The Feasibility of a Collapsible Parabolic Solar Cooker Incorporating Phase Change Materials

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Abstract: *This paper presents a solar energy-based cooking solution for reducing the dependency of refugees on firewood for cooking food. The use of firewood is associated with a variety of problems such as deforestation, environmental degradation and household air pollution. This paper proposes that a collapsible parabolic solar cooker with 12 panels and a phase change material-incorporated cooking pot is a viable alternative to firewood. The phase change material allows food cooked during the day to be kept warm and subsequently consumed as an evening meal. Furthermore, the proposed solution considers, and fits within, the cultural aspect of the refugee context. The cultural aspect is highlighted as it is a factor in determining whether refugees will accept the proposed solution. This paper also presents a cost-benefit analysis of the proposed solution which shows that if used by a family unit of four members, the payback period is 52 weeks or less. Finally, this paper concludes with recommendations pertaining to the efficiency of the system to reduce cooking time and enable the system to keep food warm for subsequent meals. These recommendations are focused on maximising the chances of acceptance of the parabolic solar cooker by refugees during humanitarian crises.*

Keywords: Parabolic solar cooker; Phase change materials; Refugees; Solar energy

Nomenclature	
A	Surface area (m^2)
c	Specific heat capacity ($J.g^{-1}.^{o}C^{-1}$)
k	Thermal conductivity ($W.m^{-1}.K^{-1}$)
L	Thickness of material (m)
m	Mass (g)
Q	Heat content (J)
T	Temperature (K)
t	Time (s)
ΔH	Latent heat of fusion ($J.g^{-1}$)
ΔT	Temperature difference (K)
ε	Emissivity
σ	Stefan-Boltzmann Constant ($W.m^{-2}.K^{-4}$)

Abbreviations	
FSANZ	Food Standards Australia New Zealand
LPG	Liquefied Petroleum Gas
PCM	Phase Change Material
UNHCR	United Nations High Commissioner for Refugees

1. INTRODUCTION

The majority of the approximately 66 million displaced persons around the world (UNHCR 2017) lack access to clean and secure energy sources relying on biomass for cooking, with over 14 million reliant on firewood alone (Lehne et al., 2016). Though convenient, the procurement and use of firewood in refugee contexts has drawbacks. One impact is deforestation and environmental degradation (Women's Refugee Commission, 2013); between 1994 and 1997, the Great Lakes refugee crisis caused thousands of Rwandans to seek refuge near Virunga National Park in the eastern part of the Democratic Republic of the Congo. Kalpers and Mushenzi (2006, cited in Crawford & Bernstein, 2008) found that this resulted in 105 km^2 of parkland, approximately equal to the area of Paris, being affected by deforestation within two years as refugees foraged for firewood.

Collecting firewood from forests is also a burden, one that often falls to women. Refugees may travel long distances from the camp to collect firewood and, in doing so, risk being victims of physical and sexual violence (Spangaro et al., 2013). Additionally household air pollution caused by burning biomass causes respiratory problems, often affecting women and children (World Bank, 2015). From a performance perspective, the traditional cookstove used in displaced contexts (an open wood fire centred around three stones) has a thermal efficiency of only 15% and is also known to produce a lot of smoke during the burn sequence (UNHCR, 2002).

Improved Cookstoves (ICS) have been implemented in humanitarian contexts (Caniato et al., 2017; Barbieri et al., 2017). The World Bank (2015) defines such cookstoves as those that 'improve on traditional baseline biomass technologies in terms of fuel savings via improved fuel efficiency'. Such cookstoves can achieve energy savings of up to 30% over three-stone fires (Barbieri et al., 2017). Example of ICS that have been implemented in humanitarian contexts include rocket stoves fuelled with wood or charcoal, gasifier stoves and liquid and gas fuelled stoves (Barbieri et al., 2017). However, the climate and health impacts of such cookstoves are still greater than that of solar cookstoves (World Bank, 2015).

Error! Reference source not found.~~Figure 1~~, which has been adopted from a World Bank report (2014) citing various sources, illustrates the health and climate impacts of traditional sources of fuel in comparison to renewable sources such as biogas and solar. From this figure, it is clear that ICS and firewood are inferior to renewable energy in terms of environmental and health impact.

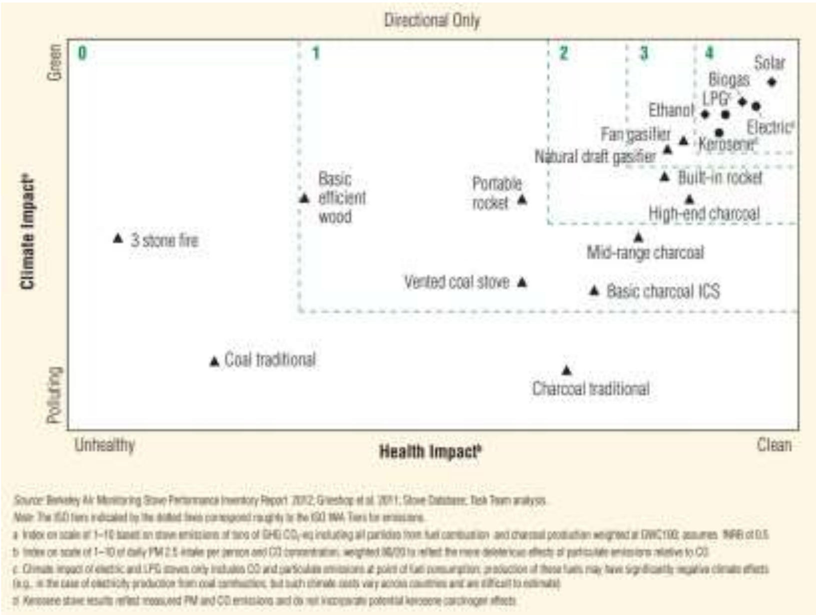


Fig. 1: Health and climate impacts of various cooking solutions

The World Bank (2015) noted that the lack of *affordable* clean alternatives and the unwillingness to pay for higher cost of clean cooking solutions are two major factors that have inhibited the global adoption of clean cooking energy. As such, the opportunity exists to develop low cost improved cookstoves.

Accordingly, solar cookstoves are a clean energy option with regards to environmental and human health. Solar cookstoves use direct solar thermal energy to heat food and can be broadly divided into three types: box, panel and parabolic. To date, the box type is the most frequently used type of solar cooker used in refugee camps, although parabolic type cookers offer the closest alternative to firewood in terms of cooking time and temperatures achieved (Lecuona et al., 2013; Chaudhary et al., 2013).

One example of the use of solar cookers in a refugee context was in the Beldangi-I Refugee Camp in Nepal. In 1998, the Vajra Foundation initiated a solar cooker project in this camp using parabolic solar cookers to reduce dependency on firewood. Initially, the organisation had tested the use of box type cookers; however, it was found that these cookers required long cooking times and had low durability due to delicate construction leading to the use of parabolic cookers. By 2004, 221 parabolic solar cookers were being used in Beldangi-I Refugee Camp for 8 months a year and half of the camp's population was able to benefit from its use (Brugman & Hart 2004).

Through testing of these cookers, it was found that the fastest time taken to boil 3 litres of water was 29 minutes, compared with 19 minutes using a kerosene stove (Brugman & Hart 2004). In the same report, it was also found that refugees needed to be educated on the use and operation of the parabolic cookers for best results. This was primarily due to the fact that the cookers needed to be adjusted at regular intervals to face the sun in order to achieve maximum thermal efficiency. Brugman and Hart (2004) also noted that the reflector panels were vulnerable to rainy weather thereby causing rust to form. The fact that the parabolic cookers were difficult to move around given the weight of the structure was also a problem in this situation. Overall, the project was considered a success although adjustments had to be made in order to improve the durability of the parabolic cookers.

In 2005, 15,000 panel-type solar cookers (called CooKits) developed by Solar Cookers International were introduced to the Iridimi Refugee Camp (Loskota 2007). Training had also been provided to the refugees on how to use the solar cookers. In a joint evaluation in 2007, it was found that the primary users of solar cookers were women. Of the 121 refugees that were interview (119 women, 2 men), all of them had indicated that they were able to use the solar cookers to cook traditional foods that they would normally cook with a wood burning stove. Other benefits such as lack of smoke and the lack of need to forage for firewood in unsafe areas were also noted. However, there remained issues with the CooKit cookers — mainly regarding durability and the impact of rain and wind on the cookers (Loskota 2007).

These experiences show that the use of solar cookers also has many limitations. The primary issue is the need for sunlight to operate ergo redundant during night time. Periods of rain and clouds further reduce the efficiency of solar cookers. The need for sunlight also goes against traditional cultural practice of indoor cooking. Durability is also a prevalent issue. Frequent replacement of solar cookers will only add to the total cost of the solution. With the use of parabolic cookers, additional issues also persist. These issues include the minimal portability of the structure and the need to realign the cooker with the sun at regular intervals.

This paper presents a proof of concept design for a parabolic solar cooking solution which incorporates a phase-change material (PCM) into the cooking vessel to improve versatility. The benefits of this particular stove design are its reduced climate and health impacts, reduced labour intensity, portability and ability to store energy to be utilised for cooking subsequent meals. The latter feature could provide additional functionality within certain cultural contexts, such as during Ramadan.

PCMs are materials that absorb energy in the form of heat when changing phases from solid to liquid or from liquid to gas, provided that the temperature of the environment is higher than their melting or boiling point. Conversely, when the temperature of the environment decreases and the PCM reverts to solid phase, it releases heat. As PCMs change phase from solid to liquid, there is a large increase in their heat content (Q). This rise in heat content during phase change is known as the latent heat of the material. It is the high latent heat storage capacity of PCMs that make them desirable for thermal heat storage applications. Different types of PCMs have been used in various experiments involving solar cooking. For example, Swami et al (2018) used paraffin wax C-23 and C-31 as a PCM in an experiment involving the use of solar air dryers and concluded that use of a PCM is an excellent way of improving fish drying rate. Tesfay et al (2014) used such as solar salt (a mixture of sodium nitrate and potassium nitrate) (Tesfay et al., 2014)for thermal storage in a successful experiment involving Injera baking at night time.

El-Sebaii et al (2011) investigated the effect of the melting/solidification fast thermal cycling of commercial grade , magnesium chloride hexahydrate on its melting point and latent heat of fusion. Their results indicated that magnesium chloride hexahydrate remained stable after

1000 cycles and would be a suitable PCM in solar cookers for cooking indoors or during low intensity solar radiation periods. Indeed, the authors noted that for solar cookers to become socially acceptable they need to be able to store thermal energy for use during non-sunshine hours. ~~(El-Sebaii 2011), and commercial grade acetanilide (~~Chaudhary et al~~.,~~ (2013) investigated the use of commercial grade acetanilide as a PCM in combination with a solar cooker based on a parabolic dish in Indian climatic conditions. Their results demonstrated, using an ordinary solar cooker, a maximum PCM temperature of 119 ^{o}C can be achieved, which is above the melting range of acetanilide (105-110 ^{o}C), and a maximum temperature of 52.2 ^{o}C in the cooking medium during the discharge process of the PCM can be achieved. ~~have been experimentally tested in solar cooking contexts.~~Moreover, in a performance evaluation of the thermal heat storage of Stearic Acid for solar cooking purposes, Saxena et al (2013) found that solar cookers equipped with storage units are beneficial for cooking methodologies as well as energy conservation.

This paper will first present the methodology of the investigation. This will entail an explanation of why certain decisions were made during the project, to set the context for the data. This will be followed by the results obtained from the experiments and a discussion of these results, which will include a cost-benefit analysis. It must be noted that the experiments were designed to simulate cooking conditions in refugee camps, due to lack of access to refugee camps where the proof of concept could be tested. Bauer and Brown (2014) synthesised a quantitative model for assessing appropriate technology for sustainable community development. Although a useful tool, this model will not be applied to the current analysis as the proposed design is a proof of concept and the model requires a survey of the end users, in this context refugees, who have used this stove design, to evaluate the appropriateness of the proposed technology. However, this model could provide a useful tool for analysis in similar studies in the future.

2. METHODOLOGY

The proof of concept for the phase change material parabolic solar cooker was developed using three lenses of design: desirability, viability and feasibility. Starting with desirability the needs of refugees were identified by examining previous projects and reports of various groups (UNHCR 2014; World Bank 2014; Women's Commission for Refugee Women and Children, 2006). From this assessment, specifically covering cultural factors such as cooking practices, a set of functional requirements were developed, as summarised in Table 1.

Table 1: Functional requirements for solar cookstoves

	Technical	**Economic**	**Socio-cultural**
Criteria	• Renewable • Ease of use • Ease of construction	• Low start-up cost • Low lifetime cost • Favourable	• Ability to cook traditional foods • Appropriate for family use • Socially

	• Mobile • Cooking time comparable to firewood • Low emissions • Night time / year-round use	cost comparison against traditional non-renewable fuel sources • Economies of scale	acceptable source of fuel (i.e. not derived from human/animal waste) • Impact on women • Participative process

A portable solar cookstove with the ability to cook evening meals was deemed to satisfy the functional requirements. This project therefore looked at the feasibility of combining a parabolic solar cooker with a PCM in the cooking vessel as a low-cost alternative to compete with firewood.

2.1 Design Context

For the proof of concept, where the integration of the PCM was critical, an established collapsible parabolic cooker design was selected from 'Parabolic Solar Cooker Designs' (Solar Cookers International Network, 2015). This design was chosen as it exhibits characteristics that would be favourable in refugee contexts, such as portability, durability and ease of construction. Figure 1 below shows the completed solar cooker in operation, whilst Figure A.1 in the Appendix shows the design instructions for the solar cooker.

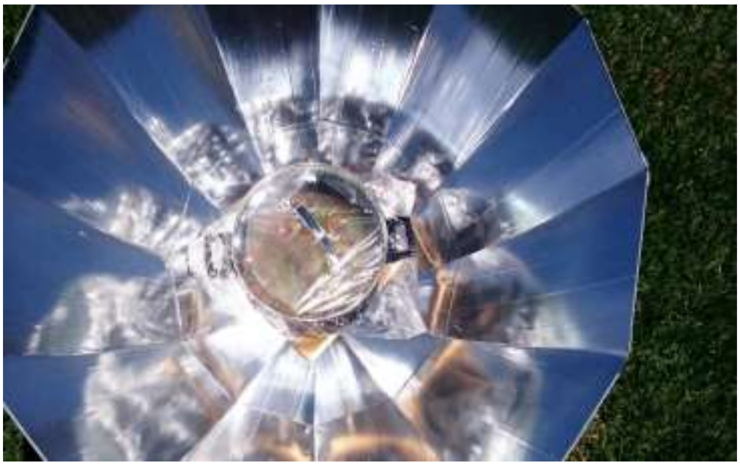


Fig. 1: Parabolic solar cooker in operation

For the proof of concept the reflective panel structure was made from Corflute®, which is a twin-wall Polypropylene sheet that exhibits characteristics such as a high strength-to-weight ratio and water resistance. It is also 100% recyclable, thereby minimising its environmental impact. Ametalin™ insulation tape was also chosen as the reflecting material. This tape is made of bi-axially oriented Polypropylene and exhibits strong adhesion and UV-resistance.

For the PCM incorporated into the cooking vessel, although a high latent heat storage capacity and high melting point are desirable properties when selecting a PCM, the PCM must also be economical and readily available. The chosen PCM also needed to be non-toxic and safe to handle to minimise risk due to direct contact with the PCM. For these reasons, Stearic Acid ($CH_3(CH_2)_{16}COOH$) was chosen as the PCM. This material is commonly used in commercial contexts and is readily available. The acid is also known to be non-toxic, albeit the solid form can cause mild irritation to skin and eyes upon contact. Additionally, the melting point of Stearic Acid is known to be in the range of 55 – 70 ^oC. This is an ideal melting point range since it is solid at room temperature and can easily melt using solar energy. More importantly, Stearic Acid needs to be able to melt during winter when exposed to sunlight, if it is to be considered a practical solution. A *minimum* temperature of 70 ^oC inside the cooking pot is necessary at *all times of the year*, since this is the temperature at which liquids such as milk and water pasteurise. ~~Furthermore, for food safety a minimum temperature of 60 °C is required while cooking (FSANZ, 2018).~~ The Australia New Zealand Food Standards Code has identified that some food are ‘potentially hazardous’ and accordingly need to be kept at certain temperatures to minimise growth of pathogenic microorganisms that may be present in the food or to prevent the formation of toxins in the food (FSANZ, 2014). Potentially hazardous foods include raw and cooked meat, dairy products, seafood, cooked rice and pasta and foods containing eggs, beans, nuts or other protein rich foods (FSANZ, 2019). Thus~~Furthermore~~, for food safety, such foods ~~a minimum temperature of 60 °C is required while cooking~~ must be maintained at a temperature of 5 °C or below or 60 °C or above (FSANZ, 2014~~8~~). Thus, the melting range of Stearic Acid is ideal.

As shown in Figure 2 the PCM was incorporated into the cooking pot by first placing 500 grams of the PCM in a stainless steel cooking pot. Then, a stainless steel bowl of smaller diameter with a wide rim was placed on top of the cooking pot, thus storing the PCM in the gap between the cooking pot and the bowl. Enough space was left for the PCM to expand as heated. The cooking pot and bowl were joined together using silver solder. A valve was attached to the cooking pot to release excess pressure. The outer cooking pot was painted black to maximise heat transfer.

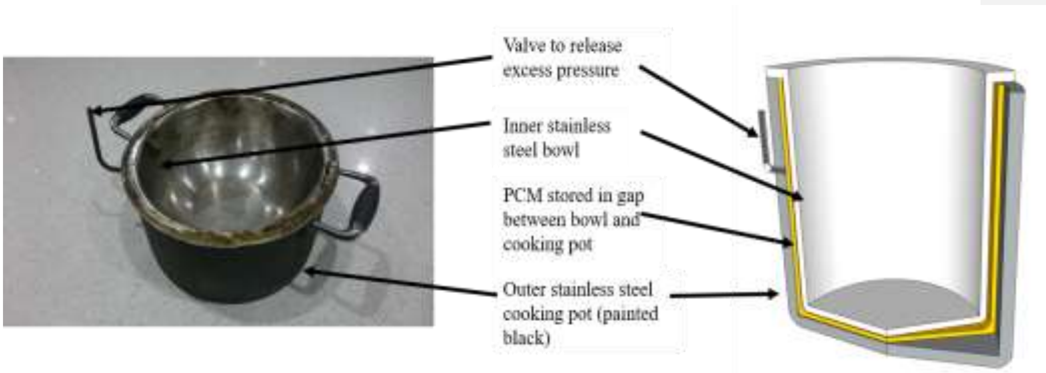


Fig. 2: Components of PCM-integrated cooking pot

To further improve the performance of the solar cooker, the cooking pot was placed inside an oven bag when exposed to the sun. This oven bag is made of clear heat resistant polyester material and can be tied easily so as to retain heat within the bag. When exposed to the sun, Thisit creates a greenhouse effect whereby the oven bag would reduce heat losses due to radiation and convection.

2.2 Testing Procedure

Two sets of experiments were conducted using the parabolic solar cooker, a baseline trial used a regular cooking vessel and a PCM trial used the PCM modified cooking vessel. Three types of grains were used as representative cooking ingredients — rice, lentils and pearled barley. These particular grains were chosen as they are commonly included in refugee diets (UNHCR, 2015). In the first round of tests each grain was cooked on its own, in the second and third trials measured amounts of vegetables and seasoning were included to simulate the food basket prepared by the World Food Programme for refugee and emergency situations (WFP, 2018). Additionally, as the WFP transitions from in-kind to cash aid food programmes, refugees have exhibited an inclination to purchase fresh vegetables, potatoes and rice from the local economy inside and outside refugee camps (Alloush et al., 2017). For the proof of concept it is important to mirror real world conditions.

For each trial, the quantity of each type of grain was enough for four servings to model family-style scenarios in refugee camps (UNHCR, 2015). The amount of water added to the cooking pot was proportional to the serving of grain in accordance with the seller's instructions summarised in Table 2.

Table 2: Food and water quantities used in experiments

Grain	Quantity of grain used (cups)	Quantity of water (cups)
Long Grain Basmati Rice	3	4.5
Whole Green Lentils	3	9
Pearled Barley	3	9

For each type of grain, three tests were undertaken. The cooking times recorded correlated to when the grain was 'cooked'. This, however, is a subjective element. The desired degree of tenderness of the grain will vary with individual preference. As such, the recorded cooking times are only indicative; individual preference of the user will dictate cooking times based on the desired tenderness of the food. Given the slow nature of solar cooking there is little risk of overcooking or burning, with the user able to control the exposure time. Indeed, the overall safety risk associated with solar cooking is low relative to fire cooking. As already mentioned, the lack of smoke produced during solar cooking is a health benefit of this process. Harm to individual users is further reduced by removing the need for a fire. However, care must still be taken when handling the cooking vessel after exposure to sunlight. These cooking vessels tend to become hot when exposed to direct sunlight for hours and, accordingly, it is not recommended that these vessels be touched directly. Instead, hands must be protected when handling cooking vessels by using oven mitts or heat absorbing cloth.

2.2.1 Baseline Trial

For each test, the solar cooker was exposed to sunlight from 1100 hrs onwards as the sun is at an optimal position in the sky during this time. The position of the parabolic cooker was adjusted at regular intervals to capture maximum amount of sunlight.

2.2.2 PCM Trial

The purpose of this trial was to investigate whether it would be possible to keep food that was cooked during day time warm enough to consume in the evening. To achieve this, a PCM was incorporated within the cooking pot to store energy using the endothermic phase change from solid to liquid when exposed to sunlight, whilst simultaneously cooking meals. Once the meal was 'cooked', the PCM-incorporated cooking pot was then stored in a thermally insulated box. Within the insulated box, the energy stored in the PCM would be *gradually* released via an exothermic phase change from liquid to solid, thus keeping the food warm until evening. Using the PCM-incorporated cooking pot, trials for each grain were conducted in the same manner as the baseline stage. At the end of the cooking period, the pot containing the cooked meal was placed in a cardboard box filled with small Styrofoam balls and covered with woollen clothes to keep the meal warm until evening. These materials exhibit low thermal conductivity (*k*), see Table 3, and minimise heat loss within the system.

Table 3: Thermal conductivity of selected materials

Material	Thermal Conductivity ($W.m^{-1}.K^{-1}$)
Cardboard	0.21
Styrofoam	0.033
Wool	~0.03

The method of using a thermally insulated environment is not novel; in communities where energy is not readily available, 'haybox cooking' or 'retained heat cooking' is used whereby a pot of food which has previously been heated to boiling point is placed in a box filled with inexpensive insulating materials such as hay, straw, wool etc. This allows the haybox to retain heat and continue cooking the meal thereby saving energy (Barbieri et al., 2017).

When conducting tests the pot containing the cooked meal was placed within the insulated box until the evening meal, which was set at 1900 hrs. At this time, the temperature of the meal inside the pot was recorded.

3. RESULTS

3.1 Baseline Stage Data

The time taken for each trial is shown in Table 4. Plots of the times taken to cook the various foods are also illustrated below.

Table 4: Baseline stage results

Food Type	Test No.	Total Cook Time (minutes)
Rice Dishes	1	69

	2	70
	3	73
	Average time	71
Lentil Dishes	1	93
	2	96
	3	95
	Average time	95
Barley Dishes	1	92
	2	90
	3	93
	Average time	92

3.2 PCM Stage Data

The dishes for this stage were prepared in the same manner as in the baseline stage. In relation to lentils, multiple trials were undertaken using the PCM-incorporated cooking apparatus. However, even after exposing the solar cooker to sunlight for more than four hours, the lentils did not reach the same level of tenderness as in the baseline stage. As such, the lentils were not deemed to be cooked.

Table 5: PCM stage results

Food Type	Trial No.	Total Time (minutes)	Maximum Recorded Temperature (ºC)
Rice Dishes	1	129	56
	2	132	55
	3	131	59
	Average	131	57
Barley Dishes	1	165	61
	2	167	57
	3	164	58
	Average	166	59

4. DISCUSSION

The results will be explained in the context of heat transfer. The main point of discussion will be the *difference* in performance of the solar cooker system during the baseline stage and the PCM-stage.

4.1 Heat Transfer

Net heat losses in solar cookers due to radiation and conduction can be modelled using the following relationships respectively:

$$Q_{net} \;/\; t = \sigma\varepsilon A(T_{env}^4 - T^4). \quad (1)$$

$$Q_{net} \;/\; t = \; kA(\Delta T \;/\; L). \quad (2)$$

Where Q_{net}/t is the rate of net energy transfer ($J.s^{-1}$); σ is the Stefan-Boltzmann constant ($W.m^{-2}.K^{-4}$); ε is the emissivity of the material; A is the surface area of the object (m^2); T_{env} is the temperature of the environment (K); T is the temperature of the object (K); k is thermal conductivity ($W.m^{-1}.K^{-1}$); ΔT is the temperature difference (K); and L is the thickness of the material (m).

As the cooking pot absorbs sunlight and converts it to heat, it reradiates energy as infrared radiation. This phenomenon is explained by blackbody radiation. The addition of a clear oven plastic bag and glass lid, also called "glazing" (Yettou et al. 2014), helped reduce heat loss by producing a localised greenhouse effect around the cooking pot (Lecuona et al. 2013). However, the glazing system is *opaque* to the infrared radiation reradiated by the cooking pot due to the longer wavelengths of the infrared radiation. Consequently, the infrared radiation trapped within the oven bag aids in increasing the temperature of the cooking pot. As evident from Eq. 1, when the temperature of the cooking pot is raised, the difference between the temperature of the environment and the cooking pot will decrease thus reducing net heat loss. The introduction of the glazing system also helped reduce heat loss due to *convection* by minimising the movement of warm air and containing it inside the oven bag.

4.2 System Performance

If the glazing system helped minimise heat losses due to radiation and convection, then the performance of the system can be explained in terms of heat loss due to *conduction*. As seen from the data, the cooking times recorded during the PCM stage were greater than the cooking times recorded during the baseline stage. The recorded increase in cooking times during the PCM stage can be explained using a *composite* cooking pot as opposed to a regular stainless steel pot in the baseline stage. As shown in Fig. 1, the composite cooking pot was made of an outer stainless steel cooking pot and an inner stainless steel bowl soldered together.

When cooking food using this PCM-incorporated composite pot, instead of being directly transferred to the food as in the baseline stage, the heat would transfer first to the PCM *and* to the inner bowl via conduction. Once the heat was conducted to the inner bowl, only then would the food begin to heat up through heat transfer between the inner bowl and the food. This effectively reduced the overall efficiency of the composite cooking pot when compared to the regular cooking pot used during the baseline stage. The consequence of this was that the net heat being transferred to the food was much less during the PCM stage when compared to the baseline stage, resulting in longer cooking times.

4.3 PCM Performance

Within the PCM-integrated composite cooking pot, a minimum of 100 ^{o}C was achieved while cooking food, as this is the boiling point of water. Then, the heat content of Stearic Acid at

100 °C can be calculated using the following relationship:

$$Q = cm\Delta T + m\Delta H. \quad (3)$$

Where Q is the heat content (J); c is the specific heat capacity of Stearic Acid, which is known to have a value of 1.590 J.g^{-1}.°C^{-1}; m is the mass of the Stearic Acid, which was chosen to be 500 grams; and ΔH is the latent heat of fusion for Stearic Acid, known to have a value of 155 J.g^{-1}. T is the temperature during the process and the ambient temperature is chosen to be 25 °C, the average melting temperature of Stearic Acid is known to be approximately 63 °C, and the final temperature to be achieved is 100 °C.

Using the above values, the heat content of the PCM can be calculated in 3 different parts:

1) The heat required to raise the temperature of Stearic Acid from 25 °C to 63 °C ($mc\Delta T_1$),
2) The heat required for the phase change of Stearic Acid at 63 °C ($m\Delta H$), and
3) The heat required to raise the temperature of Stearic Acid from 63 °C to 100 °C ($mc\Delta T_2$).

Then, the *theoretical* heat content of the PCM at 100 °C will be:

$$Q = m(c\Delta T_1 + c\Delta T_2 + \Delta H). \quad (4)$$

$$Q = 137{,}125\ J = 137.125\ kJ. \quad (5)$$

Therefore, a total of 137.125 kJ would need be supplied to the system for Stearic Acid to achieve a temperature of 100 °C. Note that this value does not take into account the amount of energy required to heat the inner steel bowl and the food contained within the bowl.

The food temperatures recorded when the composite pot was taken out of the thermally insulated box at 1900 hrs can also be used to evaluate PCM performance. Looking at Table 5, the average recorded temperature of the rice dish at 1900 hrs was approximately 57 °C, while the average recorded temperature of the barley dish was approximately 59 °C. This points to the fact that the PCM performed its function in keeping the food reasonably warm until 1900 hrs.

4.4 Grain Structure and Cooking Time

As evident from the data lentils could not be cooked using the PCM-incorporated composite cooking pot. This can be explained in terms of the starch content and structure of lentils. The ratio of amylose to amylopectin, the two constituents of starch, governs the physiochemical properties of legumes, including lentils. This in turn also impacts on their functional properties. Lentil starch is known to consist of approximately 30% amylose (Joshi et al. 2013). Lentils, being a complex carbohydrate, typically require longer cooking times although exposure to heat in excess water for an extended period of time can help reduce cooking times. Another contributing factor was the fact that during the PCM stage the overall efficiency of the composite cooker, and thus the net heat supplied to the lentils, was much lower when compared to the baseline stage.

In relation to cooking time, it is also important to consider cooling and heating times in order to prevent bacterial growth. The FSANZ recommends that food should be cooled as quickly as possible to 5 ^{o}C to minimise bacterial growth (FSANZ, unknown). Conversely, food should also be reheated as quickly as possible to prevent food poisoning causing bacteria. Bacterial growth begins to accelerate when food is reheated to temperatures above 5 oC. Accordingly, the FSANZ recommends, as a general rule, that all food should be reheated rapidly to at least 70 ^{o}C and be held at that temperature for at least two minutes (FSANZ, unknown).

4.5 Cost-benefit Analysis

A simple method for comparing cost-effectiveness is to evaluate the payback period of the proposed solution. Payback period measures the time taken for the cost of investment to be repaid based on the savings or income generated by the investment. Payback periods are important in understanding the economic viability of the design. It is also a measure of the economic risk inherent in a project. Calculating payback periods are particularly useful for potential investors in understanding the length of time required to see savings or a return in investment in a new project.

A simple formula to calculate payback period is:

$$Payback\ period = \ Total\ cost\ /\ savings\ per\ unit\ time. \qquad (6)$$

For this project, the payback period of using the PCM-integrated solution against a traditional non-renewable fuel source will be compared. Firewood will not be used for comparison; rather the comparison will be between fuels that could *replace* firewood. As such, LPG is chosen as the non-renewable fuel source for comparison as it is a portable fuel source and is often used for outdoor cooking and has even been used in the Khazir Refugee Camp in Iraq.

Additionally, the payback period for 3 different combinations of refugee family units will be calculated to identify the most viable option:

1) Family Unit 1 - 4 members
2) Family Unit 2 - 6 members
3) Family Unit 3 - 10 members (family of 4 + family of 6)

Table B.1 in the Appendix lists the materials used to construct the parabolic solar cooker along with the PCM-integrated cooking pot. The cost of using an LPG stove and gas shown in Table B.2 is quoted by Kleenheat Gas for a 45-kg bottle containing an equivalent volume of 88 L of LPG.

4.5.1 Family Unit 1

Before the payback period of using LPG can be calculated, it is first necessary to calculate the volume of LPG refugees would *theoretically* be supplied with. When Kerosene was distributed as a fuel source to Bhutanese refugees in Nepal, the UNHCR supplied up to 1 L of Kerosene to families with 3 members and an extra 0.5 L per additional family member on a weekly basis (UNHCR 2002). For a family unit of 4 members, this would be equal to 1.5 L of Kerosene per week. The specific energy of Kerosene and LPG are 46.3 $MJ.kg^{-1}$ and 49.6 $MJ.kg^{-1}$ respectively. Thus, the weekly ration of Kerosene provided to refugees can be used as an indication to calculate the quantity of LPG that refugees would be provided.

The *energy content* of Kerosene is approximately 37 $MJ.L^{-1}$. Then, if the Bhutanese refugees were supplied with 1.5 L of Kerosene per family of 4 members on a weekly basis:

$$(1.5\ \mathrm{L/week})(37\ \mathrm{MJ/L}) = 55.5\ \mathrm{MJ/week}. \quad (7)$$

Families of four members would receive a Kerosene ration containing an equivalent amount of 55.5 MJ on a weekly basis. Now, the energy content of LPG is known to be approximately 25.7 $MJ.L^{-1}$. If the same amount of energy from LPG is to be provided to refugees on a weekly basis, then:

$$55.5\ \mathrm{MJ/week}\ /\ 25.7\ \mathrm{MJ/L} \approx 2.16\ \mathrm{L/week}. \quad (8)$$

Supplying refugee families of four members with 1.5 L of Kerosene is *theoretically* equivalent to providing them with approximately 2.2 L of LPG on a weekly basis. Now, as noted above, a 45 kg LPG bottle supplied by Kleenheat Gas can store up to an equivalent volume of 88 L of LPG. Then:

$$88\ \mathrm{L}\ /\ 2.2\ \mathrm{L/week} = 40\ \mathrm{weeks}. \quad (9)$$

It would take 40 weeks for a family of four members to fully consume 88 L of LPG. Note that, for simplicity, the weekly ration of LPG is taken as 2.2 L per week rather than 2.16 L per week. The weekly cost of using this stove would be:

$$\$120.99\ /\ 40 \approx \$3.02/\mathrm{week}. \quad (10)$$

Now, if LPG stoves are replaced with parabolic solar cookers with a PCM-integrated cooking pot as proposed by this project, then the weekly saving would be $3.02 per week. Thus, the payback period of the solar cooker would be:

$$Payback\ period = Total\ cost\ /\ savings\ per\ unit\ time = \$159.69\ /\ \$3.02/\mathrm{week} \approx 52\ \mathrm{weeks}. \quad (11)$$

4.5.2 Family Unit 2

Using the same method of analysis as for Family Unit 1, a refugee family of 6 members would be supplied with a Kerosene ration of 2.5 L per week. Then, repeating the same process of calculation as before, a weekly Kerosene ration of 2.5 L is equivalent to 3.6 L of LPG. A family of 6 consuming 3.6 L of LPG per week would take approximately 24 weeks to consume 88 L of LPG, meaning that the cost per week of a single LPG bottle would be $5.04.

Then, if LPG is replaced with the parabolic solar cooker, the payback period of the solar cooker would be:

$$\$159.69\ /\ \$5.04/\mathrm{week} \approx 31\ \mathrm{weeks}. \quad (12)$$

4.5.3 Family Unit 3

For Family Unit 3, consider a composite unit consisting of a family of 4 members and a family of 6 members. Furthermore, assume that family unit 3 would be provided with 2 solar cookers instead of 1. The justification for this is that, for a group of 10 members, using 2 solar cookers would be more practical.

The weekly Kerosene ration for a group of 10 refugees would simply be the sum of the ration for 4 refugees and the ration for 6 refugees. This means that a group of 10 refugees would be supplied with a weekly Kerosene ration of 4 L. Then, repeating the same process of calculation as before, a Kerosene ration of 4 L is equivalent to 5.8 L of LPG. A group of 10 members consuming 5.8 L of LPG per week would take approximately 15 weeks to consume 88 L of LPG, meaning that the cost per week of a single LPG bottle would be \$8.07.

Then, if LPG is replaced with 2 parabolic solar cookers, the payback period of the solar cookers would be:

$$(2 \text{ x } \$159.69) \,/\, \$8.07/\text{week} \approx 39 \text{ weeks.} \qquad (13)$$

Hence, as seen from above calculations, it is more economical to supply solar cookers to larger family units. A graph illustrating payback period against household size is shown below. Nevertheless, the above calculations do not consider several factors. Firstly, the cost of materials used for building the proposed solar cooker represents *unsubsidised* costs. If subsidies or grants are made available to aid agencies seeking to build and distribute this solar cooker system, then the total price of building the system would decrease thereby also shortening the payback period. In this regard, partnership with government agencies or the private sector would be advantageous. Furthermore, the above calculations do not consider the fact that LPG bottles would need to be refilled. This is an ongoing cost associated with the use of liquid fuels. No such refill cost is associated with the use of solar cookers. The only ongoing cost associated with the use of solar cookers would be due to wear and tear.

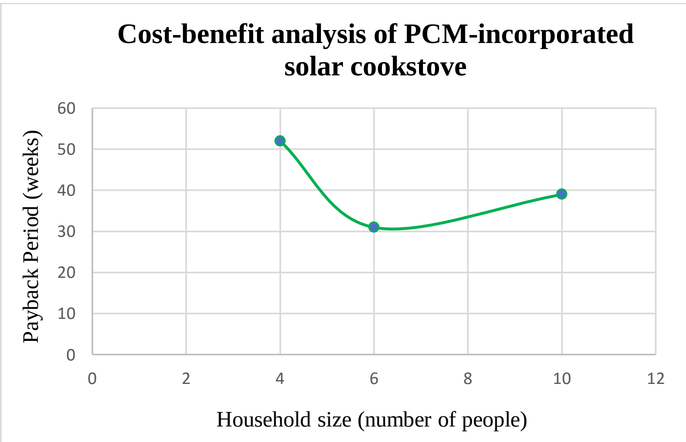


Fig. 3: Cost-benefit graph of solar cookstove based on family unit size

5. CONCLUSIONS

In refugee contexts, the extended use of firewood has negative consequences including, but not limited to, deforestation, land degradation and respiratory illnesses. As such, solar energy should be promoted as a viable alternative to overcome these issues. This paper shows that, by using a parabolic solar cooker in conjunction with a PCM-incorporated cooking pot and thermally insulated box, solar energy can indeed provide a useful alternative to firewood in contexts involving displaced persons. The proposed alternative can provide meals typically found in refugee diets and at reasonable cooking times.

Nevertheless, there remains scope for improvement. For example, reducing the surface area-to-volume ratio of the composite cooking pot should minimise heat loss due to conduction. A more robust thermally-insulated environment consisting of materials with high thermal resistivity is also essential to improving the heat retention capability of the PCM-incorporated system. Furthermore, conducting these investigations during winter will provide a more accurate data set with which to evaluate the overall applicability of the PCM and the system.

It is important to note that any solution must consider the social and cultural context of displaced persons. It is not merely enough to design a solution based on technical criteria; for refugees to accept any alternative to firewood, they must be convinced of its usefulness. This can be achieved by gathering input from them to design a technically and culturally appropriate solution.

6. DECLARATION

This paper was adapted from a research project as part of the Engineering Research Program launched by Engineers Without Borders Australia in partnership with the United Nations High Commissioner for Refugees. We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

7. REFERENCES

Alloush, M., Edward Taylor, J., Gupta, A., Valdes, R.I.R. & Gonzalez-Estrada, E. 2017, 'Economic life in refugee camps', *World Development*, 95, 334-347.

Astbury, G.R. & Hawksworth, S.J. 2007, 'Spontaneous ignition of hydrogen leaks: A review of postulated mechanisms', *International Journal of Hydrogen Energy*, 32, 2178-2185.

Barbieri, J., Riva, F. & Colombo, E. 2017, 'Cooking in refugee camps and informal settlements: A review of available technologies and impacts on the socio-economic and environmental perspective', *Sustainable Energy Technologies and Assessments*, 22, 194-207.

Bauer, A.M. & Brown, A. 2014, 'Quantitative assessment of appropriate technology', *Procedia Engineering*, 78, 345-358.

Bhattacharya, S.C., Bhatia, R., Islam, M.N. & Shah, N. 1985, 'Densified Biomass in Thailand: Potential, Status and Problems', *Biomass*, 8, 4, 255-266.

Bhattacharya, S.C., Shrestha, R.M., Wongvicha, P. & Ngamkajornvivat, S. 1989, 'A Survey of Uncarbonized Briquettes and Biocoal Markets in Thailand', *International Energy Journal*, 11, 14, 17-18.

Bolzonella, D., Pavan, P., Battistoni, P. & Cecchi, F. 2005, 'Mesophilic anaerobic digestion of waste activated sludge: influence of the solid retention time in the wastewater treatment process', *Process Biochemistry*, 40, 1453-1460.

Brugman, G. & Hart, P. 2004, *Solar Cooking: Focus on the Sun*, Technical University of Rijswijk, Rijswijk.

Buddhi, D. & Sahoo, L.K. 1997, 'Solar cooker with latent heat storage: design and experimental testing', *Energy Conversion Management*, 38, 493-498.

Caniato, M., Carliez, D. & Thulstrup, A. 2017, 'Challenges and opportunities of new energy schemes for food security in humanitarian contexts: A selective review', *Sustainable Energy Technologies and Assessments*, 22, 208-219.

Chaudhary, A., Kumar, A. & Yadav, A. 2013, 'Experimental investigation of a solar cooker based on parabolic dish collector with phase change thermal storage unit in Indian climatic conditions', *Journal of Renewable and Sustainable Energy*, vol. 5.

Crawford, A. & Bernstein, J. 2008, *MEAs, Conservation and Conflict: A case study of Virunga National Park, DRC,* International Institute for Sustainable Development, Geneva.

Cuce, E. & Cuce, P.M. 2013, 'A comprehensive review on solar cookers', *Applied Energy*, 102, 1399-1421.

Dahunsi, S.O., Oranusi, S., Owolabi, J.B. & Efeovbokhan, V.E. 2016, 'Mesophilic anaerobic co-digestion of poultry dropping and *Carica papaya* peels: Modelling and process parameter optimization study', *Bioresource Technology*, 216, 587-600.

Dutta, S. 2014, 'A review of production, storage of hydrogen and its utilization as an energy resource', *Journal of Industrial and Engineering Chemistry*, 20, 1148-1156.

El-Sebaii, A.A., Al-Heniti, S., Al-Agel, F., Al-Ghamdi, A.A. & Al-Marzouki, F. 2011, 'One thousand thermal cycles of magnesium chloride hexahydrate as a promising PCM for indoor solar cooking', *Energy Conversion and Management*, 52, 1771-1777.

Food and Agriculture Organisation of the United Nations 1990, *The briquetting of agricultural wastes for fuel*, Food and Agriculture Organisation of the United Nations, Rome.

Food and Agriculture Organisation of the United Nations 1988, *Nature and Management of Tropical Peat Soils*, Food and Agriculture Organisation of the United Nations, Rome.

Food Standards Australia and New Zealand Food Standards Code 2014, *Standard 3.2.2: Food Safety Practices and General Requirements*.

Food Standards Australia and New Zealand unknown, *Essential food safety practices*, viewed 15 February 2019, <https://www.foodstandards.gov.au/consumer/safety/faqsafety/documents/cool%20_and_reheat_food.pdf>.

Food Standards Australia and New Zealand 2019~~8~~, *Temperature control*, viewed 11~~20~~ February 2019~~8~~, <http://www.foodstandards.gov.au/consumer/safety/faqsafety/pages/foodsafetyfactsheets/foodsafetystandardst857.aspx~~http://www.foodstandards.gov.au/consumer/safety/faqsafety/pages/foodsafetyfactsheets/charitiesandcommunityorganisationsfactsheets/temperaturecontrolma1477.aspx~~>.

Grandell, L., Lehtilä, A., Kivinen, M., Koljonen, T. & Kihlman, S. 2016, 'Role of critical metals in the future markets of clean energy technologies', *Renewable Energy*, 95, 53-62.

International Energy Agency 2006, *Hydrogen Production and Storage: R&D Priorities and Gaps*, International Energy Agency, Paris.

Joshi, M., Aldred, P., McKnight, S., Panozzo, J.F., Kasapis, S., Adhikari, R. & Adhikari, B. 2013, 'Physiochemical and functional characteristics of lentil starch', *Carbohydrate Polymers*, 92, 1484-1496.

Kanimozhi, B. & Bapu, B.R.R. 2012, 'Experimental study of thermal energy storage in solar system using PCM', *Transaction of Control and Mechanical Systems*, 1, 87-92.

Lecuona, A., Nogueira, J.I., Ventas, R., Rodriguez-Hidalgo, M.D.C. & Legrand, M. 2013, 'Solar cooker of the portable parabolic type incorporating heat storage based on PCM', *Applied Energy*, 111, 1136-1146.

Lehne, J., Blyth, W., Lahn, G., Bazilian, M. & Grafham, O. 2016, 'Energy services for refugees and displaced people', *Energy Strategy Reviews*, 13-14, 134-146.

Loskota, B. 2007, *Solar Cooker Project Evaluation: Iridimi Refugee Camp*, Center for Religion and Civil Culture at the University of Southern California, California.

Makhanu, S. & Waswa, G.W. 2010, 'BIOSAN Latrines for refugee camps', *Centre for Disaster Management and Humanitarian Assistance*, Western University College of Science Technology, Kakamega, Kenya.

Ramadan, M.R.I., Aboul-Enein S. & El-Sebaii, A.A. 1988, 'A model of an improved low cost indoor solar cooker in Tanta', *Solar and Wind Technology*, 5, 387-393.

Ruiz, H. & Emery, M. 2001, *Afghanistan's Refugee Crisis*, Middle East Research and Information Project.

Saxena, A., Lath S. & Tirth, V. 2013, 'Solar Cooking by Using PCM as a Thermal Heat Storage', *MIT International Journal of Mechanical Engineering*, 3, 2, 91-95.

Sharma, S.D. & Sagara, K. 2005, 'Latent heat storage materials and systems: a review', *International Journal of Green Energy*, 2, 1-56.

Solar Cookers International 2010, *Solar Cookers for Darfur Refugees: Iridimi Camp in Eastern Chad*, Solar Cookers International, California.

Solar Cookers International Network n.d., *Collapsible Parabolic Cooker*, viewed 15 October 2015, <http://solarcooking.wikia.com/wiki/Category:Parabolic_solar_cooker_designs#All_parabolic_solar_cooker_designs.>.

Spangaro, J., Adogu, C., Ranmuthugala, G., Davies, G.P., Steinacker, L. & Zwi, A. 2013, 'What Evidence Exists for Initiatives to Reduce Risk and Incidence of Sexual Violence in Armed Conflict and Other Humanitarian Crises? A Systematic Review', *PLOS ONE*, 8, 5.

Swami, V.M., Autee, A.T. & T R, A. 2018, 'Experimental analysis of solar fish dryer using phase change material', *Journal of Energy Storage*, 20, 310-315.

Tesfay, A.H., Kahsay, M.B. & Nydal, O.J. 2014, 'Solar powered heat storage for Injera baking in Ethiopia', *Energy Procedia*, 57, 1603-1612.

Tian, Y. & Zhao, C.Y. 2013, 'A review of solar collectors and thermal energy storage in solar thermal applications', *Applied Energy*, 104, 538-553.

United Nations 2015, 'Transforming our world: the 2030 Agenda for Sustainable Development', A/RES/70/1, p. 14.

United Nations High Commissioner for Refugees 2000, 'Integrating environmental concerns in UNHCR', *Engineering & Environmental Services Section*, December, p. 6.

United Nations High Commissioner for Refugees 2002, *Cooking Options in Refugee Situations: A Handbook of Experiences in Energy Conservation and Alternative Fuels*, United Nations High Commissioner for Refugees, Geneva.

United Nations High Commissioner for Refugee 2014, *Global Strategy for Safe Access to Fuel and Energy (SAFE): A UNHCR Strategy 2014-2018*, United Nations High Commissioner for Refugees, Geneva.

United Nations High Commissioner for Refugees 2015, *Handbook for Emergencies*, 4th edn, United Nations High Commissioner for Refugees, Geneva.

United Nations High Commissioner for Refugee 2017, *Forced displacement worldwide at its highest in decades*, viewed 7 April 2018, <http://www.unhcr.org/afr/news/stories/2017/6/5941561f4/forced-displacement-worldwide-its-highest-decades.html>.

White, M.A. 2014, 'Heat storage systems', Dalhousie University, Halifax, Canada.

Women's Commission for Refugee Women and Children 2006, *Beyond Firewood: Fuel Alternatives and Protection Strategies for Displaced Women and Girls*, Women's Commission for Refugee Women and Children, New York.

Women's Refugee Commission and International Rescue Committee 2013, *Baseline Survey on Safe Access to and Use of Cooking Energy in Nzulo Camp and the Surrounding Villages in North Kivu, Democratic Republic of the Congo*, Women's Refugee Commission, New York.

World Bank Group 2014, *Clean and Improved Cooking in Sub-Saharan Africa: A Landscape Report*, The World Bank Group, Washington.

World Bank Group 2015, *Technical Report 007/15: The State of the Global Clean and Improved Cooking Sector*, The World Bank Group, Washington.

World Food Programme 2018, *The WFP Food Basket*, viewed 19 February 2018, <http://www.wfp.org/food-assistance/kind-food-assistance/wfp-food-basket>.

Yettou, F., Azouli, B., Malek, A., Gama, A. & Panwar, N.L. 2014, 'Solar cooker realizations in actual use: An overview', *Renewable and Sustainable Energy Reviews*, 37, 288-306.

8. APPENDIX

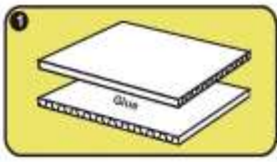
APPENDIX A

FOLD-UP PARABOLIC SOLAR COOKER

These instructions will show you how to make a low-cost parabolic solar cooker using corrugated cardboard, aluminium foil, glue, string, screws and cloth.

The cooker works when the sun's rays hit an aluminium surface and are reflected to a focal point in the parable where a black pan is placed, thus heating up the contents of the pan. This cooker can be used to prepare vegetables, grains, meat, pasta, cakes, etc. It can also be used to sterilize water, make jam…there is no limit to both its use and its construction.

1



Main material used: Corrugated cardboard

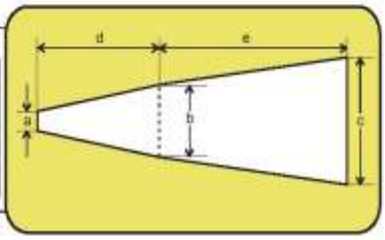
Flattened cardboard boxes or sheets of cardboard can be used.

To make the cooker more resistant, glue two pieces of cardboard together using wood glue, with the undulations perpendicular to each other. Using a paintbrush, apply some watered down glue and leave to dry with a heavy weight on top so that it doesn't lose its shape.

2 The parable is composed of 12 segments.
By increasing the surface area, greater temperatures can be reached: to make other sizes, simply change the measurement proportionally.

Segment size

(in cm)	Small	Large
a	3.5	4.0
b	13	15.0
c	23	26.5
d	24	27.6
e	37	42.6
Surfac.(m²)	**0.6**	**0.8**



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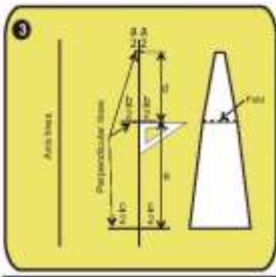


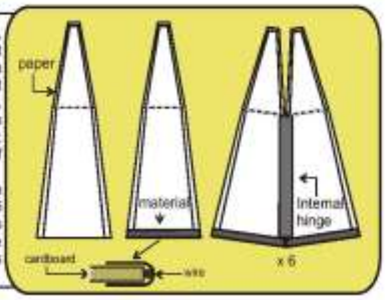
Model of one segment

The easiest way is to draw one full-sized segment on a piece of card, cut it out and then use it as a template for drawing the other 11 segments.

First draw an axis line and then a 90° perpendicular line using a set square. Then make a mark on the perpendicular line, each side of the axis, at a distance equal to half of "a". Next, measure "e" on the axis and mark the next perpendicular line, corresponding to "b" and repeat the first step. When the perpendicular lines have been completed, join the end points to make the final shape. To cut, use a scalpel and a metal ruler or pipe. As each module is completed, fold along the dotted line, pressing with a ruler or other hard object to mark the line.

4 In order to protect the cooker and make it last longer, reinforcements can be made along the borders. This is not vital but it is recommended. Apply wood glue with a paintbrush onto a strip of paper 5cm wide and then stick it onto the lateral sides and the narrow end. After this has dried, use a spatula to apply strong glue to pieces of denim 5cm wide, which should then be stuck to the free end. Suggestion: Between the cardboard and the denim, glue on a piece of thick wire, since this part is most exposed to damage.

Suggestion: internal hinge: Using strong glue, stick on a piece of material 5cm wide as shown in the picture. The 6 pairs of segments should be prepared in this way. At this stage you could paint the side without hinges and all the borders with fibre paint (for roofs) or beeswax so that it is more resistant to damp.



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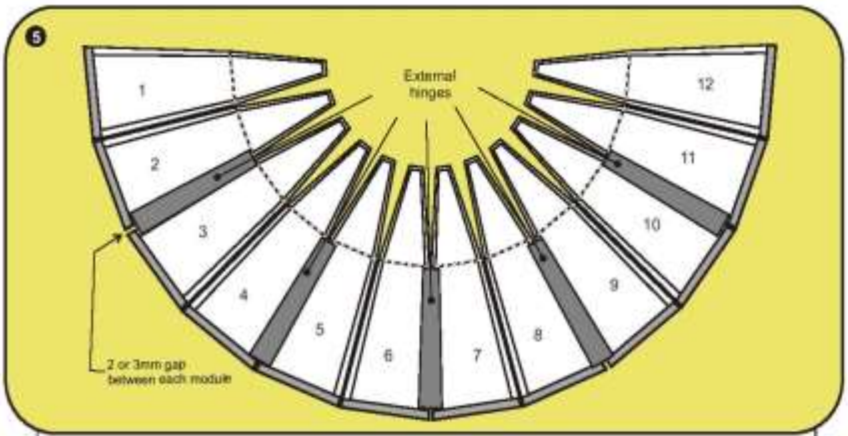
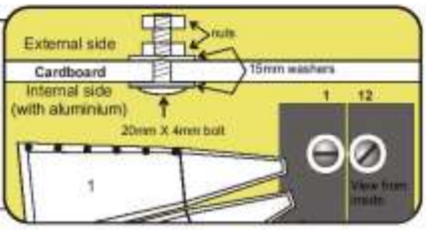


External hinges: Glue on 5 strips of cloth, each 5cm wide, thus joining the 6 modules. Between each module leave a small gap of around 2 or 3cm so that they can fold inwards when the parable is set up.
To add aluminium to the internal surface: Using a spatula, apply a layer of strong glue onto the side where the 6 hinges are located and stick on a sheet of kitchen foil so that the shiny side is uppermost. Repeat to cover the 12

6 To close the parable: Punch 6 holes along the open edges 1 and 12, as shown in the illustration, so that when the parable is closed the holes meet. Join the two sides with nuts, bolts and washers. Thread some string between the nuts on the outside, to close the ring.
The nut which is in contact with the washer can be fixed in place by putting a little glue on the thread. The other can be left free to hold the string in place when the cooker is set up or to fold for storage.



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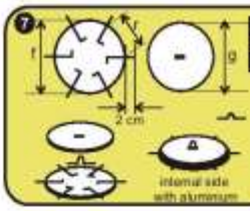
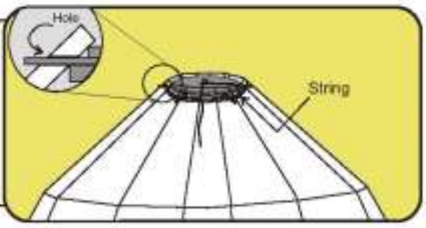
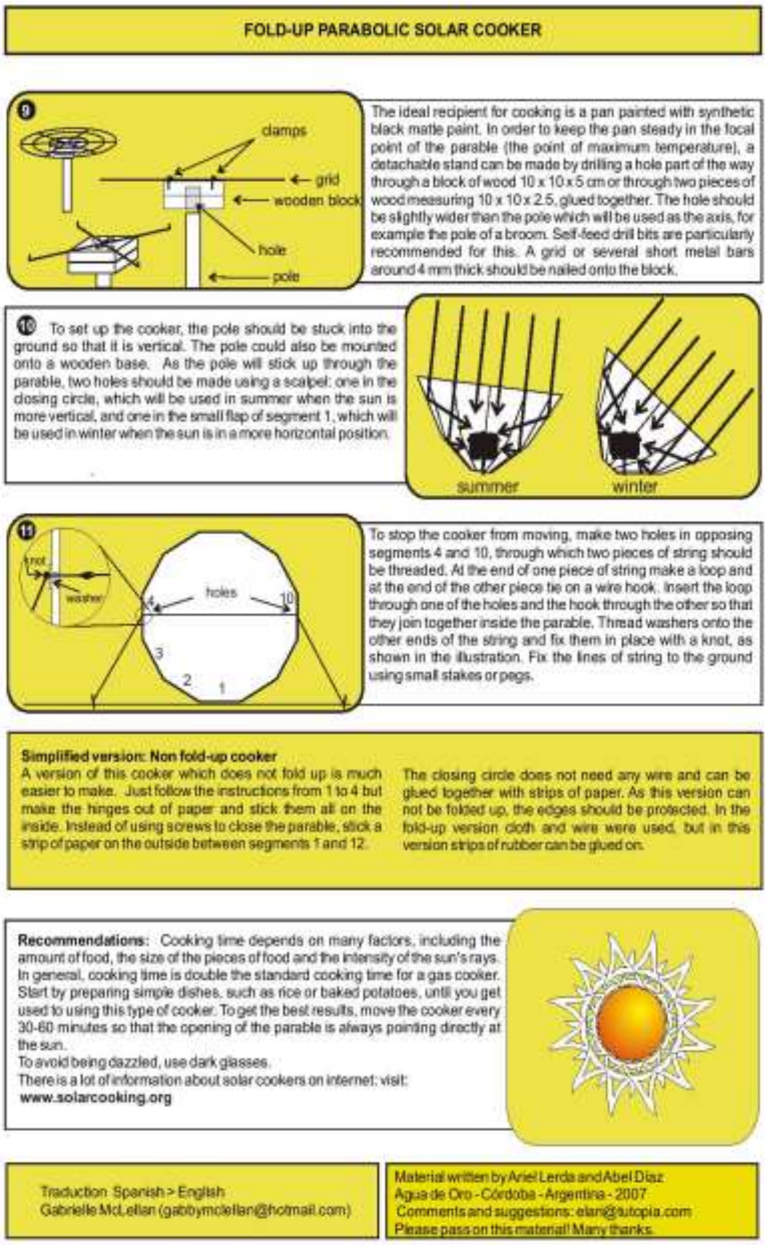


(in cm)	Small	Large
f	15	17.5
g	14	16

The closing circle: Cut out two circles of reinforced cardboard following the measurements indicated in the table. Set up the parable with string. Close the small segments provisionally with tape and mark internally where the diameter f coincides with the inside of the parable. This is the point where holes will be made for threading wire through the closing circle.
Glue the two circles together with the wire in between. The distance between the pieces of wire is equal to the radius (r) of the circle. Then glue on strips of paper to seal it.

8 Make holes in 6 alternate segments, in the middle of each. To set up the parable, tie string around the bolts and then insert the pieces of wire from the circle into the holes on the small flaps. Tie more string onto the ends of the pieces of wire which are sticking out, wrap it 3 times around the wire and then thread the end through the piece of wire in the centre.





FOLD-UP PARABOLIC SOLAR COOKER

9 The ideal recipient for cooking is a pan painted with synthetic black matte paint. In order to keep the pan steady in the focal point of the parable (the point of maximum temperature), a detachable stand can be made by drilling a hole part of the way through a block of wood 10 x 10 x 5 cm or through two pieces of wood measuring 10 x 10 x 2.5, glued together. The hole should be slightly wider than the pole which will be used as the axis, for example the pole of a broom. Self-feed drill bits are particularly recommended for this. A grid or several short metal bars around 4 mm thick should be nailed onto the block.

10 To set up the cooker, the pole should be stuck into the ground so that it is vertical. The pole could also be mounted onto a wooden base. As the pole will stick up through the parable, two holes should be made using a scalpel: one in the closing circle, which will be used in summer when the sun is more vertical, and one in the small flap of segment 1, which will be used in winter when the sun is in a more horizontal position.

11 To stop the cooker from moving, make two holes in opposing segments 4 and 10, through which two pieces of string should be threaded. At the end of one piece of string make a loop and at the end of the other piece tie on a wire hook. Insert the loop through one of the holes and the hook through the other so that they join together inside the parable. Thread washers onto the other ends of the string and fix them in place with a knot, as shown in the illustration. Fix the lines of string to the ground using small stakes or pegs.

Simplified version: Non fold-up cooker
A version of this cooker which does not fold up is much easier to make. Just follow the instructions from 1 to 4 but make the hinges out of paper and stick them all on the inside. Instead of using screws to close the parable, stick a strip of paper on the outside between segments 1 and 12. The closing circle does not need any wire and can be glued together with strips of paper. As this version can not be folded up, the edges should be protected. In the fold-up version cloth and wire were used, but in this version strips of rubber can be glued on.

Recommendations: Cooking time depends on many factors, including the amount of food, the size of the pieces of food and the intensity of the sun's rays. In general, cooking time is double the standard cooking time for a gas cooker. Start by preparing simple dishes, such as rice or baked potatoes, until you get used to using this type of cooker. To get the best results, move the cooker every 30-60 minutes so that the opening of the parable is always pointing directly at the sun.
To avoid being dazzled, use dark glasses.
There is a lot of information about solar cookers on internet: visit:
www.solarcooking.org

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Please pass on this material! Many thanks.

Figure A.1: Design instructions for Collapsible Parabolic Solar Cooker

APPENDIX B

Material	Cost
Corflute® sheets	3 x $8.85 = $26.55
Ametalin™ tape	2 x $18 = $36
Screws, nuts and washers	$22.49
Cooking pots	$10
Oven bag	$0.40
High temperature black spray paint	$20.90
Stearic acid (500 grams)	$43.35
Total	**$159.69**

Table B.1: Cost of materials to build parabolic cooker and PCM-integrated pot

Material	Cost
Single burner stove (Gasmate® camping stove)	$24.99
LPG gas (45 kg bottle)	$96
Total	**$120.99**

Table B.2: Cost of using LPG stove