, this type of cooker insulates the pot while it is heating up and after the power is turned off. When cooking dried beans, for example, they would be placed in the cooker in the evening, soaking overnight. At sunrise the beans would automatically start heating, several hours later the boiling point would be reached, the power would then be automatically shut off. Retained heat finishes the cooking process and the beans would be hot and ready to eat for lunch or dinner, this process requires a minimal amount of labor, no tracking or mixing.

When not cooking the solar panel could charge a battery which could be used for lights or fans, etc. A single PV module could supply all of a family's needs. The battery could be used to power a cooker; however storing a unit of electrical energy in a battery is a number of times more expensive than generating it, also using thermal storage rather than battery storage is more sustainable.

Keywords: Solar Electric Cooking, Solar Direct Cooking, Retained Heat Cooking, PV Direct Cooking

DESIGN AND PERFORMANCE OF AN INNOVATIVE SOLAR COOKER WITH EQUATORIAL TRACKING

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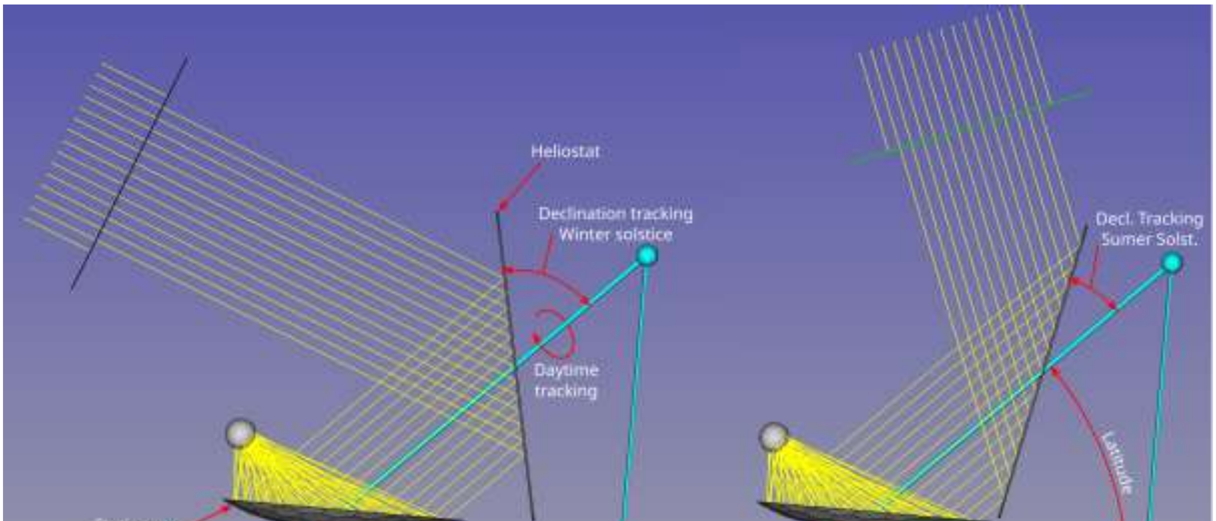
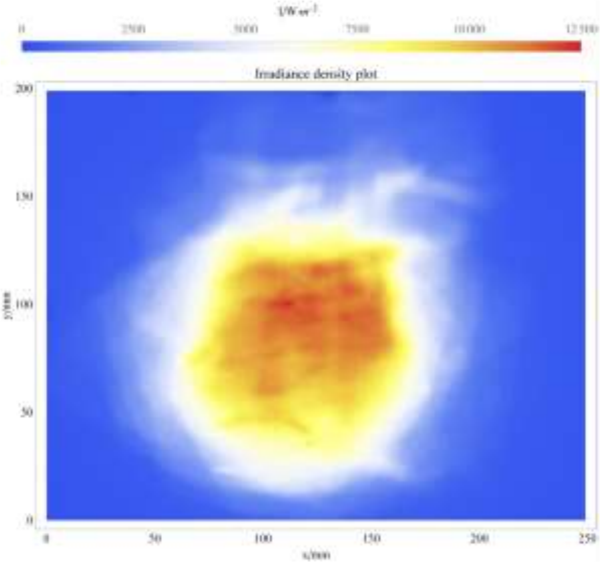
Abstract: The proposed solar cooker design combines a flat heliostat with equatorial tracking and a fixed reflector, presenting a novel approach to solar cooking. Unlike traditional solar dishes, this design offers a simple and fully automated in-day tracking mechanism. The fixed reflector concentrates sunlight, while the heliostat consistently redirects it. The initial implementation adopts an off-axis paraboloid geometry, enabling the installation of an isolated box for use as a solar oven without interfering with incoming radiation. Flat mirror patches approximate the paraboloid shape, providing an even distribution of radiation on the focus and simplifying manufacturing through additive processes or basic routers. Equatorial tracking simplifies the mechanism, with one axis moving at a constant speed of one revolution per day and the other axis requiring adjustment once every day or two.



Although the design requires a larger reflector area due to the off-axis approximation and the heliostat, the aperture through which light reaches the collector remains a constant circle perpendicular to the sun's radiation, ensuring consistent performance regardless of the time of day or year. The cooking power solely depends on available Direct Normal Irradiation (DNI), resulting in a constant Incidence Angle Modifier (IAM) value of 1.

A small-scale prototype, of 0.467 m^2 of aperture area, has been built using 3D printed tiles and an aluminum sheet with a weather-resistant protective coating. The prototype's geometry has been verified using a 3D scanner, results show good agreement between ideal and real geometry but some tiles show a maximum deviation of about 3 degrees in some areas, which suggests that there is still room for improvement of the assembly method. These results have been validated with an analysis of the radiation flux on the focus area that shows that the intercept factor in a circular area of 210 mm around the focus of the parabola of around 70%.



The full performance characterization has not been carried out yet because of bad weather conditions in the last months. Nevertheless, some tests have already been conducted following (Ruivo et al., 2022) giving a standardized cooker power for a difference of water and ambient temperatures of 50 ºC ($\dot{Q}_{s,50} = 19.75$ W). The same procedure but considering only DNI gives a result of $\dot{Q}_{s,50} = 47.21$ W. As for the cooker opto-thermal ratio (COR) (Lahkar et al., 2012), the value using the total radiation is 0.0837 for the total normal irradiation and 0.1038 for DNI. Further testing is under way with both open and box covered pots.

Keywords: Solar, solar cooker, experimentation, solar tracking.

THE SOLAR COOKING AMBASSADOR PROGRAM IN OAXACA, MEXICO: 5-YEAR EVALUATION

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Abstract: The five-year evaluation of the solar cooker "ambassador program" in Oaxaca, Mexico, aims to assess project success in terms of adoption, impact and customer satisfaction; to build the global evidence base for long-term use of inexpensive panel-type solar cookers; and to draw lessons learned to inform similar projects worldwide and further project goals including program financial sustainability.

Solar Household Energy promoted solar cooking in rural communities of Oaxaca, Mexico, where women cook predominantly with fuelwood. SHE Field Project Manager Lorena Harp trained local women "ambassadors" to sell subsidized solar cookers to fellow community members and provide customer training and support. Since 2018, over 750 solar cookers have been sold or donated in Oaxaca, often in partnership with local organizations, with ambassadors educating thousands of people.

Our December 2022 surveys showed good adoption with the average user solar cooking 2.8 days per week, liking their solar cooker, cooking a wide variety of foods, reporting good SC condition with an average age of 4 years, good impressions on fuel savings, solar cooking high-carbon foods, health benefits, and satisfaction with training and support.

This program showed success in ensuring long-term adoption, impact and satisfaction. This five-year evaluation helped identify subgroups more likely to have higher usage, and showed that solar cookers are valued and durable. Lessons learned can be applied to improve methods in order to grow the program sustainably to its full potential.

Keywords: adoption, impact, long-term evaluation, Haines solar cookers, HotPot, Mexico, usage frequency, fuel savings, health, subsidized sales, value, versatility

1. INTRODUCTION

Solar Household Energy, Inc. is a non-profit based in Washington, DC, whose mission is to promote solar cooking for human development and environmental relief in sun-rich, fuel-poor areas of the world. SHE first became engaged in promoting solar cooking in Mexico in 1998 when the HotPot (HP), a panel design solar cooker, was developed by SHE in collaboration with the Mexican Fund for the Conservation of Nature (MFCN) and the Florida Solar Energy Center. Since then, over 20,000 HotPots have been distributed in Mexico by the MFCN.
SHE has also been collaborating with Lorena Harp, a solar cooking expert based in Oaxaca de Juarez, to promote solar cooking in small rural Oaxacan communities, starting with the HotPot solar cooker in 2004, and adding two models by Haines Solar Cookers LLC in 2017. All three models are panel reflector solar cookers that come with specialized pots.
SHE contracted Lorena in 2017 to manage the ambassador program in rural Oaxacan communities, including carrying out baseline and market research, and running an ambassador-led enterprise to sell subsidized solar cookers and evaluate adoption and impact. Community baseline survey results from 22 women in seven low-income rural communities in 2017 showed that the average household burned 180 kg of wood and 49 kg of agricultural residue per month, spending 12 hours to collect it, and spent $5 on gas and $5 on charcoal from an average monthly income of $118 per month. Lorena then recruited, trained, and managed “solar cooking ambassadors,” low-income women who promote and sell Haines solar cookers on commission, and then teach and provide customer service to their fellow community members. Since sales kicked off in 2018, over ten ambassadors have been trained and hired, over 750 solar cookers have been donated or sold, and thousands have been educated in solar cooking through workshops and other events. This was sometimes carried out in partnership with local organizations, who also sometimes donated solar cookers.

2. METHODS

In December 2022, 43 randomly selected program participants were interviewed, mostly over the phone, with the purposes of evaluating the adoption and impact of solar cookers for each model; project assessment; and documenting the challenges and benefits of solar cooking from user feedback. Adoption indicators were solar cooker usage frequency, acceptance appraisal, cooking versatility, and equipment condition and durability. Impact indicators were fuel savings and health improvements. Survey questions included satisfaction with training and support, and suggestions for improvement.

3. RESULTS

A. Demographics

1) Location

The 43 survey participants lived in 18 communities in eight districts and three regions of the Mexican state of Oaxaca. 36 of them live in 17 communities in 7 districts in the “Valles Centrales” and “Sierra Norte” regions within two hours’ drive of the city of Oaxaca de Juarez where Lorena lives. In each of these 17 communities live one to three users, except for two of the poorest communities in the Zaachila district where 15 users live. Seven users live in the more distant Asuncion Ixtaltepec community/municipality in the Juchitan district in the Istmo (isthmus) region where Lorena provided solar cookers to victims of the 2017 earthquake.

Fuel type	Number of users	% users
Only gas	7	16
Mostly gas	11	26
Gas & wood/charcoal	16	37
Mostly wood/charcoal	8	19
Only wood/charcoal	1	2
Total users	**43**	**100**

2) Fuel types

Cooking fuel types were recorded as either gas or fuelwood/charcoal. Other than solar cooking, most users cooked with a mix of fuels, with 18 (42%) using only or mostly gas, and the rest (58%) using fuelwood or charcoal at least half the time (see left-hand table).

3) Solar cooker acquisition

These 43 participants had acquired 61 solar cookers, with 12 participants acquiring 2 SC, and three participants acquiring three solar cookers. Five HotPots were acquired between 2007 and 2011, 33 SC in 2018 (19 HSC1, 13 HP, 1 HSC2), and 23 SC in the next four years due to a slowing of activities during the COVID-19 pandemic. As HotPot and HSC1 acquisitions decreased after 2018, HSC2 acquisitions increased, with four out of eight HSC2 sold in 2022. Acquisitions included 36 sales and 25 donations. Slightly more Haines solar cookers were sold (23 of 42) than donated (18), whereas most HotPots were donated (18 of 20).

B. Adoption indicators

1) Solar cooker retention

At the time of survey, 40 participants (93% of them) still had in their possession 53 SC. Owners of three 2018 HSC1 solar cookers (5% of SC) no longer had one in their possession, two due to quality issues and one due to participant dissatisfaction. Four HSC1 were gifted to relatives by participants already owning one or two SC, and 1 HP burned down in a house fire. Also excluded from usage measurements below are two participants who had never used their solar cooker: one who had lent hers out before ever using it, and one who feared for her dogs, resulting in 38 solar cooker users and 51 SC.

2) Value impressions

When asked whether they liked the solar cooker, all participants answered either “yes” or “very much.” None regretted buying the solar cooker. When asked whether they would want to buy another solar cooker, 79% said yes, three said maybe, and six said no – one because she already had two solar cookers. When asked about whether their family likes the solar cooker, 84% said “yes,” five said it was all the same to their family, one said “yes and no,” due to (baseless) fears of higher exposure to radiation and its long-term health effects. Comments regarding family impressions, and additional final comments regarding personal adoption are tabulated below.

Family reaction	**Number of comments**
Like/surprised by SC capabilities	14
Good taste of SC foods	11
Family members use SC independently	10
They make/sell new dishes (cakes, jams) thanks to SC	5
Family members/friends have bought or want to buy SC	4
Fuel and financial savings	3
Other positive (good for picnics, ease of use, health)	7
Other negative (fear of radiation)	1
Total comments	**52**

Comments on personal adoption	**Number of comments**
Great tool/thank you	4
Take to work/vacation	3
Life issues (hospitalization, etc…) prevented me	2
Prefer HSC to HP	2
Other	8
Total	**19**

In the “other” category, comments included that it is a connection to light and creativity, that the participant uses it for everything, even drying rags, that it is simply a matter of willpower, that people find the solar cookers too slow, that it saves cooking labor time, that it’s important to start cooking early, that the participant has to use it on her rooftop, that high winds reduce usage, that people stopped using their solar cookers during the pandemic, that the participant can only use it on weekends but enjoys doing so very much, and that the participant is seeking support from the government for solar hot water heaters to continue taking advantage of the sun and save money.

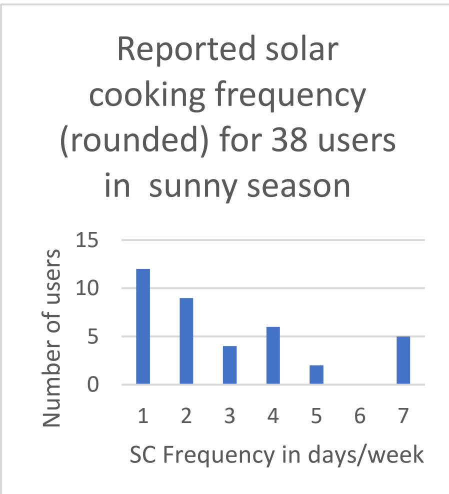
<u>3) Solar cooker versatility</u>

Uses were asked which foods they cooked most often. The solar cookers were found to have high versatility, with participants listing 55 different dishes spanning a wide variety of foods: meats, eggs, breads, cakes and other desserts, beans and other legumes, grains, starches, seeds, vegetables, and more. The 2018 baseline survey showed that most users did not have a way to bake cakes or breads prior to receiving their solar cookers, as they had no ovens. Thus, the solar cooker is very much appreciated for its ability to prepare baked foods. Solar cookers were also used for toasting seeds and dehydrating foods, and also heating water for baths. When asked why they chose these foods to solar cook, most spoke of fuel savings and good taste. Some said it was easier to use since they could leave it at home unsupervised, saving time and labor, some said it allowed them to bake breads, dehydrate, toast without burning, bain-marie ingredients, etc.

4) Solar cooking frequency

a) Overall average frequency

For these 38 users, the average solar cooking frequency per user in the sunny season was 2.8 days per week (previous studies showed that usage in the cloudy season decreased by less than half). However, true overall usage may be higher, as many users commented that they used it several times per day, used multiple solar cookers per day, (both situations were reported as solar cooking one day per week), that they shared their solar cooker with family members, or that they had used their solar cooker(s) more often previously, due to life events (moving, hospitalization), seasonal weather changes, or deteriorating solar cooker condition.



b) Owning single vs. multiple solar cookers

For users with a single solar cooker, the average usage was 2.2 days per week: 2.0 days/week for 13 HSC1 users, 2.5 days/week for 4 HSC2 users, and 2.4 days/week for 9 HP users. For those with multiple solar cookers, it was 4.1 days per week. This may be due to experienced users acquiring additional solar cookers, or additional solar cookers encouraging users to cook more often.

c) Sold vs donated solar cookers

As seen in the right-hand table, average usage is higher for users who purchased their solar cookers. This suggests participants who purchased their solar cookers are more likely to use them, perhaps because their conditions were more conducive to higher usage, and because buyers were more motivated to recoup their investment.

Sold vs. donated	Sold SC	Both SC	Donated SC
Average usage dy/wk	3.6	3.0	2.4
Number SC	8	9	21

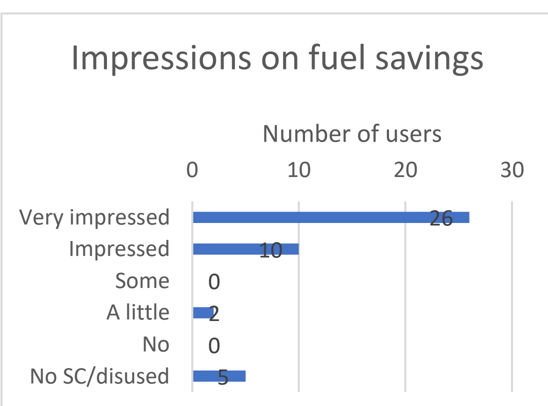
No correlation was found between fuel type and solar cooking frequency.

5) Solar cooker condition

Users were asked to describe the condition of their solar cooker(s). A rating system from the UN Clean Cooking Alliance report “A recipe for adoption and impact indices” was applied. 37 out of 55 SC still owned (67%) were in good condition. Results are displayed below:

Condition	SC model / Rating	HSC1	HSC2	HP	Total SC	% owned SC
Destroyed or in disuse (rusted pot, burnt in fire)	**1**	2	0	2	**4**	**7**
With modifications that alter its functionality (eg: slower cooking, heavy damage to parts, functions)	**2**	3	0	1	**4**	**7**
With modifications that do not alter its functionality (regular wear and tear – dull reflectors, cloudy polycarbonates, small parts lost)	**3**	7	2	1	**10**	**18**
Good conditions with low maintenance (light wear and tear, small parts (paper clips) replaced)	**4**	5	0	1	**6**	**11**
Good conditions with good maintenance (always stored after use, new condition)	**5**	11	5	15	**31**	**56**
Lent/Gifted	**N/A**	5	1	0	**6**	**N/A**
	Total SC	**33**	**8**	**20**	**61**	**100**
	Avg rating	**3.71**	**4.43**	**4.30**		

It is difficult to draw conclusions about durability of any particular solar cooker model, as there are several factors that may affect solar cooker condition. Condition generally degrades with age and usage, but this is mitigated by good maintenance, and for the HSC1, higher-quality versions improved upon previous versions' weaknesses thanks to iterative design development by Haines LLC. Indeed, there was a weak correlation (0.26) between solar cooker condition and the year it was received for the HSC1, but comments suggest this has more to do with improvements in the HSC1 over the years such as replacing string with Velcro, brass fasteners with snap buttons, or scratchable non-stick pots with stainless steel pots. Two out of three solar cookers rated 1 for destroyed had non-stick pots whose coating had rusted and were from the first batch of Haines solar cookers distributed in 2018. Many of the 2018 pots were later replaced.



B. Impact indicators

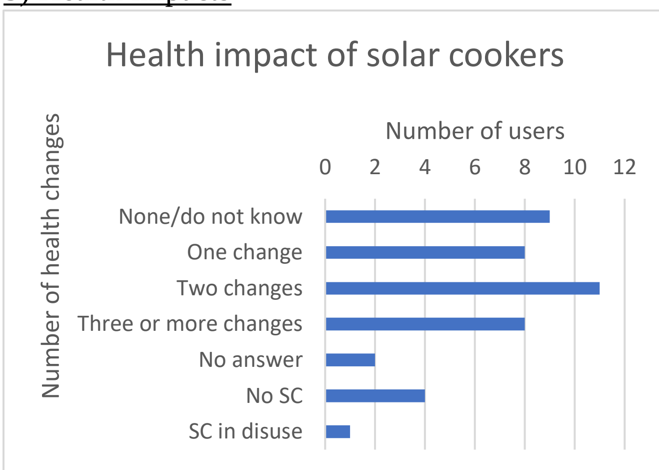
1) Fuel savings

In terms of fuel savings, 36 out of 38 users (95%) who used their solar cookers were "impressed" or "very impressed" with fuel savings, of both gas and fuelwood/charcoal. No correlation was found between fuel savings and solar cooking frequency. Participant 11, who said she uses mostly firewood but some gas, said her gas tank now lasts almost twice as long: "Mi tambo de gas me duraba antes 2 ó 3 meses, ahora me dura 4 meses."

2) Carbon impact of food choices

As mentioned earlier, users cooked a wide variety of dishes in their solar cooker. Categorizing these into food groups, we have, in decreasing number of mentions, meats (56 times), desserts (41), legumes (40), starches/grains (39), and vegetables (27). Meats and legumes are mentioned 96 times out of 203 foods mentioned, or around half. As a rule of thumb, meats and beans take more energy to cook than starches, vegetables and desserts, as the former are traditionally simmered in large pots on wood fires for hours. This implies more carbon emissions are avoided and suggests that the carbon impact of solar cooking is higher than that expected from frequency of use alone.

3) Health impacts



In terms of health impact, 27 out of 38 users (71%) noticed one or more changes in their health or that of their family since they started using the solar cooker. There was a strong correlation (Pearson CC = 0.62) between health impacts and solar cooking frequency. Most comments related to using less oil and fat when cooking with the solar cooker, as recommended by participants' doctors to lower cholesterol levels.

D. User support assessment and suggestions

1) Satisfaction with training

Users were asked if they were satisfied with the training and support they received. All 43 participants said yes, and 24 also provided comments. Ten users commented that they know how to use it well, although some reported having learning difficulties at the beginning. Three users commented that they are still learning to use it on their own. Four users commented they would appreciate more support.

2) Suggestions for additional support

Users were asked for suggestions on future support to improve solar cooker usage. All users provided comments. The most common suggestion was more workshops, mostly for general sharing of recipes and experiences (mentioned 23 times), but also specific topics (12 times) like making ointments and desserts. In terms of equipment or materials for the solar cooker, the most common suggestion was pastry molds (11 times), a recipe booklet (9 times), a new or bigger solar cooker (9 times), replacement parts (8 times), a cover from the dust (4 times), and six mentions of other items.

3) Comments on solar cooking promotion

Users were asked if they had any final comments or questions. Lorena Harp also wrote down relevant information she knew about the users. Most of the information from these comments is incorporated into the pertinent sections above. Additional topics included comments on encouraging the promotion of solar cookers in schools (3 times), hope that it spreads to other communities (3 times), ambassadors' difficulties in selling (3 times), and interest in being ambassadors (2 times).

IV. Discussion

1) Summary

In small rural communities in Oaxaca, women cook predominantly with fuelwood, as was seen in the 2017 baseline survey, and in this 2022 survey showing 58% of users use wood or charcoal for half or more of their fuel needs (excluding solar cooking). Between 2007 and 2022, the 43 survey participants had acquired 61 SC. At the time of the survey, 88% of users solar cooked regularly, and 95% of solar cookers were still in use, or lent or gifted to friends. All users liked their solar cooker, with no purchase regrets; 79% wanted to buy another; 84% reported their family liked the solar cooker. Solar cookers were found to have high versatility, not only in cooking and baking 55 dishes from all food groups, but in toasting and dehydrating foods, drying items, and heating bath water. The average user reported solar cooking 2.8 days per week. However, actual solar cooker usage, in times per week, for all its users, borrowers included, is probably higher. Higher solar cooking frequencies were found for those owning multiple solar cookers (4.1 days/week), and those who purchased their solar cookers (3.6 days per week). A few comments provided explanations for lower usage, such as damaged solar cookers, working away from home, high-wind areas, or changes in life circumstances. 67% of solar cookers were in good condition, with an average age of 4 years. The condition of the HSC1 was mildly correlated with age, as iterative design development of the HSC1 led to more durable versions with each distribution. 95% of users were impressed or very impressed with fuel savings, and nearly half of reported solar cooked foods were meats and legumes that are traditionally cooked for long periods over wood fires, increasing carbon impact. 71% noticed one or more health changes since they started solar cooking. All users said they were satisfied with training and support. Suggestions for future support included more workshops for sharing knowledge, and accessories such as pastry molds, recipe booklets, etc. Final comments showed interest in promoting solar cookers in schools, other communities, and in becoming ambassadors.

Solar cookers were highly valued for ease of use, good taste, baking capabilities, fuel savings, positive health impacts, and more. Solar cookers were found to have high versatility, but not all users are necessarily aware of their many different uses.

2) Recommendations

In the future, we should direct marketing, sales or donations to high-usage groups, such as stay-at-home cooks, who already have one solar cooker they appreciate. We can also take the users' recommendations to heart. We can organize more workshops, so that users can share recipes, tips and tricks, like how to toast seeds, stabilize solar cookers in the wind, or solar cook while you're away at work. We can also make sure that replacement parts, and accessories like pastry molds, are made available. We are currently working on creating an improved user manual with local recipes. Finally, we can improve reporting methods for more accurate future evaluations.

3) Challenges and ideas to explore

There are some challenges to implementing some of these recommendations. Ambassadors need to be paid to organize and lead workshops. To reduce costs, we could explore the use of virtual self-paced video training courses, or help users form self-help groups, or focus our efforts on one community.
Haines is developing two new models of solar cookers that we hope will solve some user issues. The new Haines 2 is more affordable, easier to assemble, and comes with heat-retention capabilities with added towels.

We could also look into buy-back programs for the few who no longer use their solar cookers due to changing life circumstances, for resale or donation.

These past 5 years of the solar cooking ambassador program has taught us many lessons, and we are still learning. We hope to continue improving our processes and products to one day build a financially sustainable social enterprise, capable of rapid growth so we can bring the benefits of solar cooking to all the people of Oaxaca and beyond.

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LOW COST INTELLIGENT VEGETABLE DEHYDRATION WITH OPTIMIZATION OF SOLAR THERMAL AND PHOTOVOLTAIC ENERGY

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Abstract: This article describes the operating principle a fruit and vegetable dehydrator modular, portable and low-energy, low-cost equipment that works exclusively with renewable energy, solar thermal and photovoltaic and can operate independently of the current atmospheric conditions. The development of this equipment was based on the knowledge that optimizing the dehydration process is essential to optimize the factors: Time, Product Quality, Energy Efficiency, Cost, Flavour and Aroma. It allows the optimization of these factors by actively controlling dehydration air temperature and air circulation velocity, depending on the type of product to be dehydrated, solar radiation and outdoor temperature at any given time. This equipment optimizes the dehydration process by reading the temperature and relative humidity conditions of the atmospheric air, the air at the entrance of the dehydration chamber and the air at the exit of the chamber, allowing at any time and through the mixture control system air flow / recirculated air, optimize the operating conditions of the equipment. This equipment is a mobile device that allows to be easily moved and placed in the position that best suits the dehydration process and allows greater efficiency in operation at all times, including solar orientation and production site. For this, in addition to its lightweight construction, the implementation of 100% rotating wheels allows ease of orientation and positioning.

Keywords: Vegetable dehydration; Solar thermal energy; Photovoltaic solar energy; Low cost dehydration.

TECHNICAL-ECONOMICAL ANALYSIS OF THE THERMOSOLAR PLANT DRYING DIFFERENT AGRICULTURAL PRODUCTS

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Abstract: In the present work, the historical experimental results of dehydration of different products (pineapple, banana, apple, mango and fig) in the hybrid solar-LP gas plant installed in Xochitepec, Morelos, Mexico are presented. Data obtained from each product will be shown taking into account the drying process, using only the thermal energy provided by a direct air heating system with 16 flat plate solar air heaters (37 m2) and by an indirect air heating system consisting of a water heating system with 16 flat plate solar collectors (37 m2), a storage hot water tank and a fin and tube heat exchanger.

This paper shows the results of the technical-economic analysis based on the real gains that can be obtained during the life cycle of the plant and thus obtain a more realistic investment recovery period. For the above, it has been taken into account on the one hand, the cost of the dehydration plant, its amortization, as well as the costs associated with maintenance, labor and energy costs (electricity); and on the other, the sale price to the public of the dehydrated product against the actual cost of producing it. The results obtained for different products will be compared to analyze the profitability of the plant from the point of view of the product to be dehydrated.

Session 3B

SUSTAINABLE/CREATIVE TOURISM: A WAY TO DISSEMINATE THE VIRUS OF SOLAR COOKING

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Abstract: The agenda 21 (1992), the conscience of more informed tourists and de degradation of the mass touristic destinations, create a tendence to a more responsible and participative tourism. In 1993 the United Nations Word Tourism Organization defined the concept of sustainable Tourism, fulfilling a set of ten points covering the three pillars of the sustainable development. In 2000, Greg Richards and Crispin Raymond developed the concept of creative tourism "Tourism which offers visitors the opportunity to develop their creative potential through active participation in courses and learning experiences which are characteristic of the holiday destination where they are undertaken". Visitors pass to be active participants, getting skills. Nowadays, after 2020 the concept of regenerative tourism is emerging. Tourism footprint, more than to be minimised had to be positive. In this sense, solar cooking is an opportunity to merge these tourism concepts (sustainable, creative, and regenerative) into a single experience. An experience focused to the demonstration, contributing to the dissemination of solar cooking as a sustainable activity, jointly with the slow food. The demonstration (procedure efficiency and tasting) had to be the main purpose of the touristic package. The time during the solar cooking is used for a solar oven construction workshop whose built ovens are raffled among the participants. The use of recycled materials used to build the ovens is emphasized (carton from boxes to do structure of the ovens and snacks packs as reflecting surfaces). A small theoretical approach is done during the workshop. But a special care had to be taken on the dimension and amount of information to be provided. It is important to keep in mind that the tourists pretend to have a good time and not a boring class. Most of the tourists are getting the first contact with solar cooking. They are not researchers neither still enthusiast. The balance between information and demotivation is a kea point. Measuring the temperature of the pans at the beginning and at the end is a demonstrative strategy, especially if in different types of ovens are used. Prior any activity safety norms had to be provided. Pans can get high temperatures not detected by eye. To save time, avoiding demotivation, preparation of the food to be cooked is done in advance without tourist participation. At the end, during the tasting, the details of solar cooking are discussed and participants invited give suggestions and clarify doubts.

DIRECT SOLAR OVEN: SUSTAINABLE FOR TASTE AND HEALTH

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Abstract: Solar ovens use clean and renewable energy to cook foods so they are an environmentally friendly alternative for traditional cooking, but this study will show that the food cooked in a direct solar oven is even more healthy.

As the interest in cooking techniques that produce tasty food but also enable the preservation of nutraceuticals is growing day by day, it will be presented a comparison between the antioxidants present in various raw and cooked food, comparing the effect of traditional and solar oven cooking.

The Helio™ direct solar oven cooks by both convection and direct radiation and provides great efficiency (300°C maximum temperature) and good insulation. However, food exposure to UV rays might cause undesirable loss of nutrients. To determine the antioxidant contents, cooked foods (vegetables, meat, etc.) have been analyzed through the DPPH assay, that measures the antioxidants in foods, and the Folin assay that establish the total phenolic content (TPC). Both analyses use spectroscopic techniques. Furthermore, a special UV filter has been used to check the effect of solar cooking without the more energetic UV solar radiations.

This research is a part of the ‘For_Eco’ project, financed by Regione Lazio (Italy), whose aim is to improve the performance of direct solar ovens.

SOLAR COOKING AS A HIGHER EDUCATION GATEWAY TOWARDS GLOBAL ENGAGEMENT, RESPONSIBILITY, AND REPAIR

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Abstract: Sacramento City College Global Studies Program and Makerspace partnered with non-profit organization Solar Education Project to create "Global Makers" with the goal of introducing students to makers of solar cookers and dehydrators around the world as a strategy for expanding students' global awareness and engagement, sense of responsibility, and duty to repair the planet. A concurrent goal is to have genuine exchange of ideas and goals with our partner makers around the world, acknowledging their role as teachers in their own right, whether or not they are affiliated with educational institutions, and affording the global community more access to information and technology in the service of improving lives. Our goal is not simply to teach and support the making of solar cookers, but also to teach and support the making of environmental justice and repair of the planet, benefiting lives and ecosystems. Along the way, the partnership has sprouted new directions and inspired expanded relationships towards those goals. For example, in the spirit of global engagement, the relationships created through Global Makers have sparked a new project, the solar cooker global Maker Challenge, to connect makers and makerspaces around the world with the goal of inspiring new designs. Another example is a globally accessible solar cooking course that is being developed. Most importantly, our session is about collaboration for the common good and the unexpected fruits such collaborations might bear. When people with varied interests, skills, and resources get together for a greater good, we are able to tackle a goal that may be unachievable alone, and to create lasting shared resources.

Keywords: Solar education, creative commons, global citizenship, global engagement, environmental ethics and justice, STEM, STEAM, experiential learning, makerspace, global studies, collaboration.

STEM THROUGH SOLAR COOKING – STUDENTS AND TEACHERS ENGAGE WITH SOLAR COOKING THEMED-BASED LEARNING

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Abstract: *Solar Education Project (SEP), located in Hubbard, Ohio, USA, is a leader in promotion of solar cookers as tools for STEM and cross curricular education. Through development of engaging theme-based curriculum, SEP lessons introduce solar cooking within the framework of various disciplines. There are many positive aspects to theme-based learning including increased retention, relevant lesson context, positive attitude toward learning, experience in collaboration, and opportunities for differentiated learning. SEP advocates for experiential learning opportunities that deepen understanding of solar cooking concepts through experimentation, activities, engineering design challenges, and extended learning opportunities.*

SEP presented this nascent concept at CONSOLFOOD 2018 with the paper, Networking to Advance the Use of Solar Cookers as Educational Tools in the Classroom. Suggested strategies included understanding educational goals and standards, identifying decision makers within institutions, networking with those decision makers, sharing proven strategies for solar cooking theme-based lessons, and participating in opportunities to educate others.

Through the intervening years, SEP has developed professional relationships with educational communities interested in engaging students in solar cooking themed-based lessons, activities, and projects. Examples include science centers, summer camps, and various types of schools: public, private, science academy, home school network, and universities.

We know what this looks like on paper, but what does it look like in practice? SEP will present a video of student engagement during classroom instruction using SEP solar cooking theme-based curriculum. Watch lessons unfold and learn from students as they share their understanding of solar cooking across disciplines. Discover the reasons teachers were drawn to solar cookers as educational tools. Hear educators discuss the advantages and challenges of this type of dedicated instruction.

Keywords: *Solar Cooking, Theme-Based, Multi-Disciplinary, Student Centered, Solar Energy, Sustainable Development Goals, Energy Literacy, Experiential Learning, STEAM*

1. INTRODUCTION

In today's rapidly evolving world, the need for promoting self-sufficiency skills that translate into everyday life is unparalleled. The sun's free energy provides a viable option. Solar cookers offer a promising solution for addressing the global challenges of energy conservation, environmental sustainability, and food security. By integrating solar cookers into educational curricula, they play a vital role in fostering a sustainable mindset among students.

Solar cookers offer a unique opportunity to introduce students to the principles of STEAM concepts, while incorporating theme-based learning. These simple devices utilize the power of sunlight to cook food using the free, renewable resource of sunlight. By providing a hands-on platform for exploring scientific and sustainability concepts, solar cookers have become a multi faced teaching tool, which results in an edible outcome. Theme based teaching offers the opportunity to inspire, educate and transform projects in a way that supports cross curricular learning. [1]

2. SEP INSPIRES TEACHERS

SEP's mission is to educate and empower individuals using solar cookers and theme-based learning. The core belief is that education should be accessible to all, creating inclusive learning environments where people from diverse backgrounds can participate and benefit. SEP works to promote solar cookers as tools for education, wellness, economic empowerment, and ecosystem recovery. SEP believes that education is a shared responsibility, and program collaboration should foster a sense of community and support for local initiatives.

Academic lessons taught within the context of life experiences provide a richness and depth of understanding for students that is impactful personally, cognitively, and socially. Solar ovens use concentrated sunlight directed at a cooking surface or into a cooking space to cook all types of foods. By introducing this tool to teachers, and incorporating solar cooking into the curriculum, teachers embrace and explore not only STEAM, but other disciplines as well – Social Science, Arts, Geography, Political Science, Language Arts and more. [2]

SEP believes that learning should be interconnected, and relevant to the world around us. Through themes such as sustainability and climate, we empower learners to connect with the pressing issues of our time and become active participants in finding solutions through extended learning. Inspiring the next generation to be the change-makers by incorporating solar cooking education into programs, teachers can empower students to make informed choices about environmental responsibility and contribute to changes in their local and global communities.

3. SEP EDUCATES: THEME-BASED LEARNING

SEP consults on a wide variety of projects in the field of education and beyond. Professional development and personal education are important aspects of creating successful programming. Collaborative networking establishes partnerships between people and organizations that contribute to the achievement of common goals. The intersection of education and sustainability offers the opportunity to reshape our world. By embracing solar cookers and theme-based learning, we help to equip future generations with vital knowledge.

3.1 Understanding Theme Based Learning

Teachers explore how theme-based learning encourages collaboration among students. Through interdisciplinary projects and activities, students learn to work together, share ideas, and collaborate in solving problems using the engineering design process.

Theme-based learning allows for differentiated instruction, catering to diverse learning styles and abilities. Teachers can explore solar cooking concepts with students at different levels, conducting investigations and projects that align with their individual learning goals. Student projects can become an extension of learning and reach into the community through service organizations, senior groups, and sustainability projects. Teachers see many positive aspects to theme-based learning, including increased retention, lessons presented in a relevant context, positive attitude toward learning, experience in collaboration, and opportunities for differentiated learning. This interdisciplinary approach allows students to explore solar cooking from multiple perspectives, while facilitating a comprehensive understanding of its benefits and applications.

Using solar cookers as teaching tools creates opportunities for interdisciplinary connections by embedding cross-curricular subject areas such as geography, social studies, reading and language arts into the learning extensions. Solar cookers inspire creativity and problem solving when practicing the engineering design process. When making solar cookers, math skills are utilized when adapting recipes, and students learn to easily apply the information learned at school, at home and in the community.

By using solar cookers, we bridge the gap between theory and practice. Students not only grasp the science and engineering behind solar technology, but they also witness firsthand how their actions can contribute to a greener planet. As they cook meals using the power of the sun, they become ambassadors of change, igniting inspiration within their communities, and promoting renewable energy solutions.[3]

3.2 Community Engagement and Relationship Building

Professional relationships and community engagement are essential components of SEP's efforts to promote solar cooking education.

- *Building partnerships:* SEP emphasizes the importance of building partnerships with educational communities interested in integrating solar cooking into their curricula. This involves establishing connections with schools, educational organizations, and other institutions to foster collaboration and knowledge sharing.
- *Cultivating long-term relationships:* SEP values the development of long-term relationships with educational communities. By maintaining ongoing communication and engagement, SEP can provide continuous support, resources, and training to educators and institutions interested in implementing solar cooking programs.
- *Partnering with educational communities:* SEP acts as a hub for educational materials by sharing advances in technology. These collaborations not only enhance the educational experience but also contribute to raising awareness about the benefits of solar cooking and promoting sustainable practices within the classroom and community.
- *SEP strives to create a global network of resources*—a place where educators collaborate, students exchange ideas, and communities come together to drive

sustainable development. Through sharing best practices, resources, and experiences, we aim to empower educators worldwide to incorporate solar education into their curricula, sparking a passion for renewable energy in the hearts of their students.

4. CURRICULUM

Through its initiatives, SEP has demonstrated the positive impact of experiential education in promoting students' understanding of solar cooking concepts. SEP's work has not only influenced classroom instruction but also extended to science centers, summer camps, public, private, and home schools, science academies, and universities. With its commitment to collaboration, advocacy and education SEP continues to play a pivotal role in advancing solar cooking as a powerful tool for higher education, global engagement, and sustainable development through the introduction of the solar cooking curriculum.

SEP highlights the value of sharing proven strategies for implementing solar cooking theme-based curriculum. This includes providing educators with comprehensive resources, lesson plans, and instructional materials that support the integration of solar cooking into subjects and grade levels. Solar cookers serve as valuable tools for STEAM and cross-curricular education. The integration of solar cookers into educational settings allows for a multifaceted approach to learning, fostering a deeper understanding of subjects and encouraging critical thinking and problem-solving skills.

4.1 Methods of Instruction

The theme for the World Teacher's Day '23 is, "Transformation of Education Begins with Teachers, celebrating the critical role of teachers in transforming learner's potential". [4]

Now, more than ever, we recognize the impacts of global teaching processes. The biggest educational trends in the United States in 2023 are Social Emotional Wellbeing, Self -Led Learning, Game Based Learning, Nano or Microlearning and Technology Integration - augmented reality (AR), virtual reality (VR) and artificial intelligence (AI). [5].

The pandemic ushered in "educator agility" [6] and an opportunity for SEP to segway to the train-the-trainer hybrid model. Teachers were accustomed to conferencing guest speakers and creating distance programs via zoom and other platforms. By reducing the amount of classroom demonstrations, SEP was able to accelerate teacher training and professional development within many Districts.

- *Project and Inquiry Based Learning*: Solar cookers provide a practical application of scientific principles, allowing students to engage in hands-on experiments and observations. By constructing, using, and experimenting with solar cookers, students can directly witness the conversion of solar energy into thermal energy, apply mathematical concepts to measure temperatures and cooking times, and analyze the efficiency of the cooking process. [7]

4.2 Theme-based learning is a pedagogical approach that integrates a specific theme or topic across multiple subjects and disciplines. In the context of solar cooking and its application in education, theme-based learning offers several benefits for students and educators. [8]

- Solar cooking, as a theme, allows students to explore practical applications of science, mathematics, social studies, and other subjects in the context of renewable energy and sustainable cooking practices.

- Theme-based learning promotes student motivation and engagement. By integrating a central theme, students find learning more interesting, meaningful, and applicable to their life through the hands-on nature of theme-based learning. Through solar cooking activities, students actively participate in constructing and using solar cookers, conducting experiments, and engaging in problem-solving tasks, fostering a deeper level of engagement. [9]
- Opportunities for extended learning exist for students wanting to engage in research, explore related topics, participate in community projects, and connect with experts or organizations involved in solar cooking and can foster a sense of lifelong learning by nurturing curiosity and encouraging students to explore solar cooking beyond the classroom setting.
- SEP emphasizes the iterative nature of engineering design. Students engage in prototyping, testing, and refining their designs based on feedback and evaluation. This iterative process enhances their problem-solving skills, critical thinking abilities, and understanding of the engineering design process.

5. IMPLEMENTATION

- Development of theme-based curriculum, teacher training initiatives, and partnerships with educational institutions to identify the audience for STEAM curriculum.
- Align the curriculum with Science Standards to assist teachers in using the lessons, experiments, and activities.
- Encourage educators to create an assessment within each lesson. Surveys, pre and post quizzes, and knowledge assessment and demonstration of skill using the EDGE Method are encouraged.
- Share case studies to showcase the program's success. Build out the program.

6. TEACHER ENGAGEMENT AND STUDENT PARTICIPATION (VIDEO)

Showcasing teacher experiences using the STEM Through Solar Cooking Curriculum emphasizes the value of capturing real-life examples and testimonials to share the impact of solar cooking as an educational tool. [10]

6.1 Demonstration of Student Engagement

- *Video footage*: The demonstrations highlight the hands-on nature of solar cooking education and its impact on student engagement. SEP includes interviews and testimonials from educators in a variety of program settings, sharing their understanding of solar cooking concepts and its connections to a variety of academic disciplines. The videos provide insights into the interdisciplinary nature of solar cooking education and its ability to foster holistic learning.

6.2 Teachers' Motivations for Using Solar Cookers as Educational Tools:

- SEP listens to educators who have incorporated solar cookers into their teaching practices. These interviews explore the motivations behind their decision to use solar cookers as educational tools, such as promoting sustainability, enhancing student engagement, and fostering critical thinking skills.
- SEP features interviews with educators discussing the advantages and challenges they have encountered in implementing dedicated solar cooking instruction. This

includes benefits such as increased student interest, hands-on learning experiences, and connections to real-world issues. It also addresses challenges like resource constraints, curriculum integration, and time management.

- By sharing the video presentation, SEP provides tangible evidence of the positive impact of solar cooking education on student engagement and teacher experiences. The inclusion of student insights and educator perspectives adds depth to the discussion and highlights the benefits of integrating solar cooking into the curriculum.

7. TRANSFORMATION

Scenario: Imagine a classroom with excited students, anxiously awaiting the bread or cake to come out of the solar cooker on a sunny day. The dough, prepared by the students, and the batter carefully measured from a recipe sent in from a student's grandmother from Europe. The solar cooker becomes the center of the hands-on experience, students share stories, and culture, all while learning about the principles of light. Extending the learning into engineering, the design challenge sparks interest in a competition to see which team can draw and build a working prototype of a solar cooker. Guided by the teacher, the students conduct experiments, adjust, and modify the prototype to optimize performance.

Students then take the solar cooker on a cultural journey as the classroom transforms, to include culinary arts, plating, and presentation of food. Sharing customs, traditions, and eating foods from other countries develops an understanding of cultural diversity. The teacher then leads the group in an exercise about environmental awareness and sustainability. The students create graphs and charts by collecting data on gas and electric cooking costs, environmental impacts, and long-term effects of pollution. Watching the transformation in the classroom, the teacher is assured that the standards are met, and the knowledge has empowered students to examine the interconnectedness of other subjects using the solar cooker! This classroom exists when using the STEAM through Solar cooking curriculum, in connection to the Teaching Standards.

Table 1. Portion of Next Generation Science Standards for Middle School Physical Science [11]

MS-PS3.1. Students who demonstrate understanding can: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]		
Performance expectation developed using following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system.	**Disciplinary Core Ideas** **PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **PS3.B: Conservation of Energy & Energy Transfer** Energy is spontaneously transferred out of hotter regions or objects and into colder ones. **ETS1.A: Defining Delimiting Engineering Problem** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. *(secondary)* **ETS1.B: Developing Possible Solutions** A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. *(secondary)*	**Crosscutting Concepts** **Energy and Matter** • The transfer of energy can be tracked as energy flows through a designed or natural system.

8. THE FUTURE

- *Launch a community engagement study:* Survey the engagement and impact of SEP's programs within the community by gathering feedback to adjust to better serve the needs of the educators and the community at large.
- *Call to Action for youth involvement:* Encouraging students to actively participate in their communities or collaborate with local libraries to reinforce learning and empower students to become change-makers in their own neighborhoods.
- *Address the need for professional development* opportunities, through curriculum resources and collaborations with relevant stakeholders. Emphasize the importance of ongoing continuous improvement of solar cooking programs.
- *Assess the long-term impacts on student* attitudes and behaviors, exploring the effectiveness of different instructional approaches, and investigating the scalability and sustainability of solar cooking programs.

9. CONCLUSION

In conclusion, SEP's practical implementation of solar cooking education demonstrated its effectiveness in engaging teachers through STEM. The videos demonstrated student participation during classroom instruction using the curriculum. Experiments and cooking activities facilitated by the teachers highlight the effectiveness of theme-based learning instruction and the impact on student engagement. The insights shared by the teachers show their understanding of how to blend the solar cooking curriculum into their lessons.

By integrating solar cooking education into the national educational system, students and community members gain valuable knowledge and become active participants in environmental conservation. By sharing best practices, resources, and experiences, we can empower educators worldwide to incorporate solar education into their curricula and ignite a passion for renewable energy in the hearts of their students. We D.A.R.E. you, to solar cook!

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Assessment for solar e-cooking at the Productive Use in Rural African Markets using Standalone Solar (PURAMS) project

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Abstract: *PURAMS, Productive Use in Rural African Markets using Standalone Solar, is a sub-project of the LEAP-RE project (GA – 963530 of the H2020 program) whose main objective is the development of an autonomous solar cooker model to overcome the challenges caused by traditional methods of cooking used in rural communities in Africa, namely, in Mozambique, Rwanda and Kenya where data collection was being carried out to understand the cooking habits (Simões T. et al., 2022).*

Biomass is the major residential energy supply and a large percentage use wood and charcoal as their main cooking fuel. In African urban areas fuels like liquefied petroleum gas (LPG), ethanol, biogas and electricity are gradually becoming more usable, nevertheless as access to electricity is increasing, cooking with electricity still remains not attractive (Clemens et al., 2018). Traditional cooking fuels have adverse health effects on the human body and leading also to environmental degradation and deterioration (Armah et al., 2019). Demand for clean cooking has been on a steady rise in Africa due to the transitions to clean renewable energies. With the aim of achieving strategic and sustainable visions of social and economic development, African countries have included in their energy and climate plans the integration of clean cooking solutions.

Standalone systems are an effective way of supplying low-power services in off-grid regions such as lighting and phone charging. With the current reduction in photovoltaic systems prices and used efficient cooking devices solar e-cooking solutions could be attainable. To facing the challenges of clean cooking at PURAMS project it was proposed a design of photovoltaic solar-powered cooker for productive use at street food vendors and households where the predominant mode of cooking is frying and boiling using traditional cooking fuels.

Keywords: *Renewable energies, solar cooking, clean energy, sustainable development.*

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Solar – thinking seeds
how to introduce the use of solar cooking in the vegetable garden in the school

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Abstract: Solar cookers are dispositives for art education in the field of environmental awareness raising in schools. The current climate protection protests show us all how much potential there is in the role of youth in our socio-political landscape. The public image is increasingly determined by painted posters and various actions. This mobilisation of youth is giving rise to new images that are developing out of a consciousness and an active desire to change and shape things. What role does contemporary art education play here, offering new perspectives for a contemporary approach? What skills does contemporary art education offer and where exactly can art practice and environmental education meet in the creation of new images and perspectives in the field of schools? These questions are the starting point for the need for an initiative that acts as an interface between art education and environmental education in the school sector. This is where I would like to talk about my experience with the use of solar cookers in artistic eco-social projects in the playground of several schools. I would like to introduce some patterns that can be adapted to the schools' own needs. I started to use the solar cooker for school projects for a contemporary art exhibition in Murcia in 2010, Manifesta 2010. Manolo Vilchez in Spain help us to organize a solar parabolic cooker and i got into the magical praxis of solar cooking. We decided to design a modular project for several schools that would allow us to open a collaborative work space with the students. We wanted to investigate with them the school environment from the perspective of the impact on the landscape. The issue of food production was fundamental and the image of a collective meal in the schoolyard appealed to us. Through the solar cooker we were able to become independent from the four walls of the school-kitchen and to work together in several groups in the courtyard.

First seed TAKING POSITION

The solar cooker orients us towards the sun like sunflowers. Through it, the children in the playground start to look at the sky and connect the sun's rays with their own shadows. We always start by defining a common play space that helps us to make collective maps of the environment in which we move. Discovering where is east, south, west and north... we start to connect with phrases we learnt at school. We move from the abstract concept of environment to the more concrete and situated concept of the site and its surroundings.

Second seed BE AWARE

We ask about the school-way, but also about where the food we eat comes from and what we will cook in the solar cooker. Then we look at the school garden in a different way because we can work directly with the spices and vegetables from the garden.

First seed TAKING POSITION

The solar cooker helps us to create a magical atmosphere in the school. Mirroring with others. Keep warm in your self confidence, but looking throw the glass. Appreciating the Quality of life and the Quality of learning together. We cook vegetarian and vegan and we see the power of the seeds around us. Fort he school we made vegan muffins, couscous with vegetables, Bread without Gluten. The recipes will adapt to the season, the things pupils are bringing and maybe the connections we start with the neighbourhood.