Solar Cookers for Africa

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Abstract

Solar cookers are cooking appliances that cook using only the sun as an energy source. A solar box cooker is a common solar cooker model that uses the greenhouse principle to heat the inside of the cooker. The cooker consists of an insulated box or oven chamber with a transparent top allowing light in, sometimes additional reflectors are added to collect more light into the oven chamber.

Sunfire Solutions is a solar energy agency based in Johannesburg, South Africa and supplies solar cooking solutions. One of the products they offer is the Sunstove, a solar box cooker. Unfortunately, customers came back unsatisfied since this cooker is not performing very well. For this reason , Sunfire Solutions would like to replace the Sunstove with a new solar box cooker model.

When replacing the Sunstove, attention should be paid to the performance, dimensions, manufacturing processes, materials and design while keeping the price as low as possible, especially since the target market consist partially of very poor people.

Investing in a new and usually unknown product such as a solar box cooker is a risk and the lower the price, the lower the risk and the easier people can afford to buy a solar box cooker. The design helps give the cooker a strong and reliable look which helps to convince customers that a solar box cooker is a good and reliable product and therefore a sound investment.

Worldwide there are many different solar box cookers available, all with unique advantages and disadvantages. An extensive research is done into finding out what materials are easily obtainable for a good price in Johannesburg. A selection of available materials was compared with materials used in existing box cookers: the most economic choice of materials is very similar to materials used in the ULOG Light, a box cooker model from Switzerland.

The new cooker design is focused on giving the cooker a reliable look. Costs for manufacturing of the cooker will be between R800 and R1000 and this will include labour hours. The cooker will be sold by Sunfire Solutions using the internet and if possible, in hardware stores.

Table of Contents

Definitions

ECSCR: European Committee for Solar Cooking Research
Gauteng: the area/province where Johannesburg is located.
GTZ: Gesellschaft für Technische Zusammenarbeit
ProBEC: the Programme for Basic Energy and Conservation
SADC: Southern Africa Developing Countries
VOC: Vereenigde Oost-Indische Compagnie; Dutch East India Company
Exchange rate: In this report the exchange rate between Rand and Euros of September 14th 2009 is taken: €1 = R11,06

Preface

This report describes a Bachelor final assignment for the study of Industrial Design at the University of Twente, The Netherlands. The project took place in South Africa at Sunfire Solutions, a solar energy agency based in Johannesburg. Sunfire Solutions sells cooking solutions: solar cookers, heat retention devices and fuel efficient stoves. The goal of this project was to replace an existing solar box cookers and making a better performing box cooker available to the South African market.

Although the idea of solar cookers was invented centuries ago, the product is still in its introduction stage. As a consequence, a lot of information is contradictory, incomplete or absent. All over the world new cookers are developed, following all kind of rules and care should be taken as to which designs or information are useful and which are not. The fact that this cooker will be mass produced in Africa means a lot of care is taken to select materials and the manufacturing processes, since similarity in prices and quality of materials and processes available in Europe or in Africa cannot be taken for granted.

I would like to thank Rogier Kauw-a-Tjoe who introduced me to Solar Cookers and Crosby Menzies. Thanks to all the great minds who wanted to share their knowledge with me: Arie de Ruiter, Marlett Balmer, Michael Götz and Michael Grupp. Very important were the people who were helping with the more practical problems: Chris Fryer for his help with building the prototype, Mark Mangold for his amazing work at Durattract, Tom Vaneker for all his suggestions and tips, Niels Hoogendoorn for his emotional support and giving me confidence. But most of all I want to thank Crosby Menzies, director of Sunfire Solutions for his hospitality and enthusiasm towards me and this project.

1. Assignment

1.1 Poverty

A solar cooker is a device that cooks using only the sun energy without any fuels. Many families in Africa are poor and this appliance can help them save money, making it highly desirable. Many areas do not have electricity yet and in places where electricity is available, people do not use it because of the high costs. Other options are paraffin, coal, gas and wood, but these are often expensive as well: on the average people in South Africa spend almost 25% of their income on housing, water, electricity, gas and other fuels [Stat SA, 2006] and people with lower income even more. For the poorest families, collecting wood is the only solution, which is a very time consuming activity, especially if the closest forest is hours of walking. Women and children walk miles to collect fuel wood every day (figure 1). During these trips, they are exposed to wild animals, attack, abduction or rape [Wentzel and Pourris, 2007].

1.2 Environmental problems

Besides the problems associated with buying and collecting fuel, there are also other problems with relying on fossil fuels.

- Emission of carbon dioxide and black carbon
- Deforestation
- Health risks

The use of gas, paraffin, coal and wood cause emission of carbon dioxide and black carbon, also known as soot. Not only carbon dioxide, but soot as well has emerged as a major and previously unappreciated source of global climate change. [Rosenthal, 2009]

Deforestation arises in areas where people are entirely depending on fuel wood. People start with collecting dead wood lying on the ground, but often more wood is required than is available. At that point, people start to cut branches from trees or take complete living trees, the resulting deforestation leads to heavy soil erosion which in turn creates more problems.

Some fuels, like paraffin, require special cooking appliances, people who do not have the money

figure 1: women collecting fuel wood

for such these cooking appliance will try to make something themselves. If this is not done correctly, users are exposed to increased polluted air resulting in very serious health problems. [Bergler e.a., 1999]

1.3 Solar cookers

A solar cooker is an appliance enabling people to cook using only the sun. Most Solar cookers have one or more reflectors, reflecting sun rays onto cooking vessels. The temperature reached is enough to prepare food with. There are many different types of Solar cooker models available, the most common types are the collecting models such as box cookers and indirect cookers.

A collecting type can be a parabolic cooker, which consists of reflecting sheets positioned in a parabolic form. The sun is reflected to the focal point of the parabola where a black cooking pot is placed. Another collecting type is the solar panel cooker. These cookers consists of reflecting panels placed around a pot. The most famous version of this cooker is the Cookit.

A box cooker is an insulated box, sometimes with one or more reflectors using the greenhouse principle. The visible light enters through a transparent sheet on top, but as soon as this light is allowed in it will be reflected or absorbed by the objects in the box cooker or oven chamber. This changes the wave length of visible light turning it into heat which is not able to pass out through the transparent sheet. For this project a box cooker will be defined as a device that uses heat from the sun to cook food in a cooking pot, by a closed insulated box with a transparent top and reflecting parts, intern and/or extern.

Indirect cookers collect solar energy outside and transport the energy inside to the place where the food is actually going to be cooked. Energy can be collected for example by running water through tubes outside while the sun is heating the tubes and the water inside the tubes. This hot water will be transported inside and used to cook.

Solar cookers can offer a perfect solution for problems described in paragraph 1.1 and 1.2: people need less fuel so they can save money and at the same time people do not have to collect as much fuel wood as before. However, despite many projects, Solar cookers are still not widely accepted.

1.4 Solar box cookers

In paragraph 1.3 a brief explanation of a solar box cooker is made. Since this project will be about this kind of solar cooker, a little bit more information may be useful.

Solar Cookers International is an organisation that tries to collect all available information about Solar Cooker worldwide and help to spread the idea of solar cooking. Their archive contains information on almost every solar cooker design worldwide. Most information in this paragraph is from them or a link found on their website.

The basic idea of a solar box cooker was invented a long time ago and nowadays solar box cookers are built all over the world. According to manufacturers and inventors most cookers reach temperatures between 120-150 °C and can be used in most parts of the world. Most of the solar cooker designs worldwide never exceed the stage of prototyping, only a couple of cookers are built using mass production. More information about different kind of cookers can be found in appendix C. In cases where solar box cookers are made in mass production, the cookers are often quite expensive: a plastic box cooker will cost for example about €250 or R2765. Other types of cookers are handmade and can be made everywhere in the worlds as long as people have simple carpentry tools.

1.5 Sunfire Solutions

Sunfire Solutions is the leading Solar Cooker promotion and development agency in Southern Africa for Solar Cooker technologies. Sunfire Solutions manufactures and supplies different types of cooking solutions: solar cookers (parabolic cookers and box cookers), heat retention devices and fuel efficient stoves.

Sunfire Solutions sells two solar box cooker models: the Sunstove and the SunCook. Sunfire Solutions has experienced some problems with the Sunstove of which the main problem is that users come back unsatisfied, because the performance is not very good. Sunfire Solutions is looking to improve the Sunstove or develop a new model box cooker to replace the Sunstove.

1.6 Target Market

Although the previous paragraphs suggest that the target market consists of really poor families, the target market is bigger than just this group. The two biggest groups are:

- People with really low incomes that struggle to make enough money for all household needs, including fuels.
- The outdoor enthusiasts, consisting of campers, green conscious people and other people wanting to cook without fuels when camping or in their backyard.

The Sunstove is a cheap and simple solar box cooker while the SunCook is better performing but way more expensive. The cooker that should replace the Sunstove, should be for people with a really low income in the first place and for outdoor enthusiast in the second place. Both target markets will be discussed through the chapters with slightly more attention for low income target market.

2. Subject Area

2.1 Needs of the target market

A solar box cooker is a cooking appliance and to be accepted it should be suitable for traditional recipes and it should be available at a good price. This paragraph will discuss these two aspects.

2.1.1 South African Cuisine

The South African kitchen is a blend of indigenous recipes and settlers cooking. Since the seventeenth century, South Africa has been settled by colonists from Portugal, the Netherlands, the United Kingdom, France and Germany. Besides influences from Europe, there are influences from Asia as well, since the Dutch East India Company (VOC) imported slaves from Asia to South Africa. As a consequence, almost every dish you can think of is available.

The low income target group:

A study for the ProBEC [Chirwa e.a., 2008] showed the 6 most common recipes (table 1) from two rural villages (Cata and Tshoxa) in South Africa and the favourable cooking appliances for these recipes. Rural villages are representative for the low income target group, since income in the rural areas of South Africa is way lower than income in urban areas [StatSSA, 2006].

Samp (boiled whole kernel white maize) is made by cooking maize in water, which means that the temperature required is only 100°C [Wikipedia, 2009].

Outdoor enthusiasts

This target group can use the box cooker in the backyard or on holiday whenever the sun is out. A very popular dinner in South Africa is "eating from the braai", in which a "braai" is some kind of barbecue. A box cooker is not the most ideal solution for preparing meat, since box cookers do not reach very high temperatures. Due to that, it will take quite a while before the meat is safe to eat. Parabolic cookers are better suited to prepare meat, box cookers to prepare side dishes, like potatoes, rice, pasta or vegetables [Menzies, 2009].

Most dishes of both target markets, require boiling water and for that, a temperature of 100 °C such as vegetables, potatoes, rice, pasta and pap. Another common side dish is bread, which should be baked in an oven. The higher the temperature, the faster it will go, there is not a strict minimum temperature for making bread. More about this can be found in 3.2.1.1 performance.

2.1.2 Traditional cooking devices

Knowing what the traditional cooking devices are, helps to understand the current cooking process. This is useful to understand what the customers are familiar with and which aspects will help to accept the cooker.

	Samp			Bread			Bones		
Energy source	Cooking time (hrs)	Cata %	Tshoxa %	Cooking time (hrs)	Cata %	Tshoxa %	Cooking time (hrs)	Cata %	Tshoxa %
Dung	5	0	2	3	0	2	4	0	2
Electricity	4	2	17	3	8	22	4	0	7
Fuelwood	4	95	60	3	87	57	3	42	15
Gas	3	0	3	2	2	2	0	0	0
Paraffin	4	3	13	3	3	13	3	2	0
Leaves and twigs	4	0	5	3	0	3	4	0	2

	Meat			Pap			Vegetables		
Energy source	Cooking time (hrs)	Cata %	Tshoxa %	Cooking time (hrs)	Cata %	Tshoxa %	Cooking time (hrs)	Cata %	Tshoxa %
Dung	0	0	0	0	0	0	0	0	0
Electricity	2	20	40	1	28	43	1	33	45
Fuelwood	2	68	40	1	53	38	1	50	30
Gas	2	0	3	1	0	3	1	0	3
Paraffin	2	12	17	1	18	15	1	17	20
Leaves and twigs	0	0	0	0	0	0	1	0	2

Table 1: Energy source preference and cooking times (hours) for various foods (most preferred sources highlighted)

In 2008, the Stellenbosch University [Chirwa e.a., 2008] did a study on kitchen management of poor families in South Africa. They had some useful information:

In 2006, 31% of the households depended on firewood and paraffin for food preparation in South Africa. Although the government introduced a national household electrification programme, a lot of families cannot afford the monthly costs for electricity. Case studies showed that the primary energy source is different for every household, it often depends on the abundance of forests in the area. Most of the households have firewood, electricity or a combination of both as primary energy source. Paraffin, coal and gas are used as well, but in common as a supplement.

When using wood, most of the people use open, unshielded wood fire. These fires are set on a metal plate that can be moved inside or outside. When using wood fire, a three-legged stove is commonly used: the stones are place round the fire, the pot stands on these three stones (figure 2).

It is striking that a lot of households use electricity or gas to re-heat food and use wood, which is in most cases cheaper, for food with a preparation time of more than one hour.

The outdoor enthusiasts have other traditional cooking devices. For cooking outside, a "braai" (a barbecue) is the most common used South African device and is often used for meat. A braai needs charcoal to get hot and is available from just a grill and a case for the charcoal to a more sophisticated one with wheels, a lid and space to store tools and charcoal. Another common used device for campers is a camping gas. With these two devices almost everything can be made except for dishes that need an oven. At home these people use often an electric or gas cooker.

2.1.3 Price

The economic situation of the target groups is probably the biggest difference between the two groups. For both groups holds that the price of a box cooker depends on three subjects: the economic situation of the users; the costs of manufacturing and transport and the price of comparable products.

Target group: lower income

The economic situation of families in South Africa is from rich to very poor. Although it is important that especially the poorest families can afford a box cooker, the price cannot be completely dependent on their income. If the price of the box cookers must drop, it might influence the quality of the product in a negative way. In case the price is too high for the poorest families, it is better to start projects to give the cookers away instead of influence the quality. To get an idea what their income is: In South Africa 23,6% of the population between 15 and 64 years old is unemployed [StatSA, 2009], 20% of the South Africans has an income lower than R11378(€1017) annually (R950(€86) a month) and another 20% has an income between R11378 and R20202(€1805) (R1683(€152) a month). [StatSA, 2006]. According to researches done by the Pro-BEC, 200 Rand (€18) is a psychological boundary: a device that costs up to 200 Rand can be bought without having a serious influence on the family. [Balmer, 2009]

The price of the box cooker should cover the costs for production and transport and be profitable for the company selling it. If this price is too high, the costs of production or transport must decrease.

Besides that, the price should be able to compete with traditional, trusted cooking appliances on the market as well. For a lot of families, a solar cooker is an unknown devise and represents an investment risk, so the risk must be as small as possible. In Lesotho, a market research is done for a heat retention device [Nthunya, 2007]. People were asked what they were willing to pay for such a device. In Lesotho, the currency is Lesotho's loti (plural meloti, M) which is pegged to the rand at a rate of 1:1. The costs of a heat retention device is now M142 and according to the market research, people were willing to pay between M150 and M312,50.

The savings in fuel can sometimes be hard to measure but Marlett Wentzel and Anastassios Pouris tried in their research of 2007. According to their research, people saved between R12 and R26 on fuels with a solar cooker with an average of R18,3 a month. In one year, people could save R220 and if the cooker would cost R900 (see conclusion of this paragraph) it would take a little bit more than 4 years before the cooker paid itself back. However, the sales prices depends on whether or not Sunfire Solutions can get cookers financed in projects so the payback time can be easily a year more or less.

figure 2: Cooking devices for both target markets.

South Africa
Cooking Process

South Africa
Outdoor cooking

Target group: outdoor enthusiasts

The economic situation of campers and green conscious people is a lot better and can afford buying a product just because it is better to the environment. For this groups holds the same: the price of the product still has to cover costs for material, manufacturing and transport.

A visit to Mica, a hardware store, learned what cooking appliances campers use and how much they are willing to pay. South Africa is famous for using the 'braai' as could be read in paragraph 2.1.2, which is often taken on holiday as well. This braai and a camping gas are products that might be replaced by a box cooker. The costs for a braai start at R200 and can get up to R5000, even if it still has to be assembled by the customer. The costs for a camping gas start at R300 and can get up to R2000. For both appliances the customer still needs to buy charcoal or gas.

If a new stove is built, the production costs will probably be higher than the costs of a Sunstove (R285, see also 2.2). The outer box will probably be more expensive since the mould for the current outer box is sponsored and it cannot be taken for granted that this will happen again. Because the Sunstove cannot reach very high temperatures, the aluminium inner box and plastic outer box can be attached without further measures: the outer box will not melt at the temperatures the Sunstove reaches. A new cooker might need an extra part to prevent the outer box from melting. The Sunstove does not contain a reflector: since it is likely that the new cooker will have a reflector, the reflector will cause additional costs.

Sunfire Solutions sold several products for different prices over the last years and concluded that the outdoor enthusiast target market is willing to pay up to 3000 Rand for the SunCook: the other solar box cooker sold by Sunfire Solutions. [Menzies, 2009]. In consultation with Sunfire Solutions, would the following be desirable: If the manufacturing costs of a new cooker are 800-1000 Rand, the cookers can be sold for 1500 to 2000 Rand for the outdoor enthusiast target market. The price for people with lower incomes can drop by the gain from selling cookers to the outdoor enthusiast target market and maybe by subsidising projects.

2.2 Product problems

The Sunstove as can be seen in figure 3, is a box cooker that is used for many years now. It is originally designed by Richard Wareham from Sungravity in the USA and since 5 years produced in Johannesburg. The Sunstove is made of four main materials, most of them recycled. The plastic outer casing is blow moulded from 75% recycled material and 25% of virgin material. It is possible to use other manufacturing methods, like injection moulding, vacuum or rotary moulding. The internal walls and bottom are made of used aluminium printing plates, sometimes painted black. The lid is made of poly-carbonate, which has a better durability and preserves its shape better than the previous used acrylic lid. The stove is insulated with (high density) fibreglass, other materials as cotton, wood, mineral wool, jute and hemp could be used as well [Bennett, 2009].

Figure 3: the Sunstove

The Sunstove does not have external reflectors, according to Sungravity this is compensated by the large upper lid. The costs of a Sunstove are 200-500 Rand, depending on the presence of supporting projects. The Sunstove made for Sunfire Solutions has manufacturing costs of R285. R105 rand is for the polycarbonate lid and R85 is for the case [Menzies, 2009]. The costs for the case are only the costs of the blow-moulding process itself since the mould was sponsored by Dick Wareham for the price of R45,000 [Bennett, unknown].

The other R95 are for the aluminium printing plates, the fibreglass insulation, paint, staples, labour hours and profit. The labour is done by one person and he builds about 100 stoves a month, which is not a fulltime job but the demand. It takes 20 to 30 minutes to assemble a stove. The aluminium plates can often be bought for transport costs since they are second hand.

In 1999 a test for the Sunstove is done by the ECSCR, the European Committee for Solar Cooking Research. Unfortunately, the ECSCR is not very active anymore. Details of this test can be found in appendix A. [Bergler e.a., 1999]

In 2000, Sungravity came with a new design because this would make the manufacturing process easier, the materials used did not change, only the shape. According to Sungravity [Sungravity, 2009], the new Sunstove will reach 80° C easily. It is possible to boil water and the pot cover can exceed to 148 °C. However, according to another research, the Sunstove only reaches 88°C and the food as well [Gayapershad e.a., 2006]. More about the performance of the Sunstove can be found in Appendix F.

In Zimbabwe, a research is done for the Sunstove specifically. [Abdul, 2007] Aim of this research was to find out what the opportunities were for the Sunstove in Zimbabwe. Below the conclusions or findings that can be of help for this project.

- The shape of the Sunstove makes it easy to transport the Sunstoves, because without the lid, the Sunstoves can be stacked. The lids will be placed on the Sunstove at their destination.
- Solar Cookers were perceived as slow and inconvenient and most people found it easier to carry on using paraffin or biomass.
- The research showed as well that people are more likely to buy a fuel efficient stove than a complete new product. With a fuel efficient stove, it can be taken for granted that you will actually save fuel and for that save money. With a new product, people do not always believe this will actually work properly and therefore they do not want to take the risk.
- A lot of people preferred the parabolic cooker over the Sunstove, because the cooking time was less, although the parabolic cooker needs more attention during cooking and is more difficult to set up as well.
- Although a lot of people were interested in the Sunstove, only a very small part would actually buy it, because it is quite an investment for something they do not know yet, and therefore do not trust.

It should be noted that this research was done in Zimbabwe, where the economic situation is not as good as in South Africa.

Evaluations in South Africa showed that the Sunstove is slow, but cheap and the only box cooker that is widely commercial available. The Sunstove is a robust design (for example: the polycarbonate lid will not immediately break when the stove is accidentally dropped), but not extremely durable and after a while, the black paint will get scratched and disappear, the inner box will bend and the insulation can pop out the casing as can be seen in figure 4. (Balmer, 2009)

According to several researches, the technical development of solar cookers has been good over the years, the efficiency gets better every year. It is likely that solar cookers are still not widely accepted because there has been paid little attention to the social context and the needs of the customer. [Wentzel and Pourris, 2007] More about this can be found in 4.1.2.

Figure 4: used Sunstove

2.3 Available manufacturing methods and materials

To avoid high transport costs, the cooker should be manufactured in Africa, if possible in Johannesburg where Sunfire Solutions is located. The chosen material effects the manufacturing process, the strength of the cooker, the price, the weight and it could limit the shape. This paragraph will discuss the possibilities.

First of all, the expected sales numbers are important by choosing material and manufacturing process. Since this product is still in the introduction stage it is important to realise that the number of sales is not very high yet, but might increase quickly. Right now an on demand principle is used and is a save strategy since this means you will not have an enormous stock which costs a lot of money. It should be checked with manufacturers in Johannesburg if they are willing to work on a on demand base. In the last 2-3 years, around 1500 box cookers are sold. It can be expected that the sales numbers will rise, but it is not sure how much. The investment costs needed for a certain manufacturing method will be divided over 1500 units to calculate a price per unit.

If the cooker is made in Johannesburg, the availability of materials and manufacturing processes will probably not be the limit, since Johannesburg offers a wide range of materials and manufacturing processes due to the big industries. To make a first selection in possible materials and manufacturing processes, the following requirements can be considered: for every material of the cooker holds that it should be cheap, durable and light. For the manufacturing process, the amount of cookers can give an indication on most likely manufacturing processes.

Materials

A first material selection can be made by CES Edupack (version used: 5.1.0, 2009) this programme allows you to select materials by giving a couple of criteria. For a first selection, materials should not get damaged by UV-radiation and rural atmosphere. Materials that suit these criteria can be found in all types of materials:

- Metals: aluminium, cast iron, steel and tin.
- Natural products: cork and bamboo.
- Ceramics: glass, phenolics an alumina.
- Plastics: epoxy, polyester, PET, Teflon, silicon and PVC.
- brick and concrete

However, the price of the material is really important as well and sometimes materials can be treated to be more suitable for outdoor use. Cheap and easily obtained materials could be: concrete, cement, cast iron, brick, all kinds of wood including plywood, cardboard and polyethylene. It should be noted that the prices found of these materials are based on prices in the UK, but for a first indication it is accurate enough and in paragraph 3.3 more thorough price research will be done.

Luckily, a lot of materials are both durable and cheap. The materials that will be added to the list of durable materials are wood and polyethylene. Cardboard will not be added since cardboard is not even close to durable and it will not be easy to get it that way.

Manufacturing processes

As mentioned before, the amount of cookers that should be made can give an indication on most likely manufacturing processes. Besides that, the selected materials will probably be used as sheet materials or will be casted or moulded, the following manufacturing processes could be suitable for sheet material, casting or moulding. Other criteria were availability in Johannesburg (checked with the yellow pages) and economic batch size, given the expectation that 1500 cookers will be sold in the next 2 years.

Casting:
- die casting
- investment casting (although only up to 1000 and might be more expensive)
- sand casting

Sheet deformation processes:
- Sheet forming
- Sheet stamping, drawing and blanking

Machining:
- sawing (band, circular)
- cropping and guillotining
- drilling
- cutting (flame, laser, electric discharge wire)
- punching, perforating, blanking and nibbling

Moulding can only be done when the mould is not very expensive, like with vacuum forming, or when a sponsor can be found for the mould like what

happened to the Sunstove. However, it is always a possibility that something has to be changed about the design and a new mould should be made. Because of this, a technique that requires an expensive mould is not preferable.

- blow moulding
- compression moulding
- expanded foam moulding (could be perfect for insulation)
- vacuum forming

Powder moulding

- pressing and sintering

Whatever manufacturing process will be chosen, it is important to make sure that the quality is constant, producers are reliable, materials are easy to obtain and not too many different materials are required.

Some currently available box cookers are build locally. Carpenters in villages get building plans and short instructions and the advantages are big: hardly any transport costs, it creates more employment and has almost no start-up costs. On the other hand, the disadvantages are quite serious as well: it is hard if not impossible to do quality control, the price is not constant and the materials that can be used are limited and can be different from village to village. If cookers are not built properly or inappropriate materials are used, the performance of the cooker can decrease dramatically and affect the credibility of solar cooking for years [SCI, 2009]. This could be avoided by integration programmes, educating the local carpenters and checking on them on regular basis but this requires a lot of time, money and skilled people who are willing to cooperate with this integration programmes. Even if this is done, Sunfire Solutions can still not guarantee a certain price or quality and the risks of putting solar cooking in a bad light still exists. For this, local manufacturing by hand will not be considered as a good manufacturing process for a new cooker.

The manufacturing of cookers will start in Johannesburg and if it turns out that the new cooker is successful, manufacturers in other capitals in Southern Africa can be approached for cooperation.

3. Product principle: Requirements and market survey

This chapter will define more clearly what kind of cooker is searched for. Therefore, it starts with requirements from the users and continues with requirements for a box cooker, a discussion what the main characteristics of a box cooker are and a comparison of existing box cookers.

3.1 Requirements given by surroundings

3.1.1 Geographical

South Africa is situated between 23° and 35° South latitude, which means South Africa can be called a temperate zone. Although most potential customers will use their cookers in South Africa, some users come from other countries in the SADC and will use the cooker more north. This means the new box cooker will be used in a tropical as well as a temperate zone. As a consequence of that, the cooker will need at least one external reflector [Popock, 2009] to gain enough solar radiation to cook properly. Since the position of the sun changes during the day and the seasons, the position of the reflector should be adaptable for optimal use of the sun.

Besides that, the geographical position tells something about the presence of circumstances that can effect a cooker: in rural areas of South Africa live termites. These small animals eat wood and can damage a Solar Cooker really bad if it is made out of wood. Therefore, it is better not to do so or to treat it with varnish.

The climate of South Africa is quite temperate, the winter (July – August) can be really cold, the temperature can even drop to the freezing point when staying on higher altitudes like Johannesburg. Summer is not very hot, the temperature seldom exceeds 25-30 ° C. The rain falls, with the exception from Cape Town, in Winter, with an average of 100-150 mm a month. Other countries in the SADC have a variety of climates, Mozambique has a humid, hot summer and a dry, little bit cooler winter; Namibia is a desert with high temperatures and only rain during two or three summer months and Zambia has all these varieties of climates spread over the country.

It might be nice to make a box cooker waterproof but this is not necessary. The cooker cannot cook when it is raining and a lot of people will take their box cooker inside when not using for safety reasons anyway. Moisture resistance is still preferable, especially because a hot, humid climate can cause wood or insulation growing mouldy.

3.1.2 Usability

As mentioned before, many projects implementing Solar Cookers turned out to a disappointment. Over the last few years more attention has been paid to technical improvement, but the customers' needs and the social context remain largely forgotten. So while people are willing to try a cooking device that can save them money or is good for the environment: it often turns out to be too cumbersome, expensive or difficult to use.

A way to find out which aspects contribute to a good usability is reading evaluations that are already done in combination with introduction programmes. Marlett Wentzel and Anastassios Pourris, both working at the University of Pretoria, summarised all evaluations done by GTZ or ProBEC in South Africa over the last 10 years (2007).

The most useful conclusions are listed in two categories: Problems that cannot be solved by the design and problems that can be solved by the design.

Problems that cannot be solved:
- Weather conditions
- Limited space to use the solar cooker and/or absence of sunny places: this is mostly the case in urban areas, where houses are built really close to each other. An option could be to take a cooker that can be easily transported, so it might be placed on a flat roof. Note: this is a problem that is unlikely to appear with the outdoor enthusiast target market, since this target market has often a big house with a nice big garden.
- Lack of storage. Note: this is a problem that is unlikely to appear with the outdoor enthusiast target market.
- Users change their cooking patterns.
- Problems with security; the cooker and/or food is stolen during the cooking process.

Problems that can be solved:
- The cooker is too small. More about this subject can be found under "3.2.1.2 dimensions"
- The temperature is not high enough.
- The cooker is too slow.
- The cooker cannot easily be transported.
- Cumbersome to clean

- Users are too lazy
- Users become bored
- Unsafe, especially for the eyes. At the moment, there are no specific rules for safety.

It should be noted that although many people complain about the performance of the Sunstove, there is still a group of happy users, so the cooker being too slow or too small is a matter of expectations as well.

In October a project with solar cookers started in Soweto, which is described in appendix H. While observing the start of the project, another problem appeared: many potential users from the lower income target market may not have had a very good education and are not familiar with IKEA or Lego. This means they may not have the insight necessary to understand how these appliances work without a good explanation. Therefore the product should be as straightforward and error-proof as possible.

3.1.3 Sales Channels

At this moment, customers, both lower income and outdoor enthusiasts, buy the Sunstove on the internet or after calling or e-mailing the company. People learned about the cooker during demonstrations or because they saw the cooker being used by neighbours or friends. [Menzies, 2009]

When the Solar Cooker was first introduced, it was told that this product could solve all the problems concerned with cooking. However, a box cooker is still quite slow and not every dish is suitable. In many programmes for people with lower incomes, box cookers are no longer promoted as a single solution, but as an add-on appliance in an integrated cooking package: it is important to give the customers some choice. [Wentzel and Pourris, 2007] Besides that, a lot of people do not trust the cookers because they do not recognise them: it should be sold through a channel they trust. This is supported by a research for heat retention devices from the University in Lesotho [Nthunya, 2007], (Table 2)

The currently used sales channels, internet, e-mail and phone, can be used for a new cooker as well. Besides that, the cookers could be sold at shops. Camping shops or hardware shops already sell cooking appliances that can be used outside so the step to a box cooker is small. For the lower income group, it is a bit more complicated: at the moment there is no shop that sells really low costs cooking appliances so this would mean a complete new branch must created. This can only happen when such a shop sells more than 1500 products a month which is not very realistic in this case. [Balmer, 2009] When a cooking device is going to cost more than R200 (see also 2.1.3 price) the sales point must also give the opportunity for end-user finance mechanisms [Wentzel and Pourris, 2007]. It might be an idea to sell the box cookers from door-to-door or at Tupperware parties where a demonstration can be done and people can ask questions, so they will trust it easier.

3.2.1 Product requirements

3.2.1.1 Performance

The performance is one of the, if not the, most important aspect of the box cooker for this project. In this project the performance is defined as the time it takes to prepare food properly in a box cooker. The shorter this time, the better it is.

The following issues are all part of the performance:

- The maximum temperature
- the time it takes to reach a certain temperature
- the heat flow
- the drop in temperature when the box has been opened to check on the food
- how thorough the food is cooked or baked

The reason to determine the performance as "the time it takes to prepare food properly" is because one of these components on its own does not give guarantee for a good performance. For example: a

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	shop	60	60.0	60.0	60.0
	manufacturer	10	10.0	10.0	70.0
	hawker	28	28.0	28.0	98.0
	not mentioned	1	1.0	1.0	99.0
	tourism centres	1	1.0	1.0	100.0
	Total	100	100.0	100.0	

Table 2: "Where do you expect to buy a heat retention device" by Nthunya, E. 2007

high end temperature says nothing about how long it will take to reach that temperature. And if the cooker can reach 100°C in 20 minutes, nobody can guarantee that you can reach a temperature above 100 °C.

However, getting this information from all cookers is quite difficult. To be sure, all cookers should be tested on the same time, on the same place so you are sure you will have the same conditions. Importing a solar cooker from Europe or the U.S.A. is expensive and really time-consuming, because a lot of cookers get delayed at the Customs. For this reason it was not feasible to do this test during this project. Unfortunately, the last time such a test was done, was in 1999. In the last 10 years a lot of models have been improved and many new models have been developed as well.

Manufacturers often only mention the maximum temperature they measured on a specific day. The other aspects have not been tested or are hard to measure (like heat flow). And even this maximum temperature is not a proper way to compare different cookers: although rules for testing a cooker have been introduced, not every manufacturer uses these rules and even if used, the place of the thermometer can cause a big difference, figure 5. [Kundapur, year unknown]

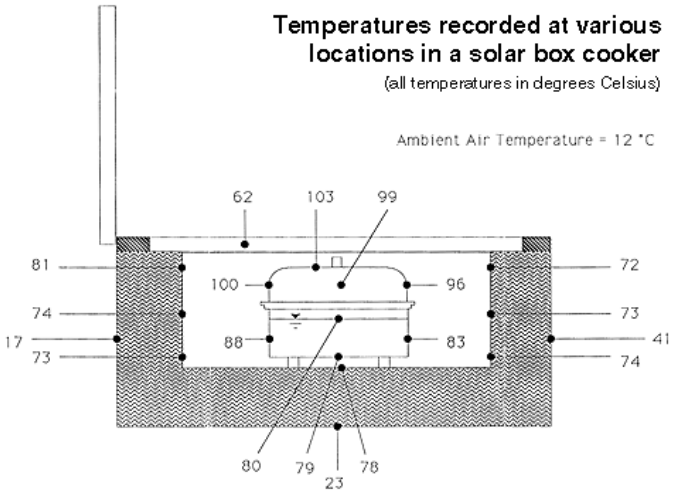


figure 5: temperatures recorded

So although the performance was the main reason to start this project, there is probably no clear, scientific answer for which cooker has the best performance. The judgement (3.2.3) of performance will be made by own experiences (Appendix F) and evaluations of solar cooker projects.

Two issues should be noted:

- When somebody decides to buy a box cooker, he or she already knows that it will take longer to prepare a meal than with conventional cooking appliances. Research showed that the time poor families will except to prepare a meal will be around two hours [Balmer, 2009].
- The equation of Arrhenius describes the influence on the temperature on the reaction rate of a chemical reaction. Since cooking is a chemical reaction, it is possible to calculate the time needed to prepare a meal. However, your temperature will not be constant as the equation assumes, you need values for the parameters of these equation and even if you can get these values, your results will only be approximate [Petrou e.a., 2002]. So this equation will not be used to determine the performance.

3.2.1.2 Dimensions

A box cooker should be obviously not too big and not too small: It is not a good idea to make the inside of a box cooker deeper than necessary since this means a larger space must be heated. On the other hand: a box cooker must be able to accept one or two reasonable sized pots and for a family of four to five members, five to six litre pots will be reasonable. [Menzies, 2009]

Let's say a pot is almost as wide as high. This would mean that a pot with a radius of 10 cm and a height of 20 cm has a volume of π*1,02*2,0 ≈ 6,3 dm3 which is equal to 6,3 L. This would be enough for a household that would like to use the cooker as an add-on device. If a pot has a radius of 15 cm, and the same height, the pot has a volume of π*1,5^2*2,0 ≈ 14 dm3 in case the family is bigger or wants to make bigger stews.

When only one small pot is taken, the inside of a box cooker should be at least 20 x 20 x 20 cm. With some space for handles and lids, this would mean 25 x 25 x 25 cm. When two pots are placed next to each other, for example a small and a big one, the inside of a box cooker should be 20 + 30 (diameter of a pot) by 30 by 20 cm as a minimum. Another option is to put the pots as showed in figure 6.

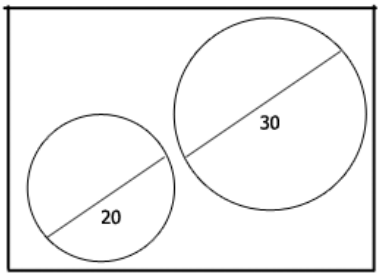


figure 6: pots in solar box cooker

If the box was a square, the sides should be at least 36 cm. With some spaces for handles and lids, this would mean that the inner dimensions must be somewhere in between 55 x 35 x 25cm and 40 x 40 x 25cm.

To make sure the cooker will be insulated well, an insulation material should surround the inner box, if this insulation material takes up to 5 cm, the minimum dimension of the outer box will be: 35 x 35 x 30 cm and the maximum dimensions of the outer box will be: 65 x 45 x 30 cm or 50 x 50 x 30 cm. It should be noted that as soon a cooker with reflector is wider in east-west direction than in north-south direction, the number of times a cooker should be repositioned to face the sun from a better position will become less. [Aalfs, 2009]

The weight of a cooker is especially important to make it easy to transport the cooker and to store it. The presence of handles can really help to make it easier to lift a heavy solar cooker and otherwise transport wheels can be considered. Of experience could be said that about 12 kg is a maximum.

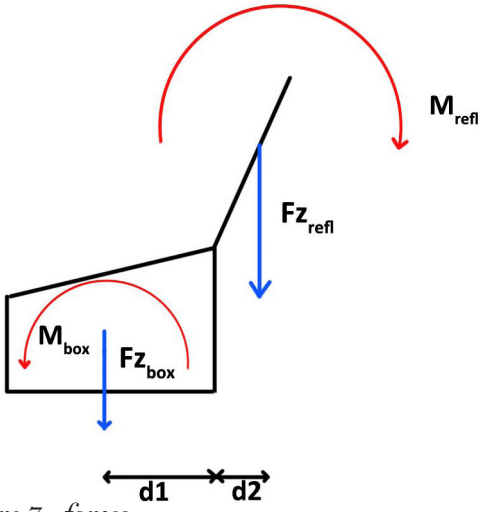


figure 7: forces

Besides the complete weight of a cooker, the division of weight is important for the cooker as well since the cooker might tilt when the weight is not divided properly. If the moment M_{refl} in figure 7 becomes bigger than the moment M_{box}, the box will tilt backwards. When a certain model is chosen and the dimensions are known, the forces and moments coming with preferred materials will be calculated to check if the box cooker will tilt or not.

3.2.2 Product parts

Convenient box cookers typically make use of five parts: the outer box, the inner box, the lid, the reflector and the insulation. This paragraph will discuss the functions of a box cooker and how they can be realised.

First of all a box cooker should be able to heat food that is put inside. More specifically, the cooker should have something to:

- Let sunrays in
- Collect as much sunrays as possible
- Convert light into heat
- Absorb heat
- Get heat to pot
- Keep heat inside
- Hold the pot
- Let the pot in and out
- Retain shape
- Protect itself and the food from animals and weather conditions
- Move the cooker

Current available box cookers use the:

- Outer box: retain shape, protect itself and the food from animals and weather conditions, reposition the cooker (often the cookers have handles or something to hold the cooker), keep heat inside (only if material is non-conducting)
- Inner box: Convert light into heat, collect as much sunrays as possible (if reflecting inner walls), absorb heat, get heat to pot, hold the pot
- Lid: let sunrays in, keep heat inside, let the pot in and out, protect itself and the food from animals and weather conditions
- Reflector: collect as much sunrays as possible
- Insulation: Keep heat inside

3.2.3 Currently available box cookers

This market research will discuss all currently available box cookers and their pros and cons. Besides that, the cookers will be judged on their flexibility: is it possible to adapt the cooker (if necessary) to be suitable for South Africa? This depends for a big part on the developer of the cooker: is he or she willing to cooperate and will he or she allow adaptations in the design?

In appendix C all cookers noticed can be found and why they are considered or not and in appendix D a

summary of the contact with the manufacturers can be found. Appendix E shows the properties of the considered cookers.

The considered cookers are:

Figure 8: From left to right, top to down: Dierckx (Dutch), ULOG Light (Swiss), T16 (French), SunCook (Portuguese), SunOven (American), SunScoop (Amerikcan), Pil Kaar (German)

The cookers will be judged by the following properties in the following order of importance.

- Performance
- Flexibility of the cooker design and the manufacturer
- Price, although it should be noticed that the price can increase or decrease as soon as another material or manufacturing process is chosen
- Introduction in other areas
- Dimensions, usability and manufacturing process

The performance is judged using own experiences, values given by the manufacturers, values found in "Kochen mit der Sonne"[Behringer and Götz, 2008] and tests done by the GTZ. To get an idea of how good or bad newer box cooker designs actually are in comparison with the Sunstove, a couple of cookers are tested for this project. These cookers were already available or really easy to obtain. Although the perceived values cannot be used as scientific, proofed numbers, it gives an indication which box cooker is better than another. An extensive report of these tests can be found in Appendix F. A summary of these tests:

The available cookers were the Sunstove, the ULOG Light, the SunOven and the SunCook and later the T16. The cookers were tested with two tests: the ice cube test and the muffin-test. With the ice cube test, ice cubes were placed in the cooker on a plate and the time it took the cooker to melt these ice cubes is measured. The range from fast to slow was (the T16 was not available during this test):

1. ULOG Light
2. SunOven
3. SunCook
4. SunStove

For the muffin test, 3 muffins were placed in the Sunstove, the ULOG Light, the SunCook and the T16. The range from fast to slow was:

1. SunCook
2. ULOG Light/T16 (very close to the SunCook)
3. Sunstove

Flexibility depends on the manufacturer and the availability of building plans. More about this can be found in appendix D. The price of the cookers and the different parts of the cookers can be found in Appendix E.
The two most important things for most customers in buying a solar cooker is price and performance. [Balmer, 2009]. The available cookers have a wide price-range and a wide performance-range, but which combination is good? If a cooker is successfully introduced in another developing country, the changes are better that the price-performance combination will work for South Africa as well. For that, earlier introduction in other countries will be discussed.

Dimensions, usability and manufacturing process can be found in Appendix E as well.
Table 2 shows a summary of how different cookers are judged on the first three criteria.

When counting the given values from the table the following range can be found:

1. ULOG Light/Dierckx/T16/SunScoop (all 10 points)
2. PilKaar (8 points)
3. Sunstove (7 points)
4. SunOven/SunCook (6 points)

	performance	**flexibility**	**price**
Excellent (4 points)	SunOven, T16, SunCook	Dierckx, ULOG Light, T16	Sunstove, SunScoop
Good (3 points)	ULOG Light, Dierckx, Pil Kaar, SunScoop	Pil Kaar, SunScoop,	ULOG Light, Dierckx
Moderate (2 points)		SunStove	T16, Pil Kaar
Bad (1 point)	SunStove	SunOven, SunCook	SunOven, SunCook

Table 3: summary

Another option to categories the cookers:

"High end, high cost": The SunCook and the SunOven, a lot of attention is paid to the manufacturing process and the design, both cookers are reliable and durable and you can see that. Unfortunately, you can also see that in the price and flexibility.
"Promote local manufacturing": The Pil Kaar and the SunScoop, both designs are made to let local carpenters or trained people build the cookers on a small scale and sell them in the villages close to them.
"DIY": The Dierckx and the ULOG Light. Both are made to reduce the costs and let people work with the materials they have. Building plans are free accessible and the manufacturers are willing to help if problems appear during building.
"False performance-price balance": the SunStove and the T16. The Sunstove is made in mass production, commercial and cheap, but with trying to lower the costs, the performance suffered too much. The T16 is the opposite: the performance is very good, but since this cooker is built by hand after one prototype (building plans do not exist), the cooker became too expensive and could not compete with other cookers.

As mentioned before, the Sunstove is not the only cookers that can be bought at Sunfire Solutions, it is also possible to order the SunCook from Portugal. This cooker is way more expensive, but is more reliable and has a better performance. The new cooker should replace the Sunstove and be way cheaper the SunCook. For t hat, the "High end, high cost" cookers are not an option.

The Pil Kaar and SunScoop ("promote local manufacturing") have as disadvantages that quality control will be very hard or very time-consuming and expensive to find people who can do this quality control and again, both companies are only willing to cooperate on their terms, which has really serious consequences for the price.

The Sunstove could be adapted to a more efficient cooker, but here another problem with the Sunstove appears: the relationship between Sunfire Solutions and the manufacturer of the Sunstove is not very well and it would be nice if a product of Sunfire Solutions does not depend on this manufacturer. Best options are T16, Dierckx and the ULOG. All of these cookers have enough potential to become a new cooker for Sunfire Solutions and are flexible enough to adapt if necessary.

3.3 Production process

For every part, the possible materials are written down with their properties and costs. Costs are based on quotes from companies in Johannesburg. Quotes are asked for batches of 20-50 products, with the expectation to get over 1000 products in the next years, all prices are including VAT (14%).

For all the parts holds: materials that are bad for the environment do not have the preference, since this product is partially to help the environment by reducing the CO_2 emission and the deforestation. The product itself should be 'green-conscious' as far as possible considering the costs and performance. Values for maximum temperature, thermal conductivity and heat capacity are found in CES Edupack unless another source is mentioned.

In appendix I, more information can be found on how the values are found and what specifications manufacturers gave.

Outer box:
Bamboo and cork were considered as possible materials in paragraph 2.3, however, bamboo and cork are very rare in South Africa, hard to get and for that really expensive, so these materials are not considered further. Ceramics are nice because they are good insulators, weather resistant and can take high temperatures, however, they are quite heavy and when you would accidentally drop the ceramic, it will probably break and not easy to fix. For that, ceramic will no longer be considered as an option for the outer box.

Other metals than mild steel have been considered as well, but the prices for only the outer box were R1000 or more, which is already the complete budget, which is the reason that these materials cannot be found in table 4.

Inner box:

For the inner box, a lot of existing cookers use printing plate (thin aluminium plates that are used to print newspapers), because it is free or cheap. However in South Africa, with an economic situation that is not as good as in Europe, every material that can be recycled, will be recycled. Printing plates are available, but it can be hard to get some, since Sunfire Solutions is not be the only company that wants these plates. Sunfire Solutions does not want to be dependent on a material that might not

Outer box	Plastic (ABS)	Plywood	Fabric	Mild steel (2 mm thick)
Manuf. process	Bending and vacuum forming	carpentry	Knitting	Cutting
Costs	±R700 a box	±R500 a box	J.G.Train ripstop R35,25 a box; Linings and textile Cordura 600D R10,50.	R250
Labour hours	Included	included	1	Included
Thermal conductivity (W/m.K)	0.226-0.235	0.3-0.5	0,03[1]	45-55
Max. Service temp. (C)	62-77	100-130	Unknown	350-420
Heat capacity (J.kg/K)	1390-1410	1660-1710	Unknown	440-520
Environmental friendly	±	±/+	+	±
Weight	2-3 kg	4,5 kg	0,15 kg	10 kg
Maintenance	-	Should be treated for outside use.	Be careful with sharp edges in surrounding.	Should be treated to stay rust free.

Table 4: possible materials for the outer box

[1] Thermal conductivity of cotton, found on http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html on November 2th 2009.

Inner box	Aluminium 0.9 mm thick	Stainless steel, 3 mm thick	Mild steel, 0.9 mm thick
Manuf. Process	Laser cut	laser cut	Laser cut
Costs	R245	R1197	R109
Labour hours	included	included	Included
Thermal conductivity (W/m.K)	80-160	12-24	45-55
Max. Service temp. (C)	130-220	750-820	350-420
Heat capacity (J.kg/K)	900-995	450-530	440-520
Reflectivity	90%	60-98% (polished or not)	60%
Weight	1,1 kg	10,8 kg	3,2 kg

Table 5: possible materials for the inner box

always be available and that does not always have the same supplier. Because of this, printing plate is no longer considered as an option.

Paragraph 4.2 explains why a metal inner box is the best option for the inner box and for that: why wood or plastic with a reflective tape on it are not considered for the inner box.

The lid:

The ULOG Light from Switzerland is using PET in the lid, this material is used in bottles and were expected to be widely available. However, in conversations with Durattract (see appendix I), PET turned out not to be as easy expected and this idea is dropped.

Lid	Single glass (soda-lime)	Double glass (soda-lime)	Glass and plastic	Poly-carbonate (2mm)
Manuf. Process	Cutting	Cutting	Cutting	Cutting
Costs	R50 - 80	± twice the price of single glass	> single glass	R180
Labour hours	Included			included
Thermal conductivity (W/m.K)	0.7-1.3	< single glass	< glass or plastic	0.189-0.218
Max. Service temp. (C)	170-400	170-400	101-400	101-144
Heat capacity (J/kg.K)	850-950	> single glass	> glass or plastic	1530-1630
Environmental friendly	++			+
Weight	2,5 kg	5 kg		0,47 kg
Maintenance	+	+	~	±

Table 6: possible materials for the lid

Insulation	Rockwool	Fibreglass	Iw24 (kind of fibreglass)	Polymer foams
Manuf. process	-	-	-	Expanded foam moulding
Costs	R62 per box	R21,50-23 per box	R28 per box	R58 per box
Labour hours	Included	Included	Included	included
Thermal conductivity (W/m.K)	0,045[2]	0,65 – 0,676		0,036 – 0,048
Max. Service temp. (C)	-	172-190	450	87 – 112
Heat capacity (J/kg.K)	unknown	1170 - 1210	unknown	1750 – 2260
Environmental friendly	±/+	±/-	±/ -	-

Table 7: possible materials for the insulation

[2] Found on http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html on November 2th 2009

Insulation:
As mentioned before, materials that are not good for the environment, do not have the preference. Sunfire Solutions rejected a previous product because of the use of polystyrene balls. Wool would be a good option, but the amount of calls that had to be made to find out more about wool showed that it will be very hard if not impossible to find a supplier of wool who has always enough wool for a reasonable price, for that wool is not preferred.

The reflector:

The reflector has been the hardest part to find materials for. The reflector should be stiff: it should not bend because of some wind since that would mean that the reflector does not reflect into the oven chamber. Due to that, it might be necessary to search for two materials: one for the reflectivity and one for stiffness.

It took a couple of weeks before a sample of aluminium could be obtained. At that point, the prototype was already made. Unfortunately it turned out that the aluminium did not have a reflectivity good enough for this cookers. It is recommended to look for other aluminium suppliers. Because the reflectivity was not good enough, the price is not mentioned in table 8.

Reflector	Aluminium	Tape + ABS sheet	Space (emergency) blanket + ABS sheet	Tape + hardboard	Space blanket + Hardboard
Manuf. process	Cutting	Cutting	Cutting and Glue on sheet	Cutting	Cutting
Costs	-	Rtape: R26 + R28,43 = R54,43	R0,50 + R28,43 = R28,93	R26 + R14,99 = R40,99	R0,50 + R14,99 = R15,49
Labour hours		0,5 - 1	0,5 - 1	1	1
Reflectivity	-	Unknown, probably around 90-95%	80%	Unknown, probably around 90-95%	80%

Table 8: possible materials for the reflector

An ordinary mirror does have a very good reflectivity but is at the same time very brittle. Since the reflector is an external part, it is likely that someday the user will accidentally drop something on the reflector or bumps into it. Due to that, a mirror is not considered.

Foil is not considered since other cookers using foil, showed how it is almost impossible to attach the foil completely smooth on the reflector which is necessary if you do not want to lose reflectivity.

Other costs will rise from hinges, screws, bolts, nails, paint and labour hours.

A hinge like a laptop hinge would be preferable because this eliminates something like a bracket to hold the reflector in the right position. Laptop hinges are friction hinges, also called friction stay hinges. Since there is no laptop manufacturer in South Africa, laptop hinges are very hard to get. Another option is hinges that are used in kitchen doors. These hinges allow you to open a door and let it stay where you left it and cost R80. The costs for screw, bolts, rivets and nails are low, a set of 10 rivets costs for example R2,00. Estimated costs for these parts per cooker are R10, estimated costs for paint are R20 a cooker.

3.4 List of requirements

Summarising the requirements as mentioned above, the following list of requirements can be made to use to test the prototype.

Requirements	**Specification**
Easily transportable	
Light	< 12 kg
Protection against theft of food or the cooker	
Right dimensions inside in cm	Between 25 x 25 x 25 and 55 x 35 x 25
Right dimensions outside in cm	Between 35 x 35 x 30 and 65 x 45 x 30
The cooker should have a good performance	A stew should take about 2 hours
Moisture resistance	
Easy to clean	
Easy to put the pots in the cooker	
Easy to get hot pots out of the cooker	
Easy to check on the food in the pot	
Easy to turn to the sun	
Easy to make ready for use	
Must not harm the user in any way	
Build of materials available and reasonable priced in Jo'burg or Gauteng	
Made with manufacturing methods available and reasonable priced in Jo'burg or Gauteng	Total including materials: < 1000 ZAR
At least one reflector should be present	
The position of this reflector should be adaptable	
It must be as cheap as possible	< 1500 ZAR
The cooker should look reliable, strong, safe and durable	
The design should match with the environment of the user	
The packaging must be of a similar style as packaging of comparable products	
Wishes	**Specification**
Weatherproof	
Must be light	< 10 kg
Made with manufacturing methods available and reasonable prices in Jo'burg or Gauteng	Total including materials: <700 ZAR
It must be as cheap as possible	< 1000 ZAR

Table 9: List of requirements

4. Redesign

This chapter will describe the decisions made on how the new cooker will be sold, what it will look like and which materials it will be made of.

4.1 Marketing

4.1.1. Sales Channels

The possible sales channels are already discussed in paragraph 3.1.3. The new design will be sold through internet, e-mail and phone in the first place.

Nedbank, a bank in South Africa, started in 2009 with environmental friendly projects. One of them was a project with parabolic cookers on trailers in Soweto that is mentioned in paragraph 3.1.2 and appendix H as well. Nedbank is planning on more of these kind of projects in 2010, some of them in cooperation with Sunfire Solutions. Sunfire Solutions is considering the use of the new box cooker in one of these projects. With such a project, the cooker will get a lot of attention.

When sales numbers increase, the cooker might be sold in shops.

4.1.2 Design and packaging

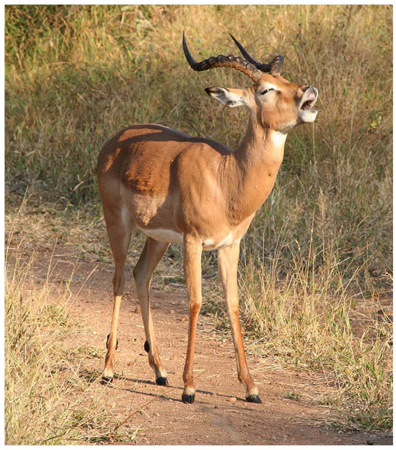
"Too often, solar cookers look as if they were assembled in a back yard by an unskilled labourer. Even poor consumers demand high-quality products and rightly so—they have to spend scarce and hard earned money on an unknown product and the purchase therefore represents some risk to them. Solar cookers need to move beyond the image of an appropriate technology product, towards a highly desirable product. Attention therefore, needs to be paid to product design, finish, packaging and marketing." [Wentzel and Pourris, 2007]

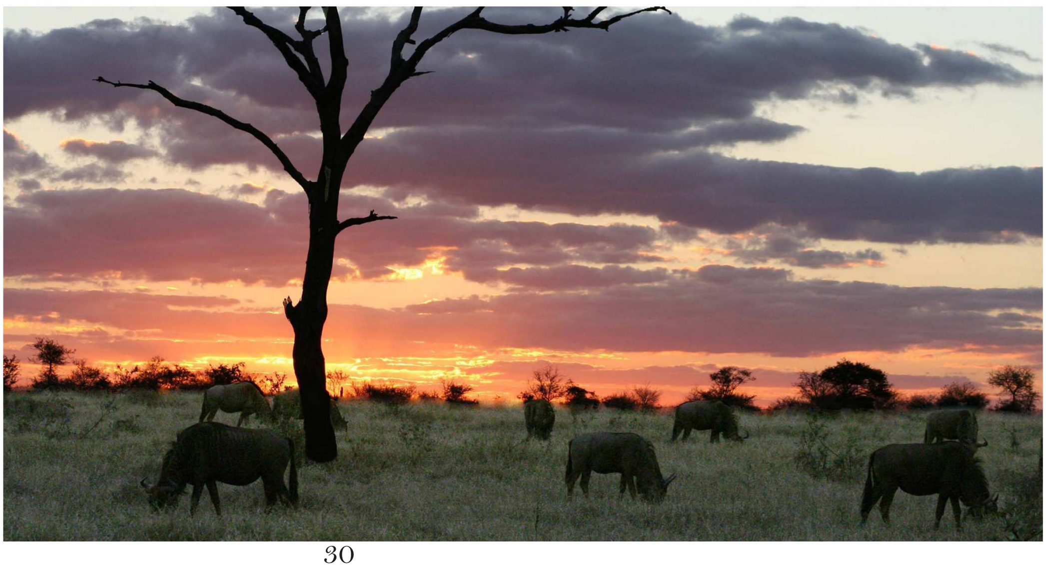
The product should show that it is reliable and that it can be trusted. This can be done by giving the cooker a strong, reliable and durable appearance and by giving it an exterior that is comparable with products in the environment of the users, so it will not look completely new and strange to them. To get a better feeling of these aspects, some collages are made. Two of them are already showed in paragraph 2.1.2 "traditional cooking devices", the others show traditional clothes, camping places, the environment and the look the new cooker should get.

figure 9: clothes collage

South Africa
Camping

South Africa
Environment





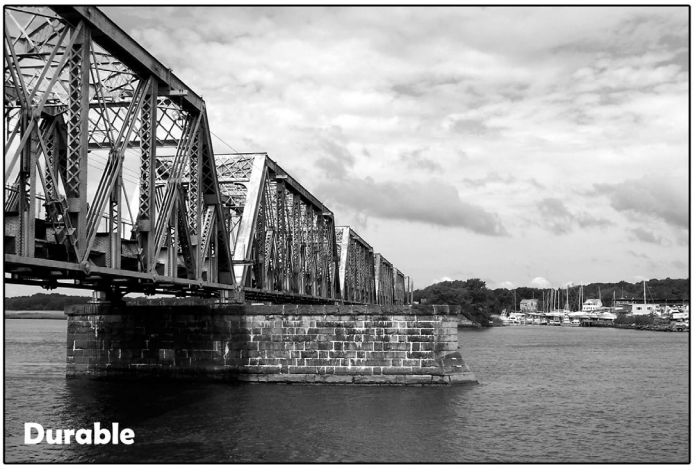


Figure 8: left top: Camping places, left down: environment, right top: goals for the look of the new cooker.

From comparable products, the collages and the circumstances where these people will use the cookers, the following conclusions should be noted during the design process:

Strong and reliable:
- words that could be linked: wide, heavy, iron, cage, clear (nothing to hide)

People with lower income:
- materials that are available in their immediate surrounding area primarily wood, corrugated iron and fabrics. This is only because they do not have anything else, not because they like it so much. So it is more important to look for materials that are durable and cheap.
- Most cooking appliances are round shaped.
- Colours are often earth coloured.

Outdoor enthusiasts:
- Materials used are aluminium, steel (sometimes with synthetic handles) or porcelain enamelled tools.
- Cooking appliances can have all kind of shapes but are always smooth, simple and without unnecessary extras.
- Colours are often 'clean' like, green, blue or 'elegant' like black or silver.

However, the main reason why products look professional and reliable, is in case the finishing of the product is well done. This means that all surfaces and edges should be smooth and without any irregularity. It means that screws or nails should be invisible or small. It means that attention must be paid to all details, how small they might seem.

Whatever the outside of the box cooker will look like, is should show that it is a box cooker and not something else. Users in evaluation projects indicated that one of the box cookers looked too much like a coffin (often just a wooden box), which is not desirable. Important is to show on the cooker itself where it comes from, who the manufacturer is and how he can be reached, so people can always come back easily when they want another stove for friends or neighbours.

4.2 Materials, processes and product design

The new box cooker should be as cheap as possible with the best performance as possible. Using less different materials and parts decreases the costs: is it possible to remove a part or combine parts? Sketches of ideas can be found in appendix G. Since this project can only take three months, no time will be spend on the idea of creating an entire new design, the basic idea of a box cookers with the five parts as discussed will be the starting point.

When looking at the functions of the different parts as described in paragraph 3.2.2, the reflector and the insulation look superfluous since the inner box collects sunrays as well and the outer box can be an insulator as well. However, only inside reflectors are not enough when cooking in an inter tropical zone (see also 3.1.1 Geographical) and at least one external reflector is necessary. For the insulation could a insulating outer case be enough, if this insulator is good enough. Care should be taken with this, because it could increase the weight dramatically: when wood is used for insulation and outer box, the walls will have to be thicker and for that, heavier. For the material selection all the five parts will be considered, depending on the chosen material for the outer box, insulation will be added or not.

Because the solar box cooker has to be as cheap as possible, without decreasing the performance, the design should not create more costs. To make sure this will not happen, the materials and the manufacturing process are chosen before the final design is made.

Outer box

For the outer box, fabric will be used with a wooden skeleton. It is the cheapest option and does still meet all the requirements and can work as already proofed with the ULOG Light. Besides that, it gives a lot of possibilities in colour and shape. Fabric will be bought from Linings and Textiles, it's called Cordura 600D and contains 2 layer: a cotton fabric layer and a PVC layer to strengthen the material and make it a bit more waterproof than with just cotton fabric. The manufacturing of the skeleton will be done by a local carpenter.

The wooden skeleton has a second function: it allows to attach the inner and the outer case easily without conducting heat (as would be the case with a metal frame) or melting (with most plastics) and hinges for the lid and the reflector can be easily screwed on top of the wood. By using fabric with a PVC layer, the wood is protected from the environment.

Using this idea, makes this cooker very similar to the ULOG light. In other words: the ULOG light is a cooker that is performing good enough to replace the Sunstove and most materials and manufacturing processes are available to produce this cooker. The main idea of this cooker will be used, but some adaptations will be made if desirable.
The shape of the outer box (figure 9) is defined by the inner box and the offset of approximately 50 mm due to the insulation (see "inner box" and "insulation" as well).

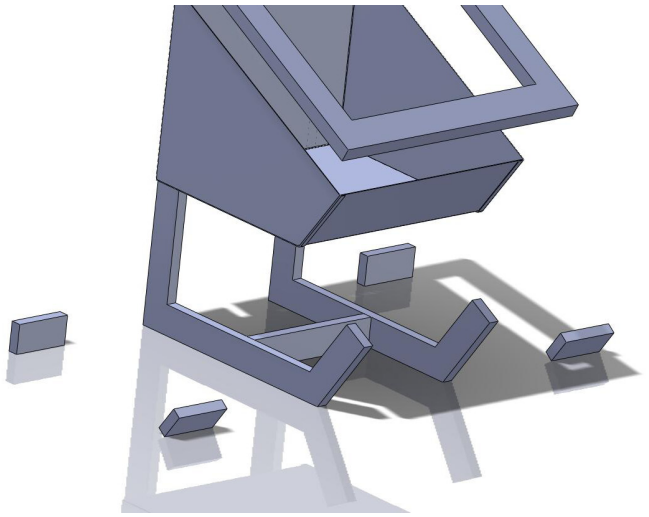


figure 9: exploded view of wooden skeleton and inner box

Design
The only thing that can still be adapted on the outer box is the use of colours, stickers and/or paint. Besides that, the contact details of Sunfire Solutions should be placed on the outer side of the box. The contact details will be painted on the back of the reflector. The fabric is available in 12 different colours, which can be found in appendix G. Red is the colour that can be associated with clothes, cooking appliances and the logo of Sunfire Solutions. It is a bright red and can be best combined with a less violent colour to create a more balanced look. A combination between red and olive green is chosen. For the prototype a blue colour is used since that was the colour that was in stock.

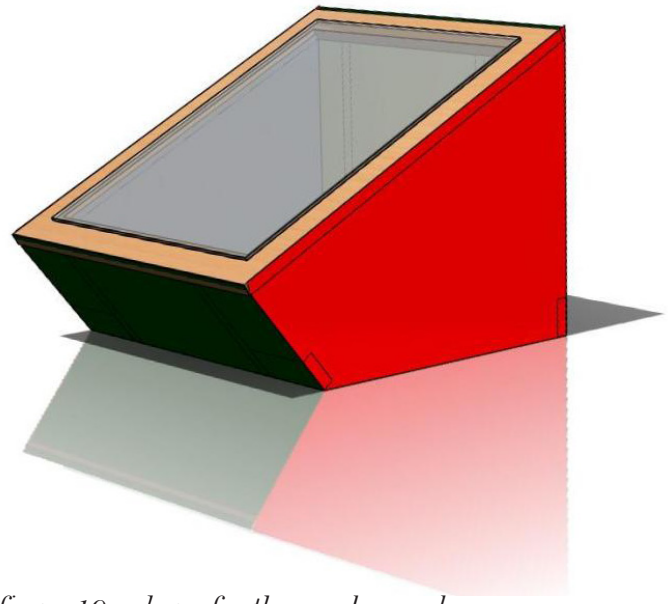


figure 10: colours for the new box cooker

Inner box

To heat the food inside the pot, as much energy as possible should get in the food. This means the pot has to be heated but not necessarily the chamber of the cooker, in other words: incoming sunrays should hit the pot immediately or be reflected to the pot. If this is not possible, the sunrays should be transformed to heat and be conducted or radiated to the pot.

The best option is a black metal bottom with reflecting walls. If sunrays fall on a reflecting bottom, the light will be reflected out the box. This could be avoided by a parabolic bottom but if you put a pot with a flat bottom on a parabolic surface, the pot will be unstable which is not desirable. The black paint will prevent reflection by absorbing the sunrays and turn it into heat. The metal bottom makes sure heat will be conducted to the rest of the bottom, including the bottom of the pot. The walls should reflect sunrays towards the pot.

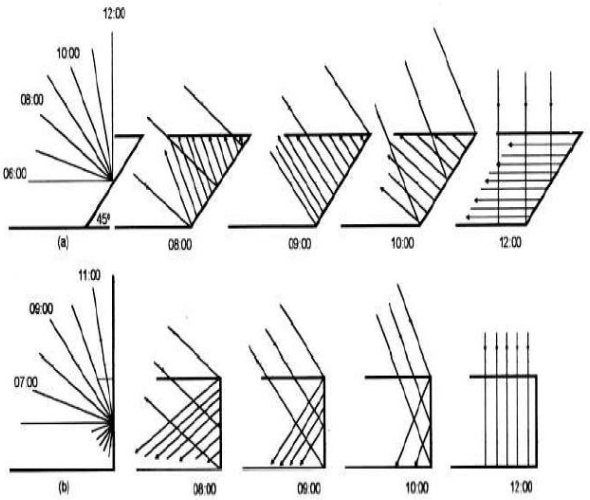


figure 11: inclined and non inclined walls with different positions facing the sun

As shown in figure 11, straight walls will be effective in the morning and afternoon, inclined walls around noon. Since the African sun is strong enough during the afternoon, the walls will be straight.

The whole inner box will be made out of one material to reduce the amount of different materials and assembling actions. Besides that, making the inner box out of one piece avoids the chances of small gaps between the bottom and walls which might cause heat loss. For the inner box a 0.9 mm thick aluminium case will be used, made by FSE lazer, the company that is already laser cutting parts for one of the parabolic cookers Sunfire Solutions sells.

The shape of the inner box depends on a couple of thinks: the front should be inclined to avoid shadows in the box when the sun is in a lower position. The bigger this angle, the less shadow will appear when the sun is in a lower position (figure 12). The glass must be as horizontal as possible to reduce glass surface, the angle between the front and the lid should not be too big and not too small either and the angle between the front and the bottom should be as big as possible. Drawings to define the most optimal angles can be found in appendix G.

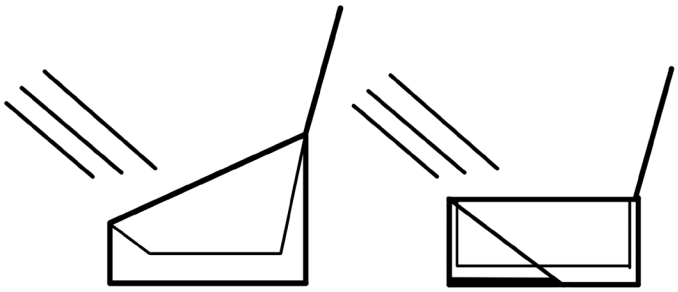


figure 12: angle of front inner box

When the inner box has a bottom of 34 cm wide and 38 cm long, the diagonal is 51 cm and allows two pots (one with a diameter of almost 20 cm and one with a diameter of almost 30 cm) in the cooker. Lips will be made on the sides so the sides can be attached to each other using small rivets (figure 13).

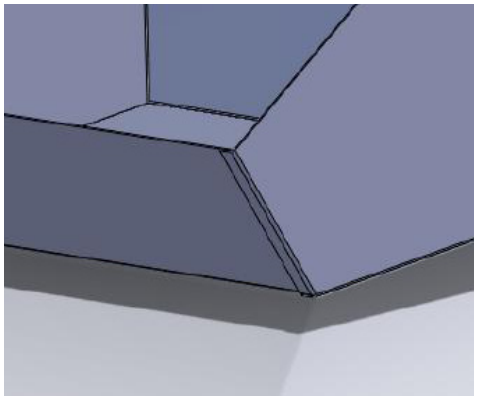


figure 13: inner box with lips

Lid

When light hits a material, the material will change the angle of the light beam. How it will change can be calculated with Snell's law:
Snell's law says: $\sin\theta 1 / \sin\theta 2 = n2/n1$ with:

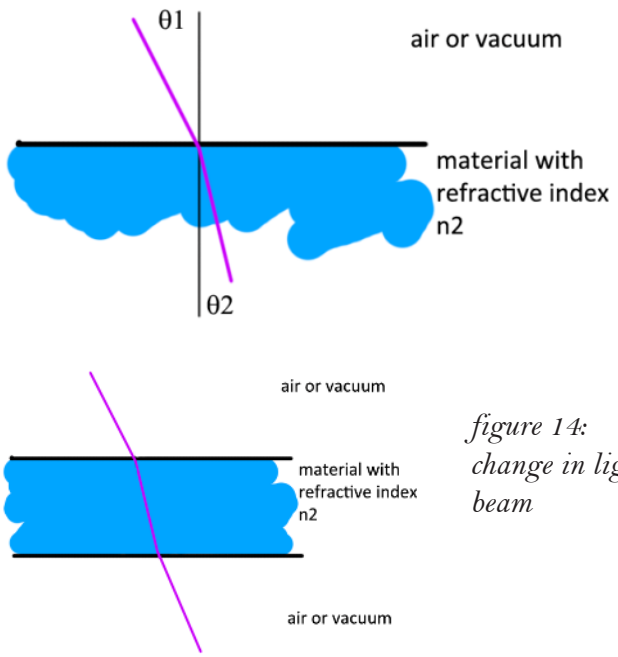


figure 14: change in light beam

Two materials that transmit light are glass and polycarbonate. If light travels from air to another material, it turns out the light beam will always bent to the normal, a bit more with polycarbonate than with glass.

When light travels from material to air, what will happen in the inner box, the opposite thing will happen. The light will bend away from the normal, but still with the same refraction index and will get the angle it had in the beginning.
The consequence for a box cooker is that the light beam coming in is replaced a little bit, but this will be not even a millimetre and for that, this phenomenon can be ignored (figure 14).

Condensation

Condensation appears when a material (in this case, water) changes from the gaseous phase into the liquid phase. Warm air can contain more water than cold air and because of that, water will condensate on a surface that is colder than its surrounding. When cooking with a box cooker, the lid, glass or plastic, will be hot on the inside and cold on the outside. Because of that, condensation might appear on the oven side of the lid and will reduce the amount of sun and heat that can come in.

Solutions:
- heat the lid until it has the same temperature as the inside of the oven
- Use double glass: the air side glass will be colder than the oven side glass: the temperature of the glass plates is more gradually spread.
- Keep a little gap between the inside of the oven and the outside, like the T16 and the SunCook do.
- Use an anti-fog spray or something similar on the oven side of the lid.

The lid will be made out of a single glass, because it is cheaper than double glass or plastic and according to the SCI, better than plastics [Aalfs, 2009]. The prototype will show if it is necessary to use double glass, although this is unlikely, since a lot of other cookers with single glass perform very well (T16, SunOven, PilKaar). The glass has a lower heat capacity and conducts better than plastics like polycarbonate, so it will get hot quicker than polycarbonate and for that, reduce condensation. On the other hand, that means that it will probably have lower insulating performances as well.

Another reason to use glass instead of polycarbonate is the fact that polycarbonate is hardly available in South Africa. As already mentioned by Margaret Bennett, manufacturer of the Sunstove (Appendix B), polycarbonate has to be shipped from the U.S.A.. Durattract, a big plastic manufacturer in Johannesburg, tried to find polycarbonate for Sunfire Solutions and came to the same conclusions: this material is only available when at least a ton is ordered. As a consequence this material is expensive and causes high start up costs.

The glass will not be placed in a window frame for two reasons. The glass will expand when the temperature rises and when a window frame is too tight, the glass will break: without a frame the glass will not brake because it is expanding. Besides that, when the user accidentally drops something on the glass and it breaks, it is easier and cheaper to replace it without a frame.

Without a frame it is not possible to use a double glass or a glass with plastic, like the ULOG Light does. When the prototype shows that it is necessary to use a double glass, a frame should be used.

Insulation

The iw 24 is a fibreglass material that is sold as a board since it is very stiff and it has a constant thickness of 50 mm. A various type is iw475, which has a higher density and for that a better insulator. Because the iw24 was not in stock, the iw475 is used for the prototype. With careful cutting, the insulation needed for one cooker can be taken from one board, which is 1,2 m by 0,604 and 50 mm thick.

Because the insulation has such a constant thickness, the outer box should have exactly the same dimensions as the inner box, with an offset of 50 mm. It is possible to give the outer box other dimensions, but this will mean that the cutting of the insulating material will become a lot more difficult, a lot more work and more expensive since it will require more material.

During the making of the prototype, the iw-insulation turned out not to be very healthy to work with. As soon as it is covered in the cooker it is no problem, but for the assembler it is an unpleasant job since very small pieces of fibre will peel into your skin and could be inhaled. For further use, a rockwool insulation might be better, even if this is slightly more expensive or gloves and a mouth cap should be provided for the assembler.

Reflector

The reflector has to be adjustable to be useful on different parts of the day, the year and the world. A couple of different positions can be chosen, like the Dierckx has, or a system that can be adjusted in every position, like the SunCook and the ULOG. The system to adjust the ULOG reflector is nice but difficult to understand and when people start to pull it, they could damage the system. The SunCook uses two adjustable plastic brackets but they are fragile and can easily break.

A less fragile or difficult system is a friction stay hinge, the kind of hinge that is used in laptop screens: the screen will stay where you left it. This hinge is found at a company called Easy Life Kitchens and the hinge has as extra feature the possibility to adjust the friction so it will be harder or easier to adjust the reflector.

The aluminium used for the inner box is reflective, but could be way better. The company Falcon offers a reflective foil called Silver Smooth that has a very good reflectivity. For the prototype, this foil with thin wood is used, which made the most sense since the skeleton is made out of wood as well. However, it turned out that the wood bends due to the heat and the surface of the wood is not smooth enough which causes a lower reflectivity. Possible solutions:

- Ask the laser cutter if they have aluminium with a better reflectivity.
- Use a ABS sheet instead of a wooden sheet. A problem could be that this sheet might twist or wiggle, see figure 15.

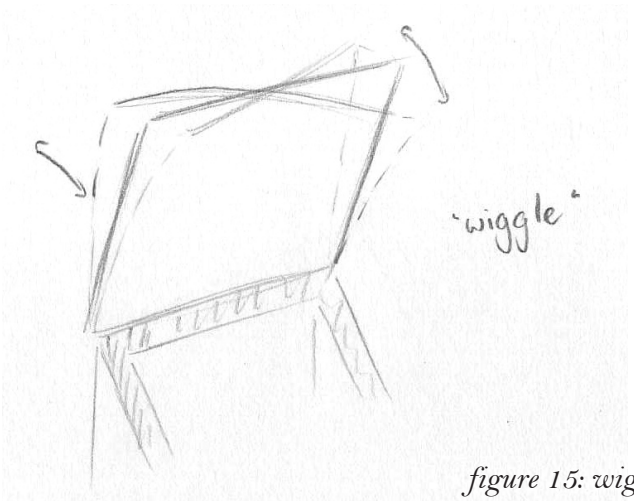
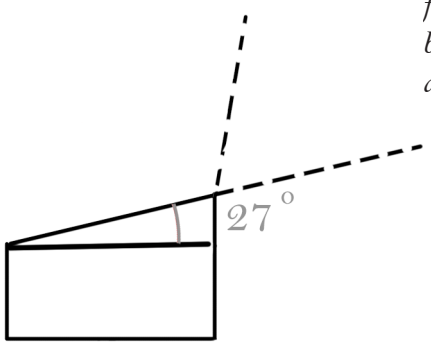


figure 15: wiggle

When the user would open the reflector to a maximum, the box should not tilt backwards as described in paragraph 3.2.1.2.

The maximum degree (figure 16) the reflector can make with the box, is defined by the friction stay hinge that is used to attach the reflector on the box. This maximum is 180 degrees. When the hinge is 'closed' the reflector is lying on the box which has an angle of 27 degrees with the horizon. This means that when the reflector is opened to a maximum, it will have an inclination of 27 degrees with the horizon (figure 16).

figure 16: degree between reflector and box



Since the reflector is 571 mm long and a square, the centre of gravity is in the middle of the reflector: 286 mm from the origin. The centre of gravity for the box is roughly at point x (figure 17) and has a distance from the origin of 170 mm. The weight of the box without the reflector can be calculated with the values of paragraph 5.3.

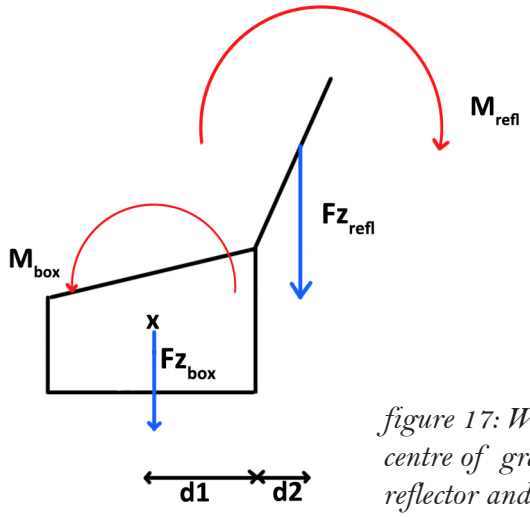


figure 17: Weight and centre of gravity of reflector and box.

Weight of the box without the reflector:
2,5 + 0,45 + 1,2 + 0,95 + 0,5 = 5,60 kg.

The moment of the reflector should be smaller or similar to the moment of the box in order not to make the box tilt backwards. The equation will be:

weight box * d1 = weight$_{max}$ reflector * d2
170*5,6 = weight$_{max}$ reflector * 286
952 = weight$_{max}$ reflector * 286
weight$_{max}$ reflector = 3,3 kg.

The final materials of the reflector are not chosen yet, but non of the options is heavier than 3,3 kg so the box will not tilt backwards.

Elaboration

As mentioned before, the elaboration of a product is very important for a professional look. A couple of different solutions are found to give the product a better look:

- On the place where the inner box and the fabric are attached on the wooden frame, a rubber strip will hide the wooden frame and the edges of the fabric and aluminium. The second aim of this piece of rubber is to seal the glass (figure 18).

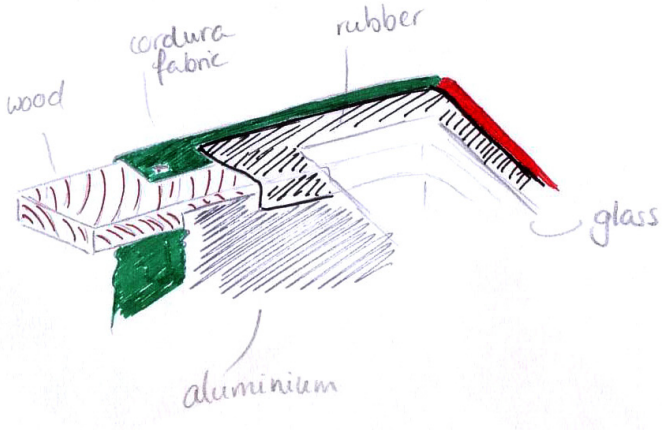


figure 18: rubber will cover the top of box

- The reflector uses a friction stay hinge. A lot of currently available cookers like the Dierckx and the Lazola use a screw on the outside of the box and a piece of wood with holes in it, to adjust the reflector. The new adjusting system is only one metal piece on the reflector and allows the user to open or adjust the reflector with one hand.
- The use of fabric on the outside, covers the screws and nails needed for the wooden skeleton, the outside will only be a coloured piece of fabric.

5. Evaluation prototype

With the materials and processes as described in chapter 4, a prototype is made:

figure 19: the prototype

In the last week of this project, the weather was so bad, the prototype could not be tested until the last afternoon when it was still pretty cloudy. Due to that, the cooker is not tested very thorough yet, but Sunfire Solutions is planning on doing this as soon as possible. Since South Africa has a couple of weeks of holiday in December and January, these tests can hopefully be done in January.

However, the prototype can still be evaluated with other information that is already available.

5.1 Price

The new cooker should replace the Sunstove and the most important factors for replacing are the price and the performance. As discussed in paragraph 2.1.3, the price for manufacturing should be between R800 and R1000.

Part list

Wooden skeleton	R100
screws, glue, nails, rivets	R10
Fabric	R15
rubber	R30
Aluminium inner box	R250
glass	R70
4 hinges	R12
handles	R20
friction stay hinge	R80
insulation	R75
2 stoppers for reflector	R3
reflector (foil + ABS)	R54

Total, excl. labour for assembling: R719

It can be concluded that the requirement for price is satisfied.

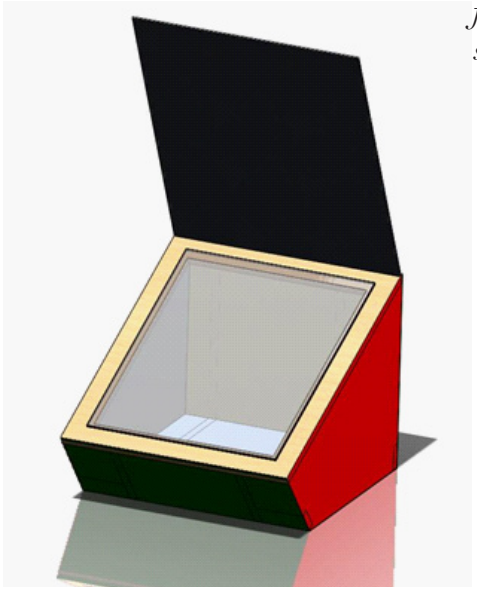


figure 20: assembled cooker

5.2 Performance

As already said, due to the bad weather, the cooker could only be tested once with a partially clouded sky. In this time, the ice cube test as described in paragraph 3.2.3 and appendix F was done. Unfortunately, after a couple of minutes, really thick clouds came over and slowed the process seriously down so it cannot seriously be compared with values found in earlier tests. However, later in the afternoon the sun came out again and the melted ice cubes caused a serious amount of steam which was realised while opening the box. This indicates that the box reached a temperature of 100°C or more, which is already more than the Sunstove.

While testing the performance, one other problem appeared: The wooden reflector started to bend due to the heat. The edges bent backwards so the light diverges. Before more tests can be done, the reflector should be replaced for something that will not bend. A proposal for other tests and materials for the reflector is sent to Sunfire Solutions and will be realised in January.

5.3 Miscellaneous

This paragraph will describe how other criteria are satisfied.

The weight of the cooker is approximately 7 kg, which makes it easy transportable:

Frame:	2,5 kg (source: Solidworks)
Fabric:	450 gram (SW and T&L)
inner box:	1,2 kg (SW)
glass:	950 gram (SW)
insulation:	0,5 kg
reflector:	900 gram (CES)

The elements that should be tested to find out if the cooker does meet all the requirements are: the performance, the reliable, strong, safe and durable look and if the design does match with the environment of the user. Sunfire Solutions expects that these criteria are fulfilled but this will turn out in the following months. Another indication that this cooker does have the right look comes from the interview with Marlett Balmer (appendix B) where she mentions that the ULOG Light, on which this product is based, always had very good reviews in solar cooking projects.

Problems that were discovered during building and using the cooker:

- The company Instant Glass in Troyeville had some troubles with drilling holes in the glass for the hinges. Every hole will cost R10 extra, and if the glass brakes during drilling, the costs are for the customer. However, other companies who were contacted in an earlier stage, told us they can deliver the glass including hinges. Because of that, it is worth to select another company.
- No handles to lift the glass or the box itself were used in the prototype. In case of the glass because it was not possible to drill holes in the glass, in case of the box because the outer skeleton did not have enough place to screw the hinges on (figure xx).
- The surface of the reflector was not very good in combination with the reflective foil. The foil started to bubble due to the surface of the wood that was not a 100% smooth.
- The cooker has to be aligned with the sun more often than a cooker with inclined walls. When the cooker is not perfect aligned, the walls will cause a shadow in the box.
- The hinges on the glass need a piece of material between the cooker and the hinge, so the cooker side of the hinge has the same height as the glass side of the hinge (see figure 22).
- The man who was supposed to make the skeleton and assemble the cooker, told that he does not want to make more box cookers. Another carpenter and assembler should be found.
- The friction stay hinge is not aligned. If one part of the hinge is attached to the side of the cooker, part two will end up next to the reflector instead of on the reflector. To solve this, the reflector should be a bit wider.
- The glass supplied by Instant Glass has still very sharp edges where somebody could cut his or her hand on.

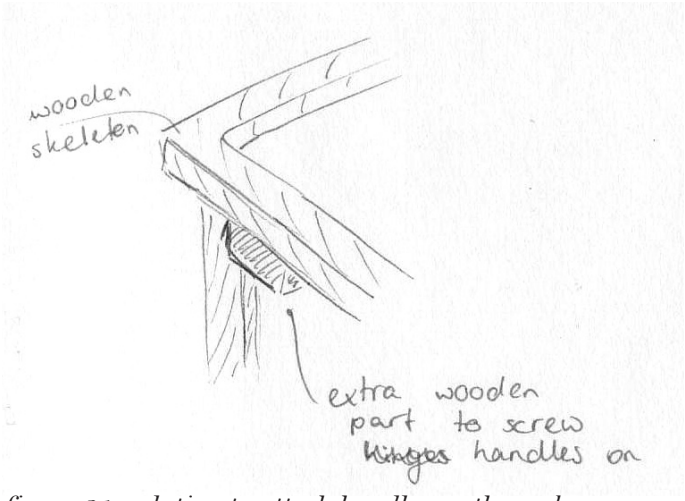


figure 21: solution to attach handles on the cooker

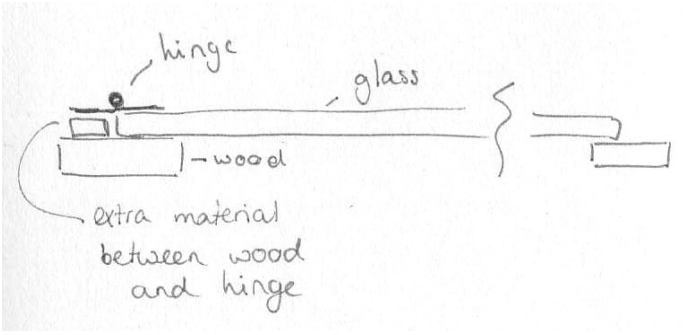


figure 22: extra material to attach hinge the right way

However, some positive things about the prototype should be mentioned as well:

- The chosen insulating material is quite strong and gives the outside of the cooker a very strong and reliable feeling.
- The combination of 16 mm plywood, iw24 fibreglass and fabric makes a very strong box.
- The chosen fabric is strong.
- The rivets that are used to fasten the inner box have a decent look and make it look professional.
- Everything fits well into each other.

- The cooker does not show any condensation until the sun goes down and the glass cools down while the air in the box is still hot.
- When opening the box, a fair amount of steam is coming out which indicates a temperature above 100°C.

The SunSoul

This cooker will get the name SunSoul. A lot of products from Sunfire Solutions start with the part 'sun' to indicate that this cooker is a part of Sunfire Solutions. The part 'soul' has two meanings:
1. The feeling, thought, the spiritual part of something.
2. Sun Oven Ulog Light, which is the name of the cooker that has been used as an example for this cooker.

Only disadvantage of this name is the fact that the name itself does not tell you that it is a box cooker. When Sunfire Solutions finds a better name for this cooker, it might change.

Recommendations

The new cooker will be introduced in South Africa in the first place. When the cooker is satisfying it can be an option to start manufacturing in other capitals/big cities in Southern Africa. However, the design is optimised for South Africa and it might be possible that the price and sales channels used in South Africa are not suitable for Southern Africa. It is recommended to do more research on sales channels and price in other parts of Southern Africa before start manufacturing in these areas.

Due to the time limit, the decision is made to use the current design of box cookers with five parts (outer box, inner box, insulation, lid and reflector) as a starting point. However it is never said that an entire different design could perform better, but that should be examined by another research.

It is possible to calculate how thick an insulating layer should be to insulate a box cooker well. When this is known, it might be possible to make a box cooker without insulation because the outer box is the insulation as well. Despite several tries, I did not succeed in calculating this by hand or with use of Solidworks.

The prototype should be tested more thorough before making other models of it. Especially the performance needs more tests.

The reflector as made in the prototype is not good enough. Another reflector should be found. This reflector has to be made out of an aluminium sheet with a better reflectivity or a plastic sheet with foil that will not bend when heated. This new reflector should be a little bit wider as well to attach the friction stay hinge on it.

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