# FABRICATION AND TESTING OF A BOX TYPE SOLAR COOKER

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## ABSTRACT

*A model box solar cooker (BSC) was fabricated using locally available low cost materials. The BSC was compared with a renowned reflector solar cooker (CooKit) for thermal performance in heating water. The BSC and the CooKit constituted the experimental treatments in this study and each solar cooker type was replicated three times in a completely randomized design (CRD). The cookers were placed in a sunny spot away from buildings and trees to avoid shading. Six black plastic water bottles (800 ml) were filled with 700 ml of distilled water and placed in the centre of each cooker for energy generation monitoring. Each bottle had a hole drilled in the lid to accommodate an ordinary thermometer. The experiment was conducted on three selected days in January, February and March, 2014. Each trial run started at 10:00 hours and ended at 17:00 hours, with water temperature recorded every 10 minutes. The BSC recorded significantly ($P < 0.05$) higher peak water temperatures of 87°C in January and 85.67°C in February and these corresponded to mean energy gains of 0.17 MJ and 0.12 MJ, respectively, compared to 79.3°C and 53.87°C peak water temperatures (corresponding to 0.12 and 0.11MJ) recorded in the CooKit in the same months.. However, the mean cumulative energy generated by the CooKit (0.16 MJ) in March was significantly ($P < 0.05$) higher than 0.11 MJ gained in the BSC. These preliminary results have shown that the locally fabricated BSC has potential to provide adequate energy for pasteurising and possibly cooking various food products. Being a design based on local materials, it offers advantages of empowering local artisans and creating employment. It is recommended that further tests be conducted under varying weather conditions in order to identify points of possible design improvements before wide spread promotion.*

**Key words:** box solar cooker, climate smart, food drying, pasteurization reflector solar cooker

## INTRODUCTION

Firewood is the major source of energy for cooking in a majority of households in Swaziland as 80% of households use it (Manyatsi and Hlope, 2010). Besides cooking, the energy generated in wood hearths is also utilised for other domestic purposes such as drying food like fruits, vegetables, root/tuber crops and space heating. Although energy from firewood has been part of human life from time immemorial, the continued cutting down of trees is one avenue for terrestrial carbon loss to the atmosphere a mechanism known for leading to global warming and climate change. This scenario calls for adoption of climate-smart energy sources which enhance ecosystems resilience to climate change (Funk, 199). Utilisation of solar energy is renowned as a credible alternative to firewood and other polluting energy sources such as fossil fuels. Solar energy is renewable and gives out no emissions to the environment. Technologies that harness energy from the sun for generation of electricity, domestic water heating and cooking have been developed, tested and improved for application in a wide range of environments (Kimambo, 2007; Ogunwa, 2006; Radabaugh, 2004). In rural southern Africa, the target is to meet household energy needs for preparing meals. To that effect, solar cookers, which are also referred to as solar stoves, are widely targeted for use in developing countries to generate energy for cooking whereas in the developed countries they are mainly used by scientists, hobbyists and environmental protection advocates. The use of solar cookers dates back to the 18$^{th}$ century (Abu-Khader *et al.*, 2011). Basic designs that are relatively less expensive include the box type and reflective panel solar cookers (Mullic *et al*., 2004; Yousif *et al*., 2012; Yahya, 2013). Besides being viewed as low technology, these solar cookers can generate enough power for cooking a wide variety of foods and pasteurizing milk and water (Smith, 2008; Uhuegbu, 2010; Yettou *et al*., 2012). Box type and reflective panel solar cookers can be fabricated in a basic carpentry shop using materials available in most countries. A preliminary trial to inactivate bacteria in drinking water using a reflective solar cooker showed that there was potential to use solar cookers to pasteurize drinking water in Swaziland (Mhazo *et al*., 2010). Adoption of solar cooking technology in Swaziland may relieve women and children in the rural areas from the tedious task of walking long distances in search of firewood (Rikoto and Garba, 2013). Unfortunately, there is not yet much interest by the local industry to fabricate solar cookers thus limiting widespread adoption of the technology. The objective of this study was to fabricate and test a box type solar cooker based on locally available materials and skills.

## MATERIALS AND METHODS

### Site description

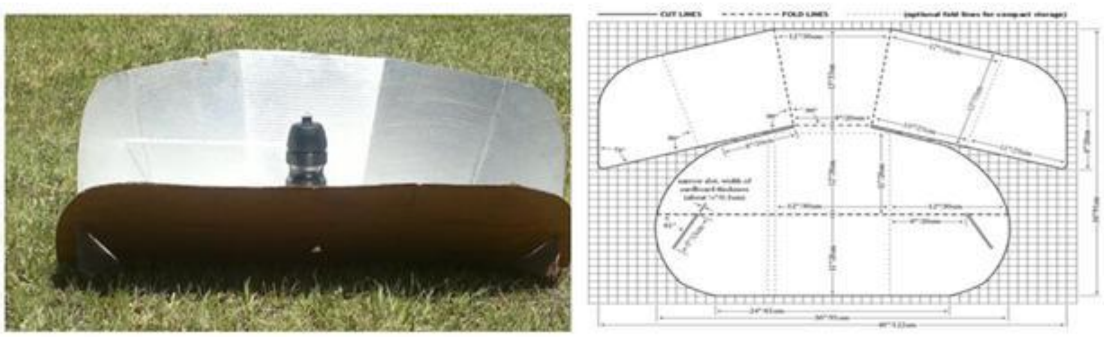
The study was conducted on selected days from January to March, 2014 at the Faculty of Agriculture, University of Swaziland. The site is located at 26$^{o}$. 34’S and 31$^{o}$ 10’ lies at an altitude of 735 m above sea level with a mean annual precipitation ranging from 850 mm to 1000 mm received, mainly between October and March. The long-term average rainfall for January, February, March and April is 80 mm, 130 mm, 75 mm and 60 mm, respectively. The annual mean temperature is 18°C, with a maximum and minimum temperature at 23°C and 11°C, respectively. The sunshine hours in summer are about 12 hours, with peak sunlight intensity received between 10:00 hours and 14:00 hours. The global radiation that reaches the ground in the area is between 800-1000 Wm$^{-2}$ per day (Murdoch, 1970).

## Design of experiment.

Two solar cooker designs; the box type and the reflective panel solar cooker constituted the treatments with the reflective panel solar cooker as a control.

*Reflective solar cookers (CooKit)*

A reflective panel solar cooker (CooKit) shown in Figure 1(a) is made of cardboard material with aluminium foil pasted on one side and is foldable into multiple reflecting surfaces to concentrate solar radiation onto a central space where the cooking vessel is kept. Heating efficiency is improved by positioning the reflective surfaces to directly face the sun. A small triangular slot at the centre of the panel is used for new position siting every time the cooker is repositioned to face the sun. Two slits on the sides of the cooker are used to join the base with the other material of the cooker and sometimes cloth pegs are used to hold the material together. The mass of each reflective solar cooker is approximately 500 g. The details of the dimensions of the reflective panel solar cookers are as shown in Figure 1(b). Although the aperture area the CooKit for solar collection was 0.56 $m^2$, the collector area responsible for reflecting the heat to the water bottles was 0.14 m2. The Cookit is considered the simplest and least expensive design among panel solar cookers, however, it can heat material up to 125ºC when the ambient temperature is over 20ºC (TFL, 1997).

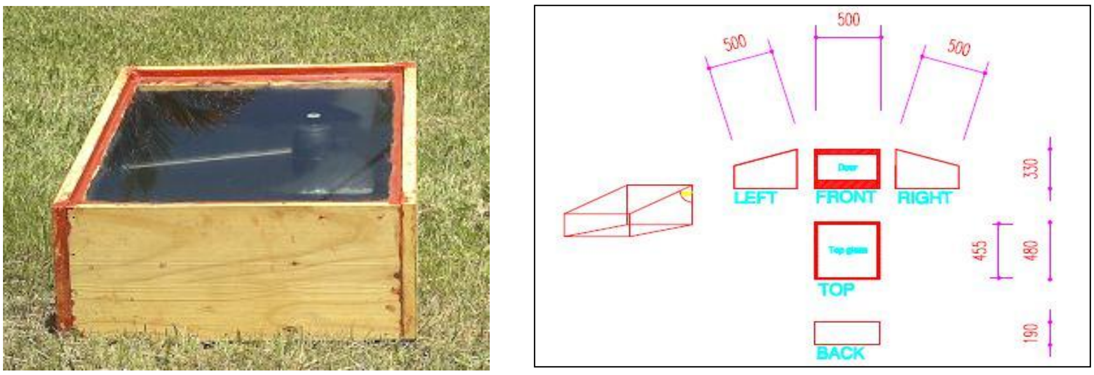


(a) (b)

Figure 1. The reflective panel solar cooker (CooKit)

*The box type solar cooker*

The box type solar cooker [Figure 2 (a)] was fabricated with assistance from the University of Swaziland, Luyengo Campus Farm Worksop technicians. The main body was 20 mm plywood pieces joined together using 2 mm steel nails. The exterior dimensions were 480 mm × 500 mm × 330 mm deep with a cooker face slope of 190 mm deep at the front [Figure 2 (b)]. The interior dimensions of the cooker were 460 mm **×** 480 mm × 310 mm deep, the interior cooker face slope was 170 mm deep at the front. Therefore, an aperture area of 0.21$m^2$ was open for the collection of solar radiation. The interior of the boxes was painted with heat resistant and non-toxic black paint to enhance heat absorption and emission. A 455 x 455 x 3mm thick glass pane was glued to the wooden sides using heat resistant silicon. A tight fitting wooden door was installed on the side of the cooker. The door was joined to the entire box using metallic flap hinges and was secured in position using wooden latches. A plastic handle was mounted on the door for easy opening.




(a) (b)

Figure 2. The box solar cooker (BSC) type.

The cookers were arranged in a completely randomized design (CRD) with each cooker design replicated three times.

*Monitoring Energy generated in the cookers*

Energy generated in the cookers was monitored on three selected days in January, February and March 2014. Weather data recorded on each experiment day are presented in Table 1

Table 1.Weather data of the three days of monitoring energy generated in the cookers.

| Date | Relative humidity (%) | Minimum Temperature (◦C) | Maximum temperature (◦C) | Cloud cover (%) | Average Wind Speed (km/h) | Bright sunshine (hours) | Rainfall (mm) |
|---|---|---|---|---|---|---|---|
| **17/01/ 2014** | 79% | 23 | 28 | 45 | 3.2 | 9.0 | 0.00 |
| **18/02/2014** | 46% | 21 | 31 | 25 | 3.2 | 12 | 0.00 |
| **15/03/2014** | 48% | 21 | 28 | 26 | 3.2 | 11 | 0.00 |

The solar cookers were placed in an open sunny space away from buildings and trees to avoid shading and maximise reception of solar radiation. The vertical reflective sections of the CooKit were secured in purpose designed slits on each side of the front piece and were held in position by laundry pegs. The CooKits were placed such that the vertical reflective section faced the direction of the sun to maximize incident radiation. This was ensured by aligning the triangular slot in the centre of the cooker with the operator's shadow when standing right in front of the device. The BSCs were placed such that the slopping glass side faced the direction of the sun. Proper alignment was ensured by standing in front (sloping side) of the BSC and shifting the cooker until one's shadow was directly cast at the centre of the box. Six black water bottles (800 ml) were filled with 700 ml (700 g) of distilled water and were placed in the centre of each solar cooker. Each bottle had a hole drilled in the lid to accommodate an ordinary thermometer. The temperature measurements were run from 10:00 hours to 17:00 hours with water temperature recorded every 10 minutes. The energy generated (J) by each solar cooker was calculated as the product of mass of water in the bottle, specific heat capacity of water and the change in water temperature in the 10 minutes interval as shown in equation 1.

$$E = (M_w C_w)(T_{wa} - T_{wb}) \quad (1)$$

Where: E = Energy generated in Joules
$M_w$ = mass of water in kg,
$C_w$ = specific heat capacity of water in J/kg ˚C,
$T_{wb}$ = water temperature at the start of each interval in ˚C,
$T_{wa}$ = water temperature at the end of each interval in ˚C

*Data analysis*
The data were analysed using the analysis of variance technique using StatSoft (Hill and Lewicki, 2007) statistical package. Means were separated by the Fisher LSD (Fisher least significance differences) at 95% confidence level.

## RESULTS AND DISCUSSION

### Water temperature attained in the solar cookers result

The mean water temperatures attained by the box type solar cooker (BSC) and reflective panel solar cooker (CooKit) in January are shown in Figure 3.The results reflected steady increase in water temperature from the time the experiment started at 10:00 hours, for the month, reaching peak temperatures between 14:00 hours and 15:00 hours and then declined thereafter until 17:00 hours when the sun was setting.

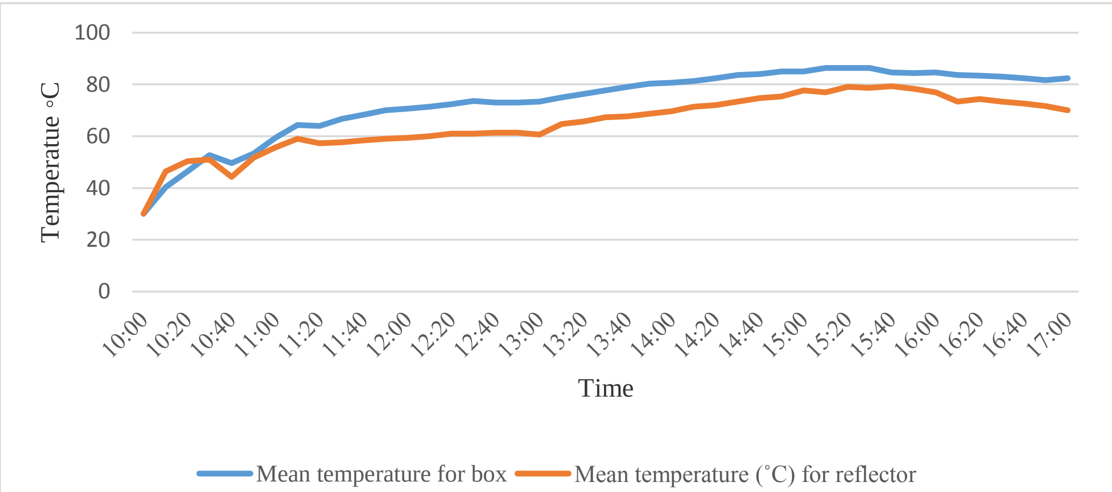



Figure 3. Mean water temperature reached in January 2014.

The experiment started at 10:00 hours with a water temperature of 30$^{o}$C. The mean water temperatures in both the BSC and the CooKit progressively increased at an average of 4.5°C in every 10 minutes and remained comparable until about 11:30 hours. Thereafter, the BSC generated significantly ($P < 0.05$) higher mean water temperatures than the CooKit until 15:00 hours. The BSC reached a peak temperature of 87°C at 15:10 hours and plateaued for about 20 minutes before dropping until the end of the experiment. The CooKit reached a peak temperature of 79.3°C at 15:40; about half an hour after the BSC before plateauing and then started dropping. The mean water temperature gap between the BSC and the CooKit was fluctuating from 15:00 hours, though the BSC remained superior until the end of the experiment at 1700 hours. Better performance of the BSC compared to the CooKit can be attributed to the capability of box type solar cookers to use both direct and diffuse solar radiation, heat insulation properties of wood and airtightness (Smith, 2008; Uhuegbu, 2010; Yettou *et al*., 2012).

The CooKit design uses direct solar radiation only and rapidly loses heat when there is interruption in the solar irradiance. The difference in heat retention capacity was revealed towards the end of the experiment where the BSC maintained higher water temperatures with an average of 0.75°C every 10 minutes higher than the CooKit despite the reduction in radiation towards sunset (from 1550 to 1700 hours). Incidences of sudden water temperature drops (e.g. at around 10:30 -10:40 hours) were observed every time there was a passing cloud and these events tended to affect the performance of the CooKit more than the BSC. The results proved that solar cookers have potential of pasteurizing food products like water and milk since the water temperatures reached were more than 63 °C (Lu *et al.*, 2013) which is the minimum required for food pasteurization.

The mean water temperatures attained by the box solar cooker type (BSC) and reflective solar cooker (CooKit) in February are shown in Figure 4. In this month, the experiment started at 10:00 hours with a water temperature of 29.1$^{o}$C. The mean water temperatures in both the BSC and the CooKit gradually increased but were analogous until about 10:50 hours then there were significantly ($P<0.05$) higher water temperatures in the box type solar cooker until 1410 hours. The BSC and CooKit reached a peak of 85.67 °C at 1440 hours and of 53.87 °C at 1450 hours, respectively, then fluctuated while dropping until the end of the experiment (1700 hours).The CooKit reached the peak temperature 10 minutes after the BSC. Although the mean temperature gap fluctuated until the end of the experiment, the BSC reached higher temperatures compared to the CooKit. The better performance of the BSC compared to the CooKit was due to its characteristics as mentioned above. The mean temperatures reached by water in BSC showed that the cooker type had potential to pasteurize food products like milk. However, the CooKit showed that this design could not pasteurize food products like milk in the selected day in February because the mean temperature reached was less than 63°C.

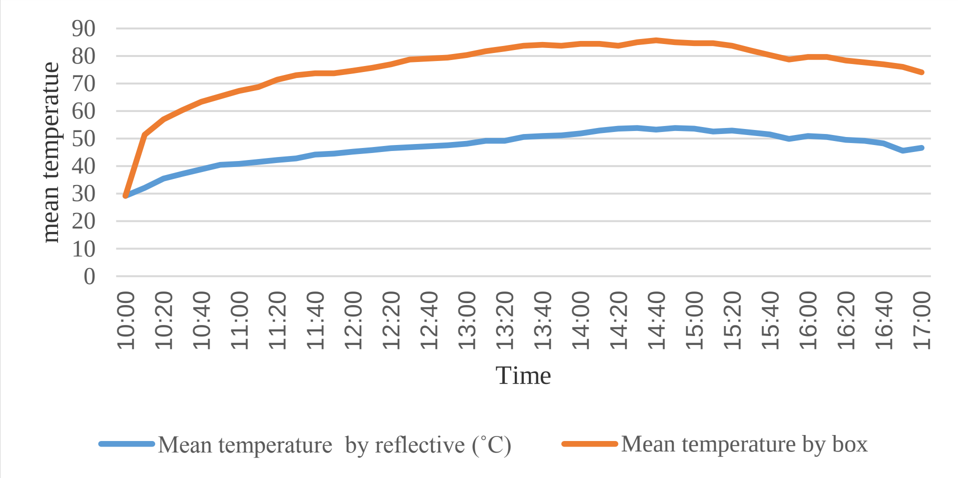



Figure 4. Mean water temperature reached in February 2014.

The mean water temperatures attained by the box solar cooker type (BSC) and reflective solar cooker (CooKit) in March are shown in Figure 5. The experiment started at 10:00 hours with a water temperature of 42.3°C. The mean water temperatures in both the solar cookers gradually increased but were corresponding until about 15:30 hours. Moreover, a significantly ($P<0.05$) higher water temperature was observed in the box type solar cooker from 15:40 hours until the end of the experiment. The BSC and CooKit reached a peak of 81°C and 82.6°C, respectively, at 14:30 hours. The water temperatures plateaued until 14:40 hours and then dropped until the end of the experiment (1700 hours).The BSC had a better performance compared to the CooKit towards the end of the experiment. The CooKit performed poorly because the design allows faster heat escape than the BSC as the radiation from the sun decreased. In this month both solar cookers proved that they had potential to pasteurize food products as they both reached mean temperatures higher than 63°C.

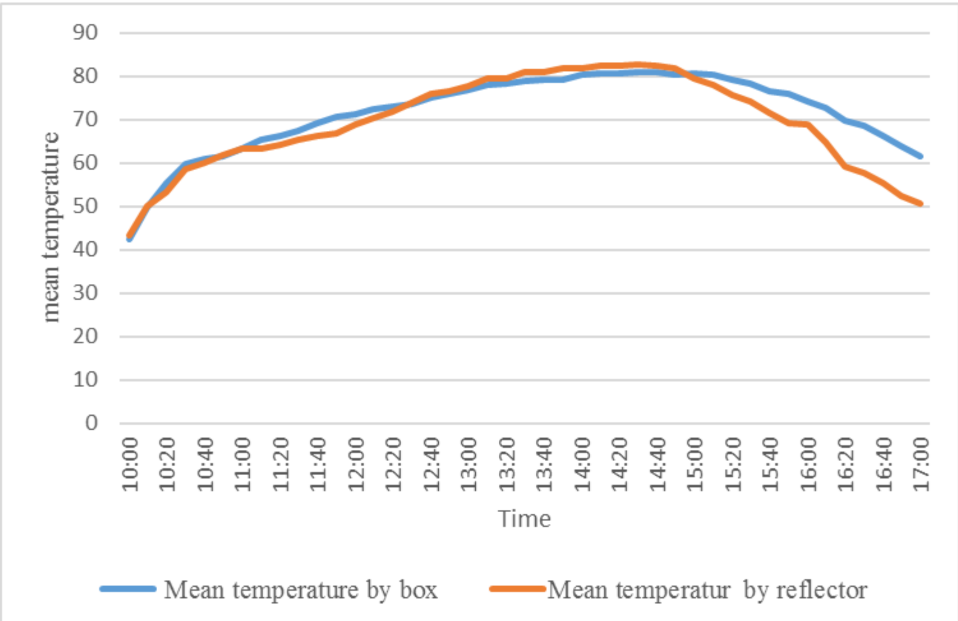



Figure 5. Mean water temperature reached in March 2014.

**Energy gained by the solar cookers.**

The experiment started at 10:00 hours. The energy gained in both the BSC and the CooKit progressively increased with each cooker generating an average of 0.008 MJ in every 10 minutes and the cookers remained comparable until about 10:40 hours. From 11:00 hours, the BSC accumulated significantly ($P < 0.05$) more energy than the CooKit until the end of the experiment. The BSC reached a peak of 0.17 MJ at 15:10 hours and remained constant until 15:30 hours where it started to lose energy until 1700 hours when the experiment ended. Moreover the CooKit reached a peak of 0.12 MJ at 15:40 and started to drop until 17:00 hours when the experiment ended. The results indicated that the BSC generated 0.05 MJ of energy more in this month than the CooKit because heat escape was limited in the BSC. The CooKit showed a great drop of energy at 10:40 hours compared to the BSC and reached a peak 30 minutes later than the BSC because heat escaped easily in this cooker type. However the energy generated by both solar cookers had potential to pasteurize food (Mullic *et al*., 2004; Yousif *et al*., 2012; Yahya, 2013).
The energy generated by solar cookers in the month of February is reflected in Figure 6.

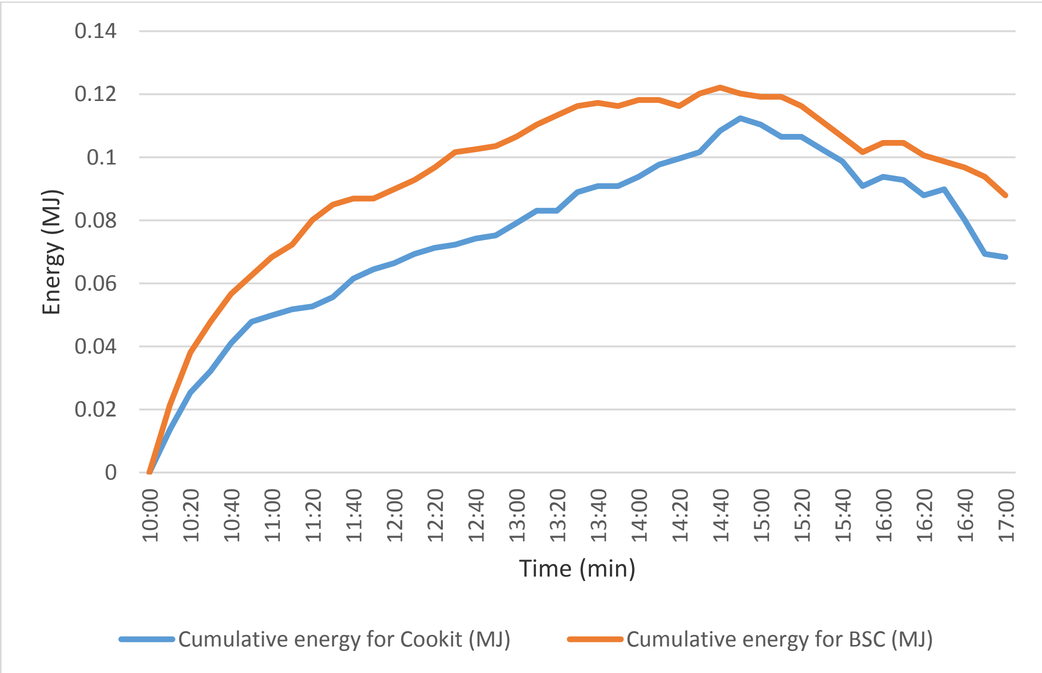



Figure 6. Cumulative energy generated by solar cookers in February 2014.

The gained energy in both the BSC and the CooKit in this month suddenly increased and was comparable until about 11:10 hours. Thereafter, the BSC accumulated significantly ($P < 0.05$) higher energy than the CooKit until 14:00 hours and the differences were then comparable until 16:40 hours. The BSC and CooKit reached a peak of 0.12 MJ at 14:40 hours and 0.11 MJ at 14:50, respectively and dropped until the end of the experiment. The results indicated BSC generated more energy again compared to the CooKit. However, the energy generated by both cookers was adequate to pasteurize food products.

Figure 7 shows the energy generated by BSC and CooKit in the month of March.

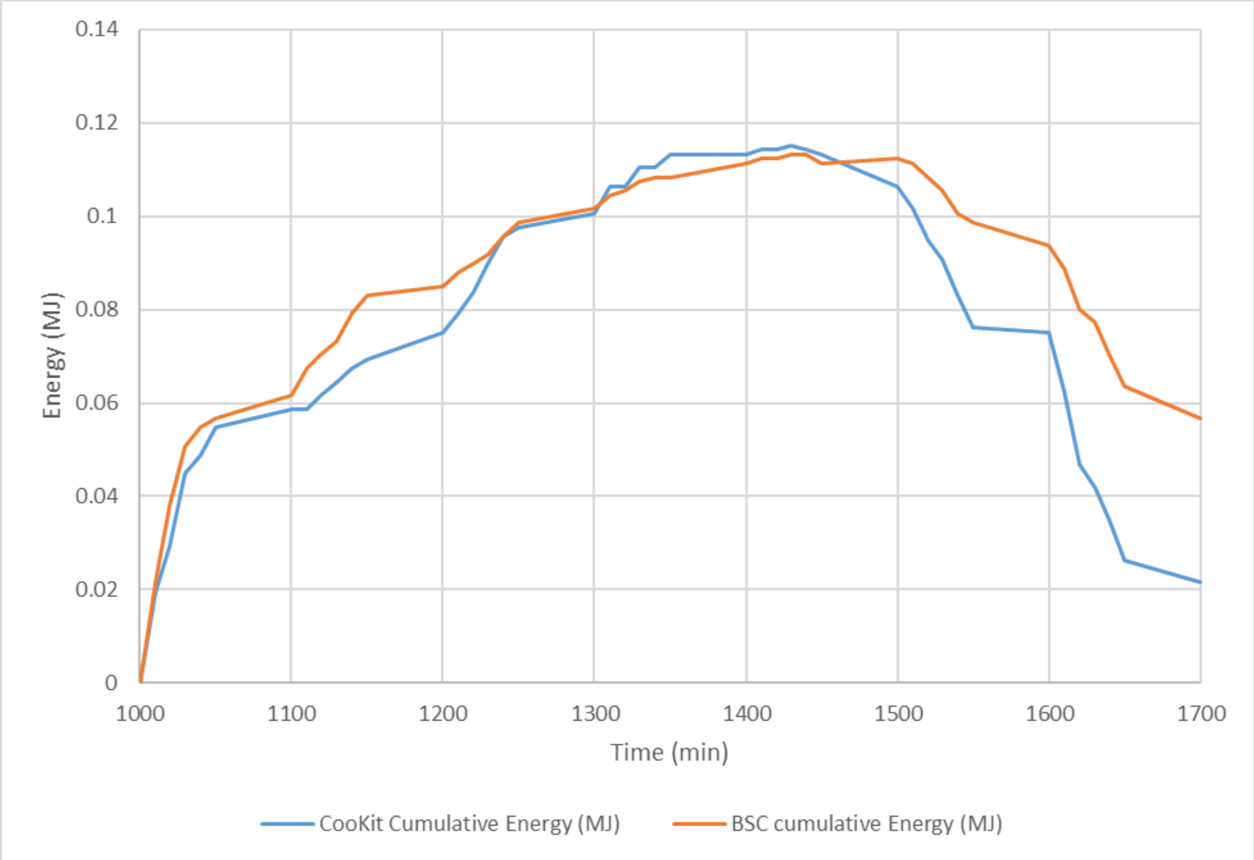



Figure 7. Cumulative energy generated by solar cookers in March 2014.

The results indicated that the rise in energy gain from 10:00 hours until 11:40 hours was not significantly different (P >0.05) between the two solar cooker designs. Thereafter energy generated by the CooKit was significantly lower compared to the BSC from 15:10 hours and lost energy significantly (P <0.05) faster until 17:00 hours. The rapid loss of energy by reflective panel solar cookers was probably for the same reason of lack of insulation. Energy generated by the BSC and CooKit reached peak of 0.16 MJ at 14:40 hours and 0.11 MJ until 14:30 hours, respectively. The CooKit reached its peak earlier than the BSC possibly due to the fact that box solar cookers are slower in heating up as they are insulated. However energy generated by both cookers was still adequate to pasteurize food products effectively (Frazer, (2006); Smith, 2008; Uhuegbu, 2010; Yettou *et al*., 2012)..

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

The objective of this study was to fabricate a box type solar cooker using local carpentry skills and material that is affordable by smallholder farmers. The results from this study have shown that the locally fabricated box type solar cooker (BSC) has more potential to pasteurize food products such as milk compared with the reflective panel solar cooker. However, the energy and temperature gains observed in both solar cooker types was adequate to pasteurize milk and possibly to cook a wide variety of foods. It can be concluded that there is adequate manufacturing skills and appropriate materials to fabricate solar cookers that can alleviate energy shortages in some households

**Recommendations**

It is recommended that more tests be conducted at different times of the year in different geographical locations and under varying climatic conditions. Effectiveness of the BSC in pasteurizing and cooking different types of foods is essential before the cookers are recommended for widespread dissemination.

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