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# Design, manufacturing, thermal characterization of a solar cooker with compound parabolic concentrator and assessment of an integrated stove use monitoring mechanism

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ABSTRACT

Efficient-use firewood cookers have been monitored successfully using Cooker Use Monitors (SUMs) that make it possible to identify use patterns by means of objective indicators. The present study proposed utilizing SUMs to study the adoption process of solar cookers. The *Jorhejpatarnskua I* solar cooker (CSJI) –a variant of the *Jorhejpatarnskua* model (CSJ)– was characterized thermically using standardized tests. This article also describes a method for integrating SUMs into the design of the solar cooker by installing a mechanical device equipped with springs in the basket that holds the cooking pot where the food is placed. This mechanism facilitates the recording of temperature patterns that identify the functioning of the solar cooker. The result of this characterization was a series of thermal parameters for the CSJI which demonstrate that it is suitable for use in the solar resource conditions that predominate in the Meseta Purépecha in Michoacán, Mexico.

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## Introduction

Nearly 22.5 million people in Mexico cook with forest biomass using combustion processes that usually involve open hearths (Serrano-Medrano, Arias-Chalico, Ghilardi, & Masera, 2014) and, therefore, release large amounts of contaminants, including $CO_2$, CO and $CH_4$. The gases released by this combustion reaction have negative effects on the health of rural inhabitants (Lim et al., 2012). Estimates for Mexico in 2015 suggest that 9154 deaths are associated annually with the risk of air pollution inside the home, a figure equivalent to one death per hour (GBD 2015, 2016). It is hoped that implementing alternative technologies, such as efficient-use firewood stoves and solar cookers, will decrease contaminant emissions. However, without the sustained adoption and utilization of such technologies, none of the expected benefits will be achieved (Ruiz-Mercado, Masera, Zamora, & Smith, 2011). Thus, it is necessary to find ways to objectively evaluate the technical performance and extent of adoption and use of such devices in order to establish their sustainability and the benefits that could accrue to their use. To this end, we utilized Cooker Use Monitors (SUMs) to measure the adoption of efficient-use firewood cookers (*Patsari*) in various rural communities in the Meseta Purépecha (Pine et al., 2011) and communities in Guatemala (Ruiz-Mercado, Canuz, & Smith, 2012; Ruiz-Mercado, Canuz, Walker, & Smith, 2013).

Worldwide, there are few experiences of monitoring the use of solar cookers in order to analyze the adoption process by means of objective indicators. In some cases, researchers have used similar measuring techniques (Grupp et al., 2009), but they have involved costly instruments that are invasive for users and, hence, inadequate for the present case. SUMs have been used to monitor the use of solar cookers in Nicaragua, where the patterns recorded provide some indications of their utilization, but offer little certainty as to the extent of their use or the purposes for which people employ them (Bauer, 2016). It is important to note, however, that the use of solar cookers has increased around the world in recent years, especially in Third World countries in Asia, Africa and Latin America. Diverse models of solar cookers exist, but they can be classified generally in two types: box and concentration cookers (González-Avilés, López-Sosa, Servín-Campuzano, & González-Pérez, 2014).

The implementation of solar cookers in Mexico has been complex and we lack scientific studies of the levels of use and the adoption process in the few documented cases. Most of the cookers that have been distributed are of the box type. Some attempts at implementing cookers of this kind have been made in the state of Michoacán (Mexico) (Ávila-Méndez, 2011), but none of those efforts have been subjected to systematic monitoring. Also, there are only a couple documented studies

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of the adoption of solar cookers. One case took place in a community in the Hotlands (*Tierra Caliente*) of Michoacán where the commercial *HotPot* solar cooker was introduced. The assessment of the adoption process conducted there quantified approximately 20% of the use of those solar devices (Velasco & Jerneck, 2008). A second study, this one in an indigenous community in Michoacán (Pérez-Códova, 2017), found that only approximately 8% of the devices installed were being used. However, in neither case were objective indicators involved in the analysis.

*The Jorhejpatarnskua I solar cooker*

The device evaluated in the present study is a concentration cooker model that uses non-focused or anidolic optics, called the *Jorhejpatarnskua I*, a modified version of an earlier model named *Jorhejparanskua* (CSJ), which means "cooking with the sun" in the Purépecha language. This model consists of a collector, a basket that holds the pot, a base and a 5-liter recipient (González-Avilés, López-Sosa, Servín-Campuzano, & González-Pérez, 2017). This new design includes a mechanism that allows users to disassemble the collector in three sections for better portability. Its cost is also lower because the reflector sheet is made of stainless steel with a mirror finish, instead of the optimized sheet usually employed for solar applications, which is over ten times more expensive than steel. To reduce heat loss through the steel reflector sheet, it is covered with a thermal insulating material made of foam rubber and covered with impermeabilizing paint. This model of solar cooker and its construction procedure are shown in Fig. 1. To achieve optimal performance, the cooker must be oriented manually towards the solar disk at 1-hour time intervals.

In light of the foregoing, the main objective of this study was to achieve a thermal characterization of the *Jorhejpatarnskua I* by determining –experimentally– the following parameters: standard cooking power, thermal yield, exergy performance, and heating and cooking times, as well as establishing an effective mechanism for adapting a SUM, given the specific characteristics of this model. The mounting mechanism developed, and the experimental tests applied, are described.

## Materials and methods

*Construction and materials*

The model of solar cooker evaluated is a device that functions by means of a solar radiation collector connected to a revolving compound parabolic concentrator (CPC) (Rabl, 1976, 1993) that makes it possible to concentrate the sun's rays on the focal region where the absorption recipient is placed. This type of CPC is safe for users because it uses

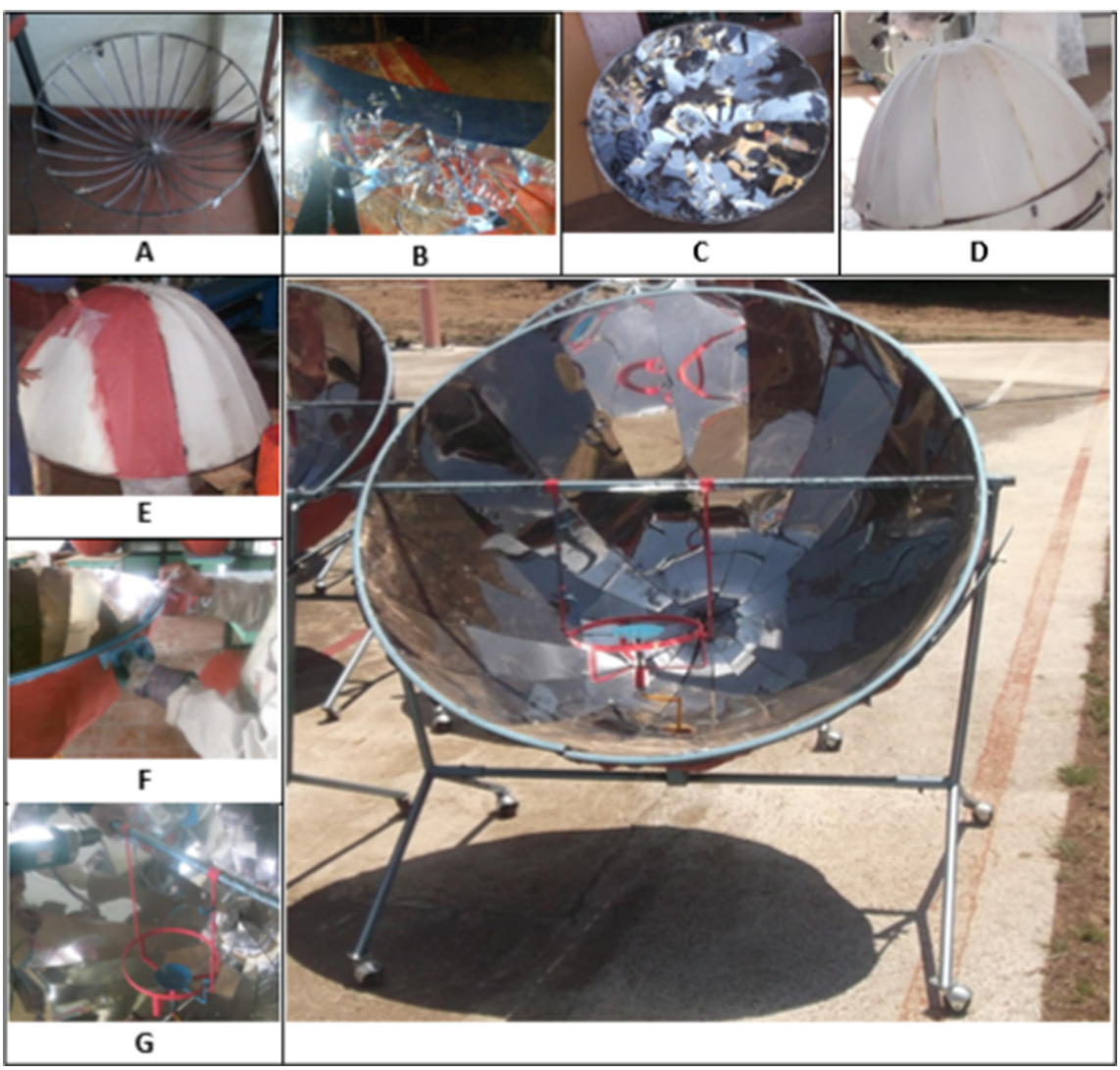


**Fig. 1.** Process of constructing the solar cooker: A) structure; B) reflectors section; C) mounting the reflectors; D) applying the thermal insulation; E) impermeabilization; F) painting and finishing; G) mounting the SUMs.

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