Solar Kitchen Project

solar is nature's gift

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The report has been written for supervisors and examiner

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Summary

This report is about the research for a final bachelor assignment for Industrial Design and Engineering. It is about the research whether it is possible to design a stove which can bake Ethiopian pancakes (injera) on solar energy.

People eat a lot of injera a day in Ethiopia, this pancake-like bread is eaten with a variety of stews. One bakes it on a clay plate which is heated with wood. The consummation of wood is a big problem in Ethiopia, not only because of the deforestation, but also because of the many consequences it has. Women are responsible to prepare dinner and therefore responsible to find ways of preparing dinner, this includes finding or buying fuel wood. In general, women spend many hours a day searching for wood. See III.2 for more about the problem cause by the usage of wood.

A journey to Ethiopia was made to do research about the problem and to be able to make a list of demand which the injera baking plate has to meet. In Part A is written about the difficult history Ethiopia has and how it has effected the target group. The target group consist of women living in the rural area. These women usually do not have sufficient income, raise the children and take care of the household. To prevent the usages of wood a solar energy based baking plate will be designed, which will work on a village scale.

Part B describes the different solutions which can contribute in the design. Many ideas were inspirited with the information gained at the International Conference in Granada. These options are discussed and judged with regards to the list of demands.

The result of Part B is used in Part C to design a total system which is able to bake injera. One of the important aspects of the designed system is the usage of oil. This fluid is able to transport heat at a high temperature (260° C). A vegetable oil is found, which is produced in Ethiopia already.

After general calculations, a design is made which meets the demands. The calculations proof the possibility of baking injera on solar energy.

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I. Foreword

After almost four months has my final bachelor assignment come to an end. After a short month of preparations was I able to start with this project. And now, three months later and a lot of hard work, can I present this report as the result of my design/research process.
The assignment is about the use of solar energy is Ethiopia. The rural people do not have a lot of money to spend and I believe that this project can contribute in improving their life's. Via SUPO, a Dutch association, I learned about the problems in the Horn of Africa. Once I saw the problems with my own eyes, it motivated me more then ever before to make this project become a success. Hopefully it will show in this report, it has been a great experience!

Before you start to read this report I would like to take the time to thank some people who helped me a lot during the last few months:

- My mother! Thanks a lot!
- Hans Schipper
- Coen Beeker
- Wieteke Kogel
- Gullilat Abera!
- Ton Putt
- Jim Kok
- Tim Veldman
- And many others...

With kind regards,

Rogier G. Kauw-A-Tjoe

II. Definitions

Birr: local currency of Ethiopia. At the moment of writing (July 2006) the exchange currency is 1 euro = 10,9 birr. For easy understanding, divide the amount of birr by 10 to get an estimation of the amount in euros.

Indoor pollution: smoke, ashes and dust caused by usage of a woodstove inside the house. With the lack of wood, plastic is sometimes used for heating. The chemicals which emerge are harmful!

Rift Valley: area in Ethiopia where all the big lakes are, this area is located in the south east of Ethiopia and borders to Kenya. This area is known for its wild life and tribes which still live there.

DDA: Donkey for Development Association, see *Annex C: Contacts, C1*.

Solar Kitchen: a bakery specialized for injera (see Chapter A.4) based on solar energy. The Solar Kitchen is a village scale bakery. A few women will bake injera in the Solar Kitchen for the whole village.

Direct cooker: a cooker based on solar energy in which the sun-beams directly heat a cooking pot.

Indirect cooker: a cooker based on solar energy in which the sun-beams are not pointed at the pot directly. The heat is stored first, before it is used for cooking.

III. Assignment

III.1 SUPO

The Association for Urban Projects in Development countries (in Dutch Stichting voor Urbane Projecten in Ontwikkelingslanden, SUPO) was founded in The Netherlands in 1977. It concerns a small association which supports several local partners in Africa. Since 2000 it has especially been engaged in contributing in the foundation of a centre for underprivileged children, as well as enhancing the usage of solar energy for preparing dinner in urban and rural areas. SUPO wants to expand these activities in Burkina Faso in the period 2006 – 2008 and also start a new program in Ethiopia. This assignment focuses especially on the preparation of the new program in Ethiopia.

III.2 Motive

In the rural areas wood is used as an energy resource for heating, light, income generation, construction and for cooking[C8]. However, the biggest part is used for cooking. Whenever a tree is cut down, no new tree is planted to replace the old tree.
But there are also other reasons why a lot of wood is used. First of all there is tradition: a lot wood is used traditionally in the Ethiopian culture. The Coffee ritual[C8] takes a lot of time, because the coffee is made on charcoal. When this charcoal is replaced by an electric cooker, the coffee will be done faster, with the consequence that the ritual will be shorter. Therefore charcoal will be used. Secondly, there is income generation[C8], one example of this is the production of an alcoholic drink in the Rift Valley. This is made out of water and grains and is comparable to vodka. The alcohol percentage is about 85%. When it is made, a lot of wood is used. In the process the drink will be distilled at a temperature higher than 100° C; this process lasts 12 hours. The heat is generated with wood which is cut down around the villages, they do not buy it. The alcoholic drink is called Arake.

If all usage is counted, research[L1] says that 90% of the energy used in Ethiopia comes from fuel wood. Figures from the 'Integrated forest policy development in Ethiopia'[L1] give a shocking image of the wood problem in Ethiopia. The demand for wood, in 2004, was 50 million m^3, when the production was only 20 million m^3. The predictions are that the demand will only grow while the production will decrease.
The amount of people, and its growth, will cause a bigger (wood) problem. In 2004 there were 67 million people living in Ethiopia. Predictions for 2025 are 110 million people. However, even though the predicted growth is 2.7% a year, the population is already 77,4 million (2006)[C3]. This will cause the demand for fuel to be even greater than expected.

The consequence of the current shortage of wood is that less than 3% of the country is covered with trees. In the 1950s this was 40%. (deforestation)
However, there are more consequences of the large usage of wood:

- Because of the extensive search for fuel, no rural woman can participate in society[C1]. None of them are able to have a social life. They can not have gatherings or meetings because of this.

- Because women (of any age) are responsible for making dinner, they are also responsible for finding ways of making dinner. The men do not care about this process and do not help, because the women should arrange it. If women are not able to make dinner they will be banned from their village or imprisoned in a hut in their own village. If they are banned, it is likely they will end up in prostitution. Because of this there is no emancipation and women can not be educated.
- In 2004 60% of the soil of Ethiopia was already affected by erosion[L1], 10% of the soil is affected in a way that it can't be used for agriculture anymore.
- Cow dung is used for fuel or is sold to others, in this case it will not return to the natural circle of life. The nutrients of the cow dung will not return to the country, so the minerals will not be in the soil any more. This development will contribute to a further decreasing quality of the soil[C3]. In Addis Ababa this cow dung is mainly used for baking bread.
  Because of the lack of nutrients in the soil, an estimated 1 – 1,5 million less metric ton grain is produced a year[L1], in spite of all the measures that have been taken.
- Because of the indoor pollution a lot of people have problems with their eyes and lungs[C1]. The indoor pollution is also caused by the burning of plastic. This is sometimes done when no other fuel materials can be found.
- Rift Valley Children and Women Development Association[C8] helps in their food security program to irrigate the land with water from the Ziway Lake. But one problem appeared: the lake became smaller. After research it appeared that deforestation was the cause. The water disappears in the ground, and is not held by the soil which brings it back to the lake.

In Ethiopia a great portion of the country gets 5,7 kW per m^2 sunshine a day. That means that the total solar energy which is in the county is[C5]:

$$1{,}1 \text{ million } km^2 \times 1000 \times 5{,}7 \text{ kW} = 6{,}27 \text{ billion kW a day!}$$

Why is this present energy not used instead of the energy source which is not present?

III.3 Objective

A great part of Ethiopia has little, but there is one thing they have plenty: sunlight. Would it not be better if this part of the population in Ethiopia would not have to spend hours a day to find wood? Would the population of the cities not be better off if they could spend less money on buying wood or charcoal? Of course the answer is YES! One way to achieve this is to lower the usage of wood. Here the usage of solar energy comes on: in what way can solar energy be used effectively?
The assignment is as follows: design a "solar kitchen". In a solar kitchen a few women out of a village will be baking injera (see chapter A.4) These will be made available, probably in exchange for money, to the rest of the population of the village.
The goal is to produce the solar kitchen in Ethiopia, that is why only materials available in the Ethiopia can be used. The costs, on a village scale, have to be low!

The objective of this research is to design a Solar Kitchen, with which "injera" can be baked, by analyzing which demands it has to meet and which functions it will have, of which a prototype will be made. After testing, correct blueprints will be the end result.

III.4 Organization & Strategy

The assignment was mainly carried out in The Netherlands at the University of Twente in Enschede. It was supported by Coen Beeker, of SUPO, and Wieteke Kogel, of the University of Twente. Technical support was given by Ton Put of WOT, Working group for Techniques in Development countries.
The assignment was carried out in three months, the first part was done in Ethiopia. To be able to analyse the target group and the problem, a journey to Ethiopia was made. The journey is discussed in Part A. The second part was done in Granada, where a international congress on Solar Cookers was visited. The concept phase was done here, this part is discussed in part B. Finally, the detailed design was done in Enschede, this part is discussed in part C.
All information in part A is retrieved via interviews in Ethiopia. This choice has been made because literature is difficult to get by. Because of this the conclusions of part A are fully based on the interviews.

Ethiopia
Part A

In the first part of this report the research phase will be discussed. The journey to Ethiopia is the main subject of this part. In the weeks of June 17th until July 1st Addis Ababa, the capital of Ethiopia, was visited. The information will be discussed in concordance with the research proposal. (in Dutch, see Annex A)

Chapter A.1: Ethiopia and its history

Ethiopia[L3] is one of the most historic countries of Africa, probably one of the most historic countries in the world. Because it has never really been colonized, most of the historic jewels have stayed intact and in the country. The National Language of Ethiopia is Amharic, which has existed for more than 2000 years. The area of the land is 1,1 million km^2.
Ethiopia has a mild climate with average temperatures of 22° C, even though it is just above the equator. Because most of Ethiopia is elevated to an average height of 2000m, the climate is comfortable. Ethiopia has a high number of hours of sunshine a day, see chapter C.2.1.2 for more information on this.

Addis Ababa is the capital of Ethiopia, which is located in the middle of the country. Addis Ababa means 'new flower' and was founded in 1886, by the wife of emperor Menelik II, Taitu. It has evolved into a vibrating capital since then with an estimated 3 – 5 million inhabitants. Addis Ababa has become the center of Africa: since 1958 it has been the headquarters of the United Nations Economic Commission for Africa (ECA) and, since 1963, the headquarters of the African Union (AU).

Illustration A.1.1: Map of Ethiopia

At this moment the government is headed by Prime Minister Meles Zenawi of the Ethiopian People's Revolutionary Democratic Front (EPRDF). He has been PM since 1995 when the Federal Democratic Republic of Ethiopia was proclaimed. But he lead an interim government from 1991 after the liberation of the Derg regime. In 2005 the party of Meles Zenawi lost the free democratic elections in Ethiopia, however, they will not leave office. Ethiopia is not unfamiliar with these political instabilities.

On 2 November 1930 Ras Tafari was crowned as the last emperor, Haile Selassie. During his regency there were several governments and / or occupying forces. In 1933 the Italians occupied Ethiopia, not because they wanted something that

Ethiopia had (raw materials or possessions etc), but because of the strategic location between Italy's two colonies (Eritrea and Somalia). During this war (colonization process) the Italians made Ethiopians inferior citizens. A lot of innocent citizens were also killed. After having been part of the Italian empire for a few years, Ethiopia was declared independent in 1941, after an intensive war.

After these years Ethiopia was rebuilt with the assistance of the USA. At the same time Emperor Haile Selassie became more and more an autocratic ruler. People demonstrated against the great corruption, among other things, and the famine of 1972 – 1974. This escalated in 1974 when a radical and powerful military group, called the Derg, took over the country. After the emperor and his men were dethroned, the Derg formed the first democratic government of Ethiopia. In 1974 a socialist state was declared and carried out a series of revolutionary reforms. Meanwhile Somalia invaded Ethiopia. In 1984 – 1985 another famine followed a drought. The government plans to reform the country all fail, and another group started to form a rebel group. They tried to knock down the socialistic regime, this group was the Ethiopian People's Revolutionary Democratic Front (EPRDF).

Illustration A.1.2: Flag of Ethiopia with EPRDF emblem

Prime Minister Meles Zenawi put his country through a war (1998 – 2000) with Eritrea, which has officially not ended yet. However, a demilitarized strip of 25 km deep was formed under UN supervision.
After all the suffering (drought, famine, wars, regimes who neglected them, etc.) the peasants do not have much left. The rich get richer and the poor get poorer. Unfortunately, the current government does not have sufficient plans to improve this situation, they only have plans to improve their own lives.

Chapter A.2: Program

To be able to answer the research questions, described in the Research proposal (in Dutch, see Annex A), a journey to Ethiopia was made. This choice was made because very little literature is available. Some research questions are: in which context will it be working? What is done with solar energy in Ethiopia at this moment? And which demands does the design have to meet?
To get a general idea of the visit to Ethiopia and the sources which have been used, this chapter gives a short overview of the two weeks in Ethiopia and which people were met.

June 17th: Arrival in Addis Ababa, Ethiopia
June 19th: Meeting Gullilat Abera, DDA, Addis Ababa
June 20th: Meeting Tim Veldman, ESPBC, Debre Zeit
June 21th: Calling for making appointments (embassy & UNDP)
June 22th: Meeting Gullilat Abera, DDA, Addis Ababa
June 23th - June 25th: Visit and journey to National Park Nechisar, Arba Minch (South of Ethiopia, Journey trough Rift Valley)
June 26th: Rest day + Calling for making appointment (embassy)
June 27th: Visit and journey to Gende Gorba
June 28th: A day in Addis Ababa + Meeting with Janny Poley of Royal Dutch Embassy, Addis Ababa
June 29th: Meeting Gullilat Abera, DDA, Addis Ababa + Meeting Rift Valley Association, Addis Ababa + Meeting Adama City Manager
June 30th: Visit to Addis Ababa Museum, Addis Ababa
July 1st: Visit to Ethnological Museum, Addis Ababa + Meeting Gullilat Abera, DDA, Addis Ababa + Departure Addis Ababa, Ethiopia

All these people have been interviewed and the conclusions can be read in part A.

Chapter A.3: Target group

The target group[C1,C3,C7] lives in the Urban and the Rural Areas. The target group defines itself with the fact that they can not afford to buy fuel. This fuel is mainly wood, but also gasoline, electricity and kerosene. In the Urban areas the target group can not afford to buy wood: because of a shortage of wood the price increases. The rural people have not been able to afford it for a long time and have started searching for anything that can be burned. This takes a large amount of time (3 – 6 hours a day).

Illustration A.3.1: Target group

A.3.1 Rural people

Around 80% of the Ethiopian population lives in the rural areas [L1]. The target group consists of the farmers' wives. Some women do not have a husband. All women are head of the household. Their income is not sufficient to be able to buy fuel. The food often comes from their land itself. They grow their own vegetables and grain. Therefore, the main activity of the day is finding fuel to be able to cook. Besides this, they work on the land and raise the children. Women also work on the land, in some regions the women do all the work on the land and the men do nothing.
The children in the rural areas are mainly young, under the age of 12. After this age the children will start working in the cities. They start their days next to the highway hoping that someone will pick them up and give them jobs. The young children have several tasks: watching the herd, raising their younger siblings, some small tasks at home; being a messenger for instance and at a later age taking care of parents and grandparent at old age.
In the rural area people have a lot of children because of several reasons: there is no recreation, there is no family planning, no birth control and the man is dominant. A woman can not say no, because she can not object against the will of her husband.
Besides the husband being dominant, the women also depend on their husband. This is because most women are illiterate, they have had to search for fuel and arrange the household from an early age. Therefore, they have never had the chance to get an education. They cannot read or write and therefore do not know what is happening around them in the world. However, men mostly do not know

this either, because they are uninterested. Women are completely dependent on their husband, they do not have any awareness. Different associations have tried to change this; however, at this moment most of the women are still illiterate.
It is difficult to say something about the income of the target group, because most of them do not have an income. And if they do, it varies a lot, depending on the season and whether they can even get a job or not in a certain month. The DDA beneficiaries get their income in cash or in kind. For example: they work in someone's household and they get some grain. Usually women in the rural area do not work. In general there is no work in the rural areas, men will go to the cities to work or they are hired to work on someone else's land. In the last case they get about 100 to 200 birr a year.
Most rural villages have a population between a couple of hundred to a couple of thousand. The village of the current DDA project, Gende Gorba, has 1975 inhabitants.

A.3.2 Location

The idea of this project is to make a Solar Kitchen on village scale. However, this will cause several problems:

- The organization will be difficult. Who is going to work in the Kitchen? Who will pay them? Who is allowed to buy from the women in the kitchen? Will they still work when others quit? A lot of questions that are raised[C1] with this project proposal.
- Women will still have to walk to the village to buy injera: the people in the rural area are widely spread in general.

It would be better to have a Solar Kitchen in each house in a village. This way, the cooker will totally replace the current stoves. Otherwise people will still use their own stoves to boil water and make injera when they do not want to buy their injera.

Illustration A.3.2: Location for Solar Kitchen

However, a big problem with this option is that people can not afford an individual solar cooker unless the costs are under 10 euros. SUPO does not want to support the people with funds, so the price cannot be lowered this way. To make a first step in the development of solar cookers, a solar kitchen on village scale should be made. The costs can be higher because more people can contribute a small amount of money. By just baking injera (see Chapter A.4) a large part of the wood consummation can be cut, the solar kitchen contributes in solving the problem in this way.

The Solar Kitchen can be tested on the premises of the Peasant Association[C2]. When it is tested at this location, it will be tested at the same location where it will be working eventually. At the same time, it will be a demonstration for the women who will be using it. And therefore a good way to promote the Solar Kitchen.

Chapter A.4: Injera

This project will be about baking injera on solar energy to contribute to solving the problem which is caused by the shortage of wood. Injera is eaten almost every meal and consequently causes the largest part of the wood consumption. But what is injera? How is it made? To be able to make an injera bakery, one must understand what injera is and how it is made. In this chapter that information can be read.

A.4.1 What is injera?

Injera is a kind of thin pancake. At one side it is flat and the other side of the injera has a bubbly structure. Injera is light sour of taste. It can be eaten cold as well as warm. Usually Injera is eaten with a large amount of different stews.

Illustration A.4.1a: Injera with a stew, A.4.1b: Injera with another stew

Injera[L2] or Enjera (incorrectly Injura) is made out of teff flour, which means 'lost'. Teff is a tiny and round grain that flourishes in the highlands of Ethiopia. While teff is very nutritious, it contains practically no gluten.

It is traditionally eaten in Ethiopia, Somalia (where it is also called lahoh or injero) and Eritrea. The flour is mixed with water and allowed to ferment for a few days. It is then ready to bake into large thin pancakes, done either on a electric stove or fire based stove.
Injera is put on a plate as an extra plate for the stews (these stews are called Watt). The stews are placed on the injera. Sometimes the stews are mixed with pieces of injera. Before serving, the injera is closed, to keep the stew warm.

One of the stews which can be eaten with injera consists of pieces of injera, tomato sauce (cooked tomatoes), onion, carrots, salt and lots of pepper (chilli pepper). Sometimes there are pieces of meat in it as well: goat, sheep or ox meat are common. Using the right hand, small pieces of injera are torn and used to eat the stews.

Illustation A.4.2: Fermentation of Teff

A.4.2 How is injera made?

At this moment there are three different methods to make injera. These methods differ in energy source and baking method. The methods are traditional (with wood), electric and renewable methods. With all the methods one thing is equal, the baking temperature: to be able to bake injera in the right way, the baking plate should be 220° C[c9].

Traditional
Traditionally injera is baked on a clay platter, under this platter there is a fire. The clay becomes equally hot in a few minutes. The 'mutard', batter, is made out of teff. When the platter is hot enough, the mutard is poured over it. A cover is put over the batter and the injera is baked. The women know exactly when the injera is done, it is only then that the cover is lifted. They know this because they are thought to bake injera from an early age. The baking time is about 3 minutes. When the cover is lifted, the injera is done. Usually they put the injera in a basket and more injera are baked.

Advantages:
- Bakes in the traditional way
- Cheap option, it is just made out of clay and rocks.

Disadvantages:
- It uses a lot of wood
- It produces a lot of smoke

Illustration A.4.3: Traditional injera stove   Illustration A.4.4: Injera basket

To save wood a wood saving stove has been made. This stove covers the sides, so that the heat will not escape. With the same wood the stove can stay hot for a longer amount of time. Also, because of the use of a chimney the same heat can be used again. This heat is mainly used for boiling water. The advantage of this is that it uses less wood. However, it still uses wood and produces smoke.

Illustration A.4.5: Wood saving stove

Electric

In urban areas people do not use wood, but electricity. The injera is also baked on clay with a cover, but no wood is used. An electric wire runs through the clay. Because of the electric resistance heat is generated. This spirally shaped wire will also heat the clay equally. The baking method is the same as the traditional method. The surface of both an electrical and traditional platter is slightly rounded.

Illustration A.4.6: Electric injera stove

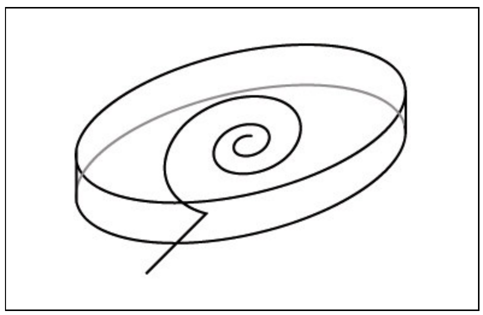

Illustration A.4.7: Wire in clay plate

Advantages:
- It does not use wood
- It can bake in the traditional way
- It does not produce any smoke

Disadvantages:
- It uses electricity which is also very expensive and a lot of rural people do not have access to the electricity network.
- Buying one of these is too expensive for rural people

Renewable methods
To be able to make injera faster new methods are designed. Gezahagn[C9] is designing two new methods. The first is an automatic injera baker. The batter is sprayed on a aluminium role, which is exactly 217° C. During the baking process the injera roles to another role. Eventually this machine makes a entire role of injera. This method does not use a cover. Unfortunately, pictures could not be made because of a patent application.
The second method uses two baking plates, both made out of clay. During the baking of one injera, the plate is turned around and another injera is made on the other side. The injera sticks to the surface because of the heat. Just before it is

done, the plate is turned around again and the injera comes loose. This method uses a cover.
Research of Gezahagn[C9] proved that it is possible to make injera on Aluminium and Cast Iron. The temperature should be around 220° (217° for aluminium as mentioned before).

Advantages:
- It does not produce any smoke
- It does not use any wood
- It can make a lot of injera automatically

Disadvantages:
- Because of the electronic system, the automatic cooker is extremely expensive for rural people.
- It uses electricity, it causes the same problems as described above.
- It does not use the traditional way of baking: a lot of training is necessary.

Chapter A.5: Injera stove and solar stove development

This chapter will discuss the development of injera stoves (using wood) and solar injera stoves. Before designing a new solar stove, it is good to know which developments there are on this level. This chapter will also discuss the solar stoves already implemented.

A.5.1 Development injera stove

Ethiopian people depend on their equipment to be able to cook. They must be sure that a new device will make the injera in the same way, so that it will taste the same. This is important because food is all they have. Moreover, Ethiopians want their food to be perfect (the taste should not differ, as should the shape and the proportions) otherwise they will not eat it.
Because of the above-mentioned reasons, innovation of a stove is very difficult. Most new products do not consider culture, cooking habits and demands of the users. Most people do not consider the fact that poor people have demands too. Therefore, these products will not succeed. There is one product that has succeeded and that is the Wood Saving Stove. The Wood Saving Stove has already been used in the 80s. (Janny Polley[C3] has seen them in those years) But, it's only now that these stoves are being broadly implemented in villages[C1]. Why is this? Was the problem not big enough in those years? Unfortunately, there is no answer.

Illustration A.5.1: Awra Amba is a innovative village[C3] where they are developing a kindergarten and use the Wood Saving Stove.

A.5.2 Development solar stove

The same conservative attitude towards cooking equipments applies to solar stoves. The idea of a wood saving stove is relatively new[C2], so the idea of a stove based on solar energy is even more innovative. The wood saving stove is used a lot now, and appreciated a great deal, especially because this stove does not produce as much smoke. Unfortunately it still produces a lot of smoke, so people still have eye and long diseases. A solar based stove will be appreciated, because it does not produce any smoke and saves even more fuel, namely all of it!

There used to be a Rural Energy Centre in Addis Ababa[C3]. However, no-one knows whether this institute is still active or not. The fact that this, governmental, centre is not publicly active is a sign that the government is not promoting renewable energy in Ethiopia.

As head of the environmental program for the Horn of Africa, Janny Polley[C3] has not seen any solar projects in Ethiopia, other than the few known. These are projects which occasionally try to introduce a solar cooker(CooKit or Solar Oven). Unfortunately there are no substantial projects in Ethiopia.

Some solar application will be explained below. However, this is general information. The advantages and disadvantages will be explained in Part B.

Solar Oven[C5,C6]
This principle makes use of the greenhouse effect. This reflection and black areas sun-beams are “trapped” in the solar oven. Solar ovens can generally reach a temperature of 150° C.

Illustration A.5.2: Solar Oven made by Bereket

Parabolic cooker [C5,C6]
A parabolic cooker directs the sun-beams into one point. At this point all the energy comes together and heat is generated. The heat point can get a temperature of 200° C.

Illustration A.5.3: Parabolic cooker

Community Solar Cooker [C5,C6]: 7 m^2
The community solar cooker makes use of a parabolic receiver that is called the Scheffler receiver. All the sun-beams are also directed to one point, only in this

case there are a lot more sun-beams than with the parabolic cooker. The temperature can reach 700° C.

Illustration A.5.4: Scheffler receiver

Illustration A.5.5: Scheffler focus point

CooKit[C1]
the CooKit is a low-cost solar cooker initiative of Solar Cookers International (SCI). It is a light weight panel solar cooker. It is made out of cardboard and aluminium foil. The costs are € 5.

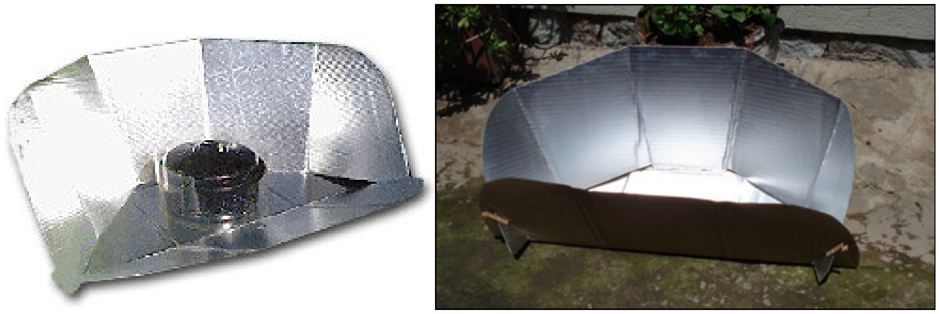

Illustration A.5.6a & A.5.6b: CooKit

A.5.3 Introduced solar applications

Until now DDA[C1] has not been aware of any Solar Cookers that can make Injera. DDA has two Solar Cookers: the CooKit and a Solar Oven. The problem with the Solar Oven is that it is difficult to transport. One has to have a special car, good quality, to transport it, so that it will not break. Because the roads are not good in Ethiopia, the Solar Oven will break because of vibrations.
The CooKit has been demonstrated but can not be produced on a big scale, because aluminium is difficult to get. The CooKit as well as the Solar Oven have the problem that they can not reach high temperatures (220° C). Therefore it takes a long time before dinner is ready.
The usage of solar applications is becoming more and more popular[C2], but most people can not afford it. The CooKit has been tested in Gende Gorba and has been shown to several women. After they had seen the presentation, they believed in the solution. They wanted to use it themselves. Unfortunately, it is too expensive to produce them for everybody.

Another solar application that is introduced is at the school in Gende Gorba. They started using Solar energy for powering the TV etc. They got these sun collectors from the local church.

The government[C8] does not have a lot of initiatives with regard to solar energy / cookers. A few stoves have been introduced, but this is not sufficient enough. On paper there are some plans, but nothing happens with these plans. It is too expensive, the capacity is not sufficient and the knowledge of solar cookers is not present. Some solar panels have been installed on clinics to heat water and generate light.
During the Derg regime people experimented with bio-gas. This failed because of the expense: a bio-gas installation costs 1600 birr, which is far too much for a rural family. However, the current government says they will try this again.

But hopefully a change will come: the Dutch minister of foreign aid[C3] has recently given a large amount of money to be spent on renewable energy in the Horn of Africa. This money will be spent by GTZ (Gesellschaft für Technische Zusammenarbeit, a German aid organization). They have a lot of experience in this area and have a department specialized in renewable energy: energizing development department. This department is focussing on three main topics:

- Enlarge the energy network by making more access points to this network in the rural areas.
- Developing Micro Hydro Power: (just like the Swiss) Micro Hydro Power are small systems which can generate energy. Artificial lakes are used on a larger scale to generate energy.
- Solar energy: promoting and enabling the usages of solar energy especially in clinics and schools, but also in other places.

The third topic indicates that a change is on hand. However, GTZ has not started any projects yet, and this will probably take a few months before they decide how to spend the money in each topic.

A.5.4 Advantages

Here is a short summary of all the advantages when solar energy is used instead of wood as energy source.

- Time: women will not have to spend several (3 – 6) hours a day searching for wood, or walking to the place where it can be bought. With this time a change can be on hand:
    - Women will be able to participate in society
    - Children can get an education
    - Emancipation will be able to start in Ethiopia
    - Villages will be able to develop
- Money: the people who can afford to buy wood, are struggling to get this money. With solar energy these people will not have to buy the wood anymore and therefore have some "extra" money.
- Fertilizer: the people in the rural area will not have to use cow dung as fuel. Therefore, the fertilizer will return to the soil and the soil will remain fertile.
- Deforestation: whenever trees are planted now, they are most likely to be used for fuel. When wood is not necessary anymore, trees will get a chance to grow. A good policy against erosion will finally have potential to succeed. The soil will also become more fertile, so that crops will be able to grow in a good way and more crops will grow on the same soil.
- Indoor pollution: without smoke and dust inside the homes of many people, indoor pollution will not resolve in eye and lung diseases.
- The level of the lakes will not be influenced by irrigation.

Chapter A.6: Solar Kitchen

The chapters above have discussed the target group, injera and the development on stoves. In this chapter the exact functions and demands are discussed.

A.6.1 Functions

The main function will be the baking of Injera, this was the motive to start this project. It should focus on baking injera, because this is the main dish that uses a lot of wood. However, besides this it could be multi purpose, so that people will be able to use the Solar Kitchen instead of a wooden stove.

- Boiling water: or at least pasteurizing water to avoid diseases being spread. Water should be heated to at least 65° C for at least 2 minutes.
- Baking of other foods, which are made on the current Injera stove now, for instance bread.
- Standard pots should fit on the Injera Cooker.

A.6.2 List of requirements (users)

U1. The solar kitchen should be of acceptable size. It could be seen that the Sheffler would not be accepted as a cooking device because it is too big[C6].

WISH U2. In some rural areas they eat less Injera, therefore the cooker will be used less. To enhance the usage of the cooker it should be multi purpose[C8].

U3. To be able to make the injera in the same way it is made now, the Solar Kitchen should be able to be at a high temperature (220° C) for a long time (15*5min = 75 min).

U4. The cooker should produce less smoke than stoves which are used now.

WISH U5, in case of a multi purpose solar kitchen, the Solar Kitchen should be able to hold 2 litres (2 kilo) of water. This is what the maximum weight will be while making stews or water for tea.

U6. They should be able to make the same amounts of food as they do now, which is at least: 15 injera per 3 days.

A.6.3 List of requirements (producers)

P1. Everything that has to be imported is very expensive. The import taxes are between 40% and 180%![C5] The height of the tax depends on the product, solar products are not free of tax.
Additional problem with importing products is that you never know when they arrive. The products often stay somewhere, for no specific reason; in this case you also have to pay for the storage costs. Therefore, materials should be accessible in Ethiopia.

Common materials to use are: recycled aluminium (lithograph of printing office), wood, glass, wool (for isolation), aluminium foil from the supermarket, clay, straw, etc.

WISH P2. Any reflecting material should be replaced by mirrors[C6]. These are cheap in Ethiopia and easy to make. Selam uses mirrors of 15 x 20 cm.

P3. The size of the sun-beam receivers should not be out of proportion[C6]. At Salam they have a receiver of 7 m^3 which could not be sold because of the size.

A.6.4 List of requirements (involved associations)

A1. The costs of the Solar Kitchen determine whether it can be implemented and whether it can be a success. Therefore, the costs should not be more than 100 - 200 euros for a Solar Kitchen on village scale.

A2. A problem with solar energy (by reflection) is that there is a big chance that users will get blinded by the reflectors. With repeatedly getting blinded, people will end up getting eye problems. Therefore, users should not get blinded while using the Solar Kitchen.

A3. The users should be able to maintain the Solar Kitchen

A4. The cooker should use less wood

A5. The method of baking injera should not be any different[C1], it should only change the energy source. People are very conservative about their necessities of life. This is because they depend a great deal on it, so they cannot afford to take chances on a new product. The food must be ready at dinner time!
Apart from this, the culture works in a way that women are responsible for making this dinner, but should also provide the means of making a dinner. Her husband provides money or rests during the day. If she is not able to provide a decent meal she will, eventually, be chased away from the village. This is a great deal of pressure on every female in a village.

A6. The clay baking plate of the current stoves have a diameter of 90 – 100 cm. It's about 2 cm's thick[C2]. The diameter is this size because of the traditional size of the injera.

A7. Apart from the design itself is it very important to promote the solar stove in a good manner! One should not just tell about it, because no-one will believe you. People are very sceptical and conservative, but once people see it working they will believe that it is possible to use a stove based on solar energy. Therefore, it should be practical[C2], and the users should think that as well. That's why it is important to test the solar stove in the villages itself. Once people see it, they will believe it and start wanting to use it.

WISH A8. It has advantages to make a solar based stove on a household scale[C2]. This is mainly because stoves on village scale will bring a lot of organizational problems: who will maintain the solar stove for example? This will be a great problem, one can already see that with other programs on village scale. If it is on a household scale everybody will manage their own stove.

WISH A9. Tradition has been a great problem in implementing solar cookers until now. This should be considered[C8].

Granada
Part B

Part B of this report is about the concept designs which were generated for the Solar Kitchen. After the research, done in Ethiopia, a list of demands and functions is clear. This report talks about the concept designs which followed those demands and functions. Also one of those concepts will be chosen. This concept will be deepened.

Chapter B.1: Method

After the research in Ethiopia there was a clearer idea of the possibilities of solar cooking and a better image of the target group and context was made. With this information the outlines of a Solar Kitchen were made. These elements will be discussed in the chapter below. For each element of the outlines some solutions were found and arranged in a morphologic scheme. This scheme was made presentable and shown at the Solar Cookers International Conference in Granada (July 11th – July 15th). During these short presentations / conversations to solar experts or experienced solar users, the ideas were tested and a lot of new ideas were generated. A lot of new ideas were generated during the conference. In this report all the ideas.

Chapter B.2: Outline design

With the list of demands, functions, possibilities and knowledge in mind an outline design was made. In this design a system of four elements was made. These are the elements on which the Solar Kitchen will be working. These elements represent a working principle and can be implemented as one or more physical elements.

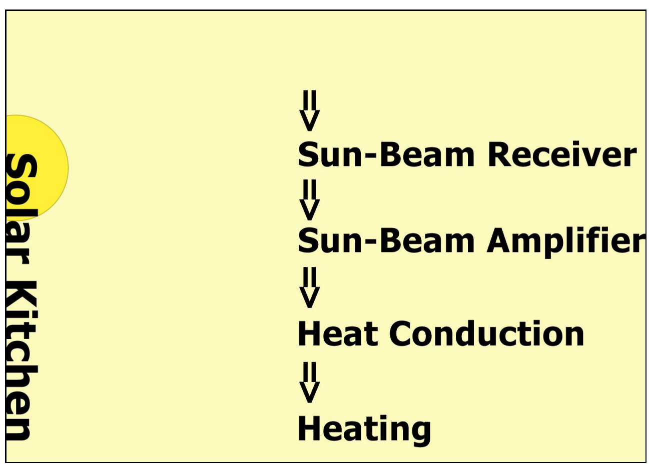

Illustration B.2.1

The outline design consists of:
- **Sun-beam receiver:** This element collects the sun-beams. It makes the sun-beams come together and form the heat that eventually will be used to bake on.
- **Sun-Beam Amplifier:** The collected sun-beams should be amplified in a positive or negative way. By amplifying the sun-beams, in either way, the temperature can be adjusted.
- **Heat Conduction:** Once the sun-beams are collected and adjusted, they should be transported to the place where they should “deliver” the heat. The conduction makes it possible that the collected sun-beams are used for cooking.

- **Heating:** Of course one element should make the cooking possible. This element gets the sun-beams of the conductor and transfers them into heat.

Chapter B.3: Elements of outline design

This chapter will talk about the elements of the outline design. The main objective is to get as many elements as possible, so that the broadest image will be made. Also, the best elements can be chosen when all options are clear.
Prior to the conference in Granada, all known options were made into pictures, so that a small presentation could be made by using the pictures. The ideas for each element were inspired in Ethiopia and by the own technical understanding and ideas.
First of all the ideas presented at the conference in Granada will be discussed, secondly the ideas which were generated at the conference. All these ideas will be described with the usage, advantages and disadvantages.

B.3.1 Sun-beam receiver

First of all the two ideas for the Sun-beam receiver which were generated before the conference will be discussed. These two are the parabolic receiver and the lens.

Lens
A lens made out of glass will be used to "catch" the parallel sun-beams and convert them into one point. (see Illustration B.3.1) This point will have the energy of all the beams caught. Therefore the point will be able to generate a lot of heat.

Advantages:

- One point will convert a lot of energy, and will therefore be able to generate more heat.
- A lens is made out of glass, a material which is easy to get in Ethiopia and therefore cheap.
- It is easy to make.

Disadvantages:

- The energy at the focus point should be used, or transported, from/at that point.
- To be able to get enough energy, the lens should be relatively large.
- Must have a sun tracking system, otherwise the focus point will not generate sufficient heat. Besides, the focus point will not be at the right place if the sun is not tracked in the right way.

Parabolic receiver
As seen in many solar cookers, a parabolic receiver can be used. (See Illustration B.3.1) The receiver is made out of aluminum and directs all the received sun-beams into one point. Difference with the lens option is that the focus point is in front of the receiver. At the focus point the beams should be directed, with a mirror, to the place where the energy is used.
This option can be used in two different ways: a parabolic receiver with the focus point in the parabola or a parabolic receiver with the focus point outside the parabola. There are no big differences, the blinding because of the reflection is worst with the focus point outside the parabola.

Advantages:

- This system has proven its possibilities to generate a lot of heat. It is used all over the world.

Disadvantages:

- Must have a sun tracking system, otherwise the focus point will not generate sufficient heat and will not be at the right place.
- The reflectors, of a parabola with the focus point inside the parabola, are made out of aluminum, this material is not easy to get in Ethiopia, making this receiver very expensive. However, a parabola with the focus point outside the parabola, can be made out of mirrors.
- Also this system, just like the lens, will not generate one beam with all the energy, but will make a focused point. After that, the beams will diverge again. The illustration B.3.1 is therefore incorrect. The heat should be used in the focused point.
- If the parabola is not well aligned to the sun, the focused point will not be in the middle. Therefore, it is easy to get blinded while aligning and using this cooker.

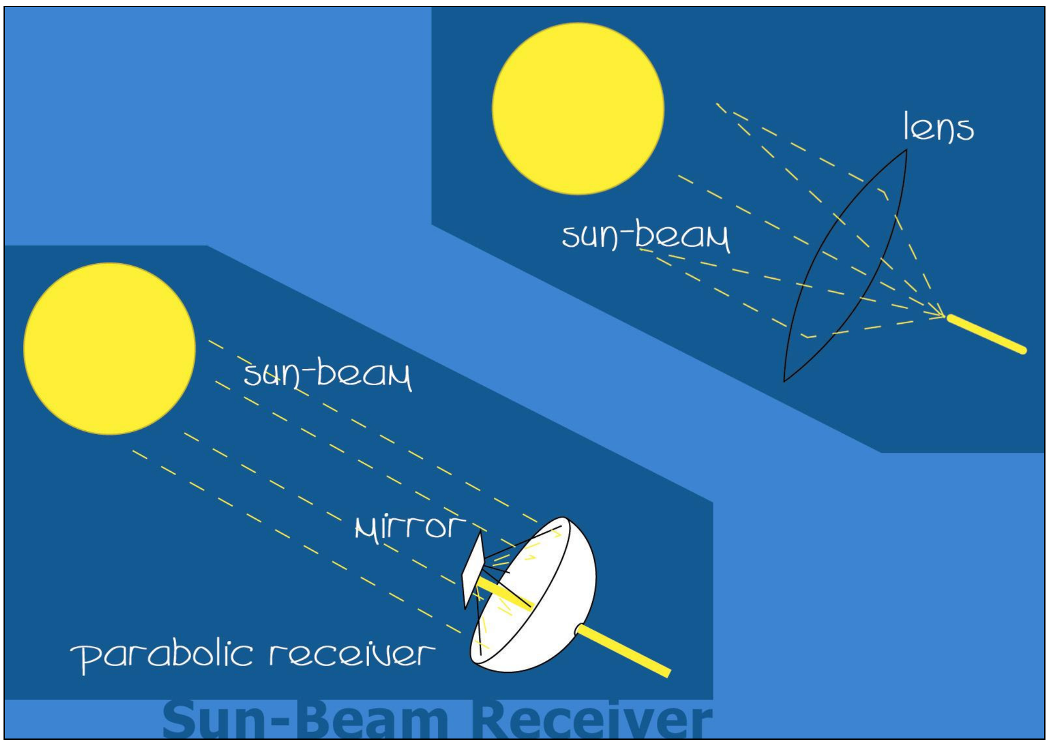

Illustration B.3.1: Sun-Beam Receiver options

Flat panel
The box receiver, also called a flat panel, is a flat object which collects the sun-beams through reflector and "catches" them into a glass box. In this box the sun-beam heats the object within by the greenhouse effect. The heat should be transported from within the box.

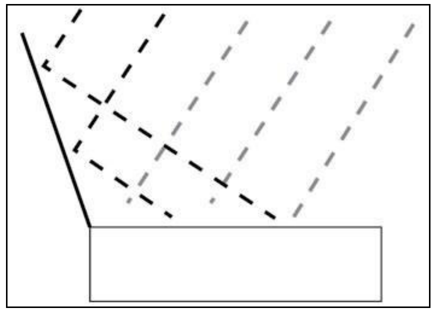

Illustration B.3.2: flat plate receiver

Advantages:

- The box receiver does not use a tracking system for the sun, because the sun-beams do not have to be directed into one point. Therefore random reflection is good enough for this system.
- This is a cheap system, because there is no tracking system. Also the materials can vary a lot so that the cheapest material can be chosen.
- There is no blinding reflection.

Disadvantages:

- A lot of reflectors are necessary to get a high temperature.

In the sun

The receiving element should heat the final object, but it can also be heated directly. One can place the object to be heated directly in the sun. A variant of the option is to place a baking plate into the sunshine and get this heated.

Advantages:

- Because this option does not use a lot of elements it is very cheap.

Disadvantages:

- To keep replacing the baking plate from the sun to the baking place should be very heavy. This is difficult for the users.
- The heat will not be sufficient enough. It will only become hot enough (220°C) if it can be in the full sun for a long time.
- When it cools down, it takes a long time before one can bake again.

Parallel receiver

This method uses two parallel mirrors, it directs the sunbeams to the place where it can be absorbed. See illustration B.3.3.

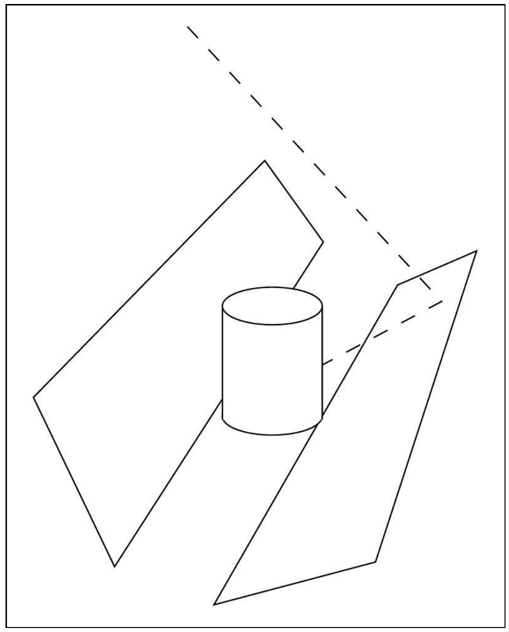

Illustration B.3.3: parallel receiver

Advantages:

- It is a cheap option because of few elements.

Disadvantages:

- Because of random reflection, not enough energy can be absorbed to get high temperatures.

B.3.2 Sun-beam amplifier

It is a difficult task to be able to amplify the sun-beam. One should create a way to get more energy in one beam. Because of this difficulty only one option was presented at the conference. However, another option was found at the conference in Granada.

Lens

The idea to get several sun-beams into one point has been explained in B.3.1. This does not generate a beam with more energy, but a point with more energy. In finding ideas for this outline design element, the fact that the beam would not have more energy than the beams that were converted into this point had not been taken into consideration. Therefore, this will not amplify the beam. In order to amplify the beam with a lens, several beams with more energy should be provided. Then these beams will be converted into one point with more energy than the system of B.3.1. Because it is almost impossible to provide amplified beams which can be converted, this option is not realistic.

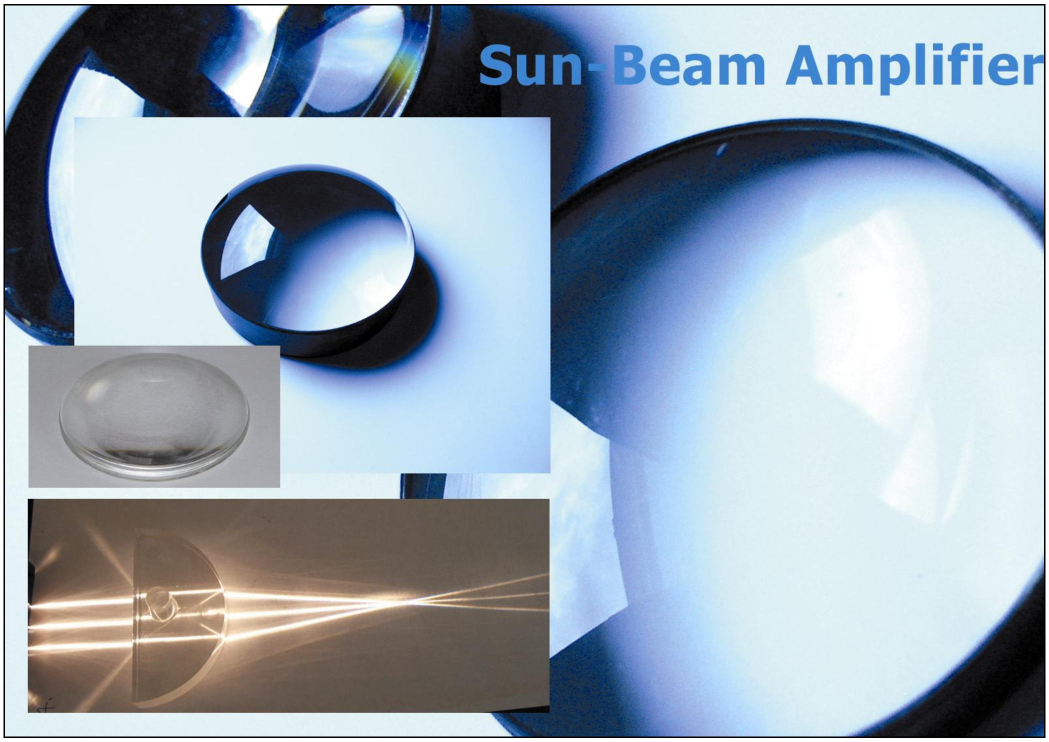

Illustration B.3.4: Sun-Beam Amplifier options

Reflectors
In order to be able to amplify a sun-beam, more energy should be added. The only way to do this, with solar energy only, is to use more reflectors. These reflectors will direct more sun-beams to the point where the energy is used. Thus energy will be added and the temperature can rise.

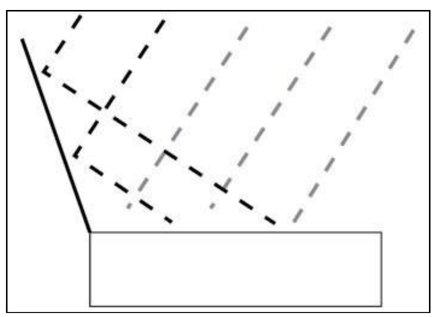
Illustration B.3.5: Reflectors add more energy

B.3.3 Heat conduction

Because of safety reasons (one does not want to be blinded by the sun-beam receiver) and cultural reasons (one wants to bake on a stove that looks the same and is located inside) the sun-beam receiver is placed away from the heating element. To get the heat/sun-beams from the receiver to the heater, a conductor must be used. In this paragraph the options for conduction.

Mirrors
If one sun-beam is generated it should be possible to redirect these sun-beams with mirrors. (See Illustration B.3.6) One can redirect these beams through several angles to the heating element.

Advantages:

- The sun-beam does not have to be converted into heat to be able to transport the sun-beam.
- The materials are cheap, because all materials used are available in Ethiopia.

Disadvantages:

- While redirecting the sun-beam, the beam goes from mirror to mirror. Every time it is reflected, sun energy will be lost because of the imperfect reflection. This is due to two factor: the aluminum reflector is not 100% smooth and the sun-beam has to go through a bit of glass. The latter will result in diverging the sun-beam. These factors will result in a sun-beam with less energy at the end than at the beginning.
- Lots of mirrors are necessary, and will therefore get more expensive (even though the materials are cheap) and will break faster because of all components.

Wires

As with electricity, the energy can be transported through a wire. The wire can be made out of copper, fiberglass or any other metal. The sun-beam should be converted into heat and absorbed by the wire.

Advantages:

- Once the heat is in the wire, it can be used for the heating directly.
- Wires, copper wires not fiberglass, are available in Ethiopia.

Disadvantages:

- While transporting the heat in through the wire a lot of energy is lost because of resistance.
- A lot of energy will be lost while converting the sun-beam into heat in the wire.

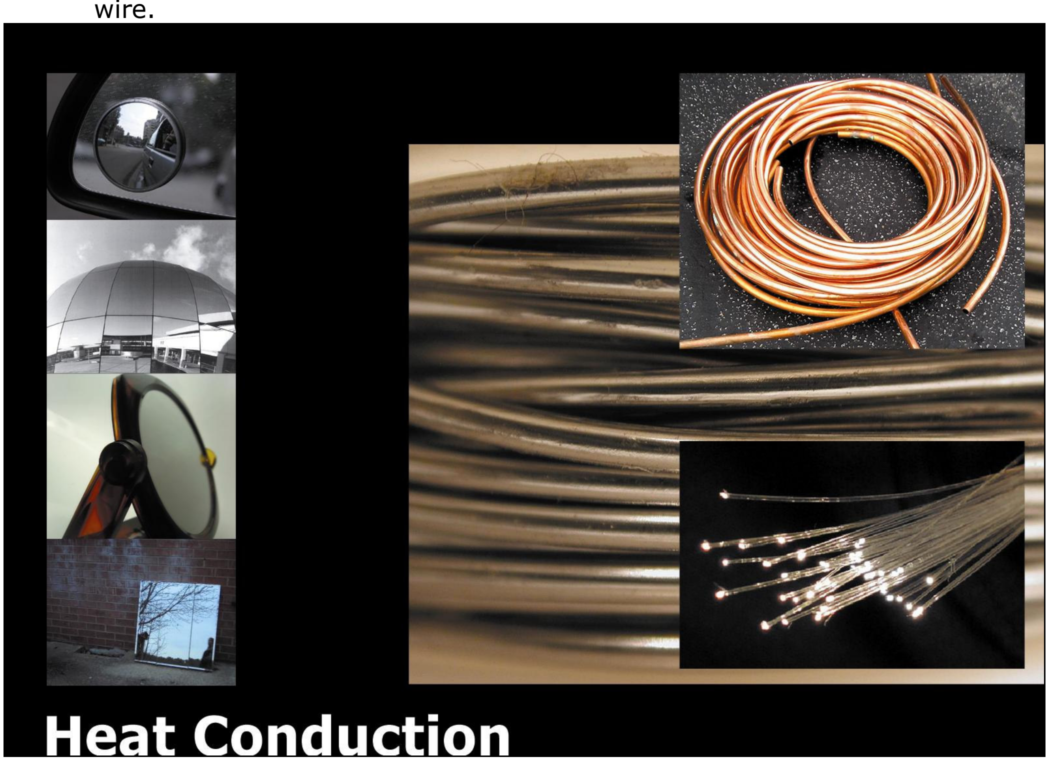

Illustration B.3.6: Heat Conduction options

Oil
An idea which was generated in Granada at the conference is to use oil. This can be any kind of oil; peanut oil is mostly used. In the oil the heat is stored and can be transported through in. The oil should not get above the boiling point, which is 570° K (300° C).

Advantages:

- The oil can be heated with any sun-beam receiver.
- With proper insulation the oil will stay hot for a long time: the oil can store the heat for a while.
- It is easy to get the heat into the oil and to get the heat out of the oil. No conversion is necessary, therefore, no energy will be lost.
- Oil can reach high temperatures, 220 - 240° C.

Disadvantages:

- Oil (vegetable oil) should probably be changed once in a while (this should be tested)
- Oil (vegetable oil) is not richly available in Ethiopia, but can be grown there.

Steam
The same as oil, the heat can be "put into" water. This will become steam because of the heat. Again with proper insulation, the steam can store the heat for a long time.

Advantages:

- The steam can also be heated by any sun-beam receiver.
- Steam can store the heat for a while.
- Again, no conversion is necessary, therefore, no energy will be lost.
- Water is available in Ethiopia and can therefore be used easily.

Disadvantages:

- Steam can not reach high temperatures. Steam does not get a higher temperature (at normal atmosphere) than the boiling point of water (100° C). By changing the atmosphere the temperature can be increased to 130° C, which is still too low.

B.3.4 Heating

The last element of the outline design is the heating element. With this element the injera is actually baked.

Clay
The current injera stoves are made out of clay. The electric stoves contain a wire in the clay, the traditional stoves use fire to heat the clay.

Advantages:

- The clay is used in current stoves. By using clay in the Solar Kitchen the method of cooking will not be changed.
- The clay gets hot equally.
- Once it is hot, it stays hot for a long time, without adding a lot of new energy.
- Clay is very cheap and present in the whole of Ethiopia.

Disadvantages:

- With full heat (220° C) under it, it takes about 10 – 15 minutes to get hot.

- It can break more easily than metal, therefore it should be replaced once in a while. (but this is cheap)

Cast Iron
Research by Gazahagn (see *Annex C C9*) concluded that Cast Iron could also be used for making injera. This works, in this case, just like a grilling pan.

Advantages:
- Because of good conduction qualities, cast iron gets hot fast.
- Cast iron is durable.

Disadvantages:
- The same as getting hot fast, cast iron also cools down fast.
- Because of the good conduction qualities, the places that are heated are a bit warmer than the places that are not heated. The cast iron is not equally hot. This can be seen with food that is baked on cast iron.
- It is not that easy to get in Ethiopia.

Aluminum
Gezahagn's research also pointed out that aluminum can be used to bake injera, just like cast iron.

Advantages:
- Because of good conduction qualities, aluminum gets hot fast.
- Aluminum is durable.

Disadvantages:
- The same as getting hot fast, aluminum also cools down fast.
- Because of the good conduction qualities, the places that are heated are a bit warmer than the places that are not heated. The aluminum is not equally hot. This can be seen with food that is baked on aluminum.
- It is not easy at all to get in Ethiopia.

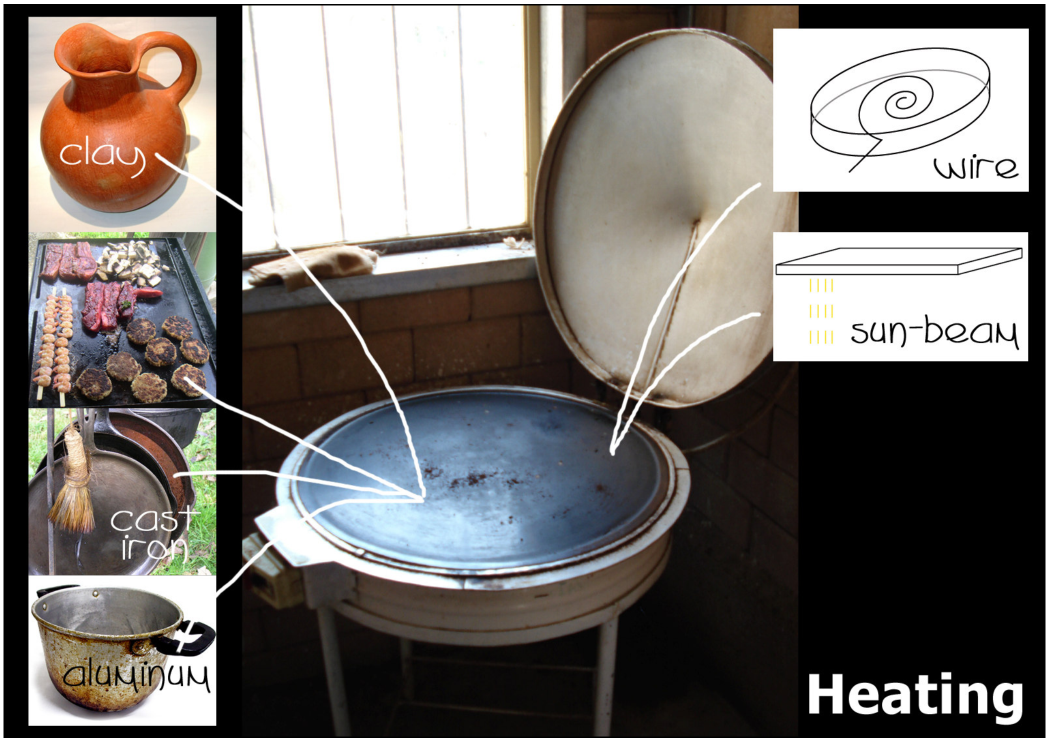

Illustration B.3.7: Heating options

The method of heat conduction that is used results in the method of heating the material chosen. An overview:

- *Mirrors:* sun-beam aimed at the material so that the material gets hot. By dividing the beam the material can be heated equally. The beam will lose heat in this case.
- *Wires:* when wires are used, the wires can be embedded in, or fixed onto, the material. Because of resistance the heat will be released and the material will be heated.
- *Oil:* just like a wire a tube will be embedded in or fixed onto the material. The hot oil will run through this and radiate the heat, therefore, heating the material.
- *Stream:* just like oil, the steam will run through a tube.

B.3.5 Choice of elements

To be able to make a choice of all proposed elements one should review the list of demands. Described below are all elements with a judgment whether it meets the demand or not. Green mean yes, orange: partially, red: no, and 'NR' : not relevant for this element. At the end, all judgments are added up. With these points it becomes clear which element meets most demands. Green gets 2 points, orange: 1 point, red: 0 points.

Demands: Sun-Beam Receiver

Demand	Lens	Parabolic	Flat panel	In the sun	Parallel
U1					
U3					
U4					
U6	NR	NR	NR	NR	NR
P1					
P3					
A1					
A2					
A3					
A4					
A5	NR	NR	NR	NR	NR
A6	NR	NR	NR	NR	NR
A7					
	14 points	9 points	17 points	15 points	11 points

Result according to the list of demands: Sun-beam receiver: flat panel receiver

Demands: Sun-Beam Amplifier

Demand	Lens	Reflector
U1		
U3		
U4	NR	NR
U6	NR	NR
P1		
P3		
A1		
A2		
A3		
A4		
A5	NR	NR
A6	NR	NR
A7		
	0 points	14 points

Result according to the list of demands: Sun-beam amplifier: reflectors. Because the usage of a lens to amplify the sun-beams is technically not possible with only sun-beams, it does not meet any demands.

Demands: Heat Conduction

Demand	Mirrors	Wires	Oil	Steam
U1	NR	NR	NR	NR
U3				
U4	NR	NR	NR	NR
U6	NR	NR	NR	NR
P1				
P3	NR	NR	NR	NR
A1				
A2				
A3				
A4	NR	NR	NR	NR
A5	NR	NR	NR	NR
A6	NR	NR	NR	NR
A7				
	8 points	10 points	11 points	9 points

Result according to the list of demands: Heat conduction: oil. If one looks at the function list, one can see that only one option is certain of working. Oil is the only one that can reach a high temperature (220° C), this is necessary to be able to bake injera.

Demands: Heating

Demand	Clay	Cast Iron	Aluminium
U1	NR	NR	NR
U3			
U4	NR	NR	NR
U6	NR	NR	NR
P1			
P3	NR	NR	NR
A1			
A2			
A3			
A4	NR	NR	NR
A5			
A6			
A7			
	14 points	12 point	10 points

Result according to the list of demands: Heating: clay (tubes embedded in the clay for heating)

Enschede
Part C

This part, part 3, takes the results of part 2 and make a detailed design out of it. In this part a detailed design is made out of every element and if necessary some calculations are made to analyze the system.

Chapter C.1 Detailed outline design

The working principals have been chosen for the outline design for the Solar Kitchen. It is important now to deepen this technically. How do the techniques work together? How to use these techniques so that the demands certainly will be met? The four elements chosen should be designed in detail, so that it will work in one system.
While searching for more information on these four elements, it appeared that one system exists that uses most of these elements. K. Schwarzer, of the Solar Institute Jülich part of the Hochschule Aachen, has designed a system which is an indirect solar cooker. Schwarzer has described his indirect cooking system in many papers and in the book Solarkocher[L7].

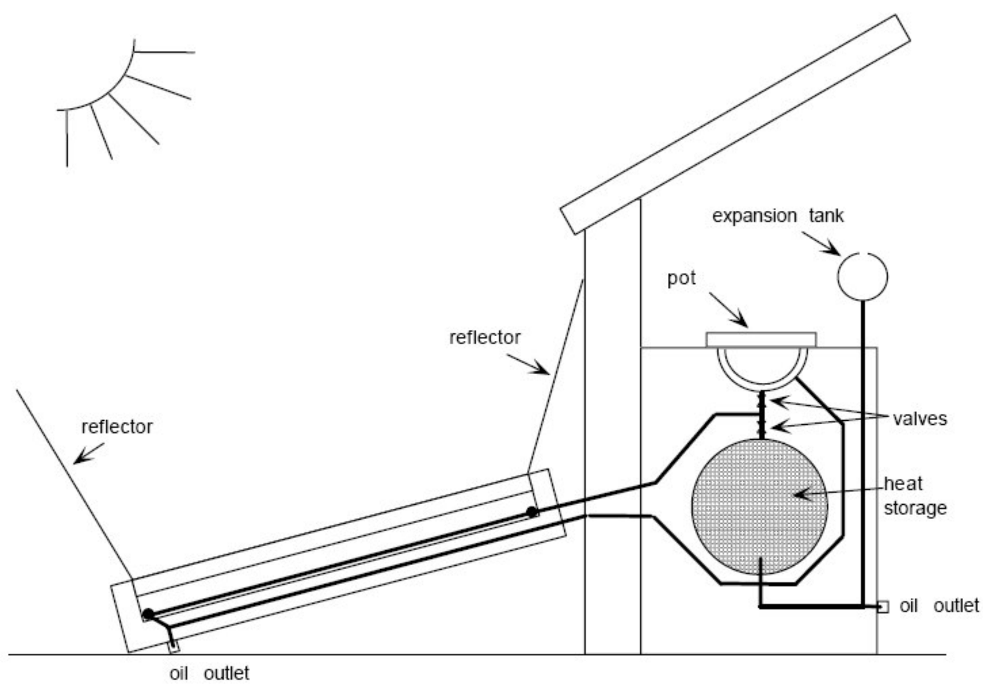

Illustration C.1.1 Schwarzer model indirect cooker

As seen in illustration C.1.1 the Schwarzer model cooker can be used indoors, this is one of the advantages of this model. But, another advantage is that it uses vegetable oil as transmitting fluid. This fluid can reach temperatures of 240° C[L8].

C.1.1 Description Schwarzer

(see Illustration C.1.1)
The receiver consists of a flat panel receiver, that uses the greenhouse effect for heating. In this box the tubes with oil are located. The temperature in the box is amplified with reflectors. Because of the heat in the box, the tubes get hot as well. To enhance the heating, the tubes are fixed to black metal plates. These plates get hot because of the absorption (black color) and make the tubes hot, because of conduction.

The Schwarzer model uses heat convection to move the oil around. (a passive system [L12]) This means that hot oil can rise in the system, and colder oil descends. (this is called *Convection*) This is why the hottest point should be the highest point. No external energy is necessary to pump the oil around.

The hot oil runs to the top of the barrel where it is stored. When the valves open, the hot oil can rise even higher, which it does. The oil is used to heat the baking plate and cools down. The oils descends again to the point where it can be heated again by the receiver.

Properties

- The maximum length of the transportation tubes in the Schwarzer model, while maintaining the insulation effect, is 90 cm[L10]
- An individual *direct* cooker consists of: a 1 m^2 sun collector and 7 liters of groundnut oil[L10]. It can prepare food for around eight to ten people. Costs: $625.
- A community *direct* cooker consists of: a 2 m^2 sun collector and 10 liters of groundnut oil[L10]. It can cook for 25 adults, or 40 children, and can be used in institutions, schools. Costs: $1050.
- A community *indirect* cooker consists of: a 2 m^2 sun collector and 40 liters of groundnut oil[L10]. Because of the heat storage it can also be used at night. It can cook for 25 adults, or 40 children. Costs: $1200.

Advantages

- The transmitting fluid, vegetable oil, can get temperatures of 240° C[L8].
- Temperature can be controlled[L9], because of the use of valves.
- Because the oil is heated all day, one can rely on the cooker.[L11]
- Very low maintenance[L11], because of the low amount of small parts.
- No blinding reflection while cooking.
- Longer life time (than a parabolic cooker) [L11].

Disadvantages

- Some oil may set fire at temperatures above 250° C[L9]
- In the model of Schwarzer the pots are fixed.
- Because of complex construction and high amounts of components the costs are high[L9].

A parabolic receiver is not advisable because this has a lot of problems with the list of demands: a parabolic receiver is expensive, in Europe one costs around 200 euros, this will be more expensive in Ethiopia, because of import taxes (there is no aluminum in Ethiopia). Also, a parabolic receiver will cause blinding, because of the reflection while one is cooking.
The Schwarzer model is the only system known, without parabolic receivers, which can achieve high temperatures and uses the outline elements chosen. Because of this reason, the Schwarzer model will be used as basis for the Solar Kitchen, the working principals will be used. However, many elements should be changed, to make optimal use for baking injera, also to be able to lower the price which is of great importance.

C.1.2 Outline design

With the information above, the element choice and the explanation of the Schwarzer model, more is clear about the working of the outline design of the Solar Kitchen. However, only working principals are clear, the details will be discussed now. The Schwarzer system cannot be copied entirely for injera baking use: the pots can not be used for baking injera and the temperature is not high enough. That is why the system will be changed. What should be achieved?

- The receiver should be enhanced to be able to receive more sun-beams.
- The pots should be replaced by a baking plate for injera.
- The price should be lowered.

With this information the outline design of the Solar Kitchen will look as follows.

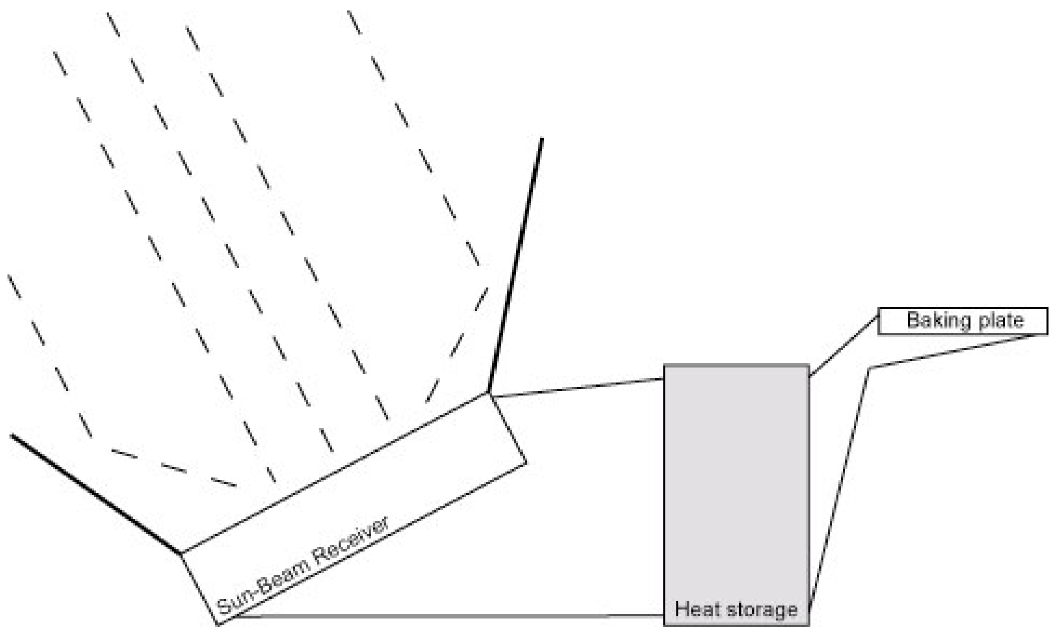

Illustration C.1.2: Outline system

Chapter C.2 Detailed Solar Kitchen design

In this chapter every element will be discussed and a detailed design is made.

C.2.1. Sun-Beam Receiver and Amplification

The Sun-Beam receiver and the Amplification of the Schwarzer model is working correctly. This is making the oil to rise to high temperatures. The oil used in the Schwarzer model is Peanut oil, this can only get a temperature of 231° C[L5]. With all the system heat loss, the ultimate temperature is 180°C. This temperature can be achieved with a receiver of 1 m^2.
The goal of the Solar Kitchen is to bake at 220°C. Therefore the receiver should make the oil around 270°C. To achieve this, another oil should be used and the receiver should get more energy into the oil. Therefore a larger receiver should be used, and larger reflectors should be used. A sun-beam receiver of 2 m^2 is chosen with reflectors of also 2 m^2. Also, another material for the tubes is used. The Schwarzer model uses steel tubes, the Solar Kitchen will use Copper tubes. These tubes will be able to absorb more energy. (See Chapter C.2.2.2)

C.2.1.1. Receiver

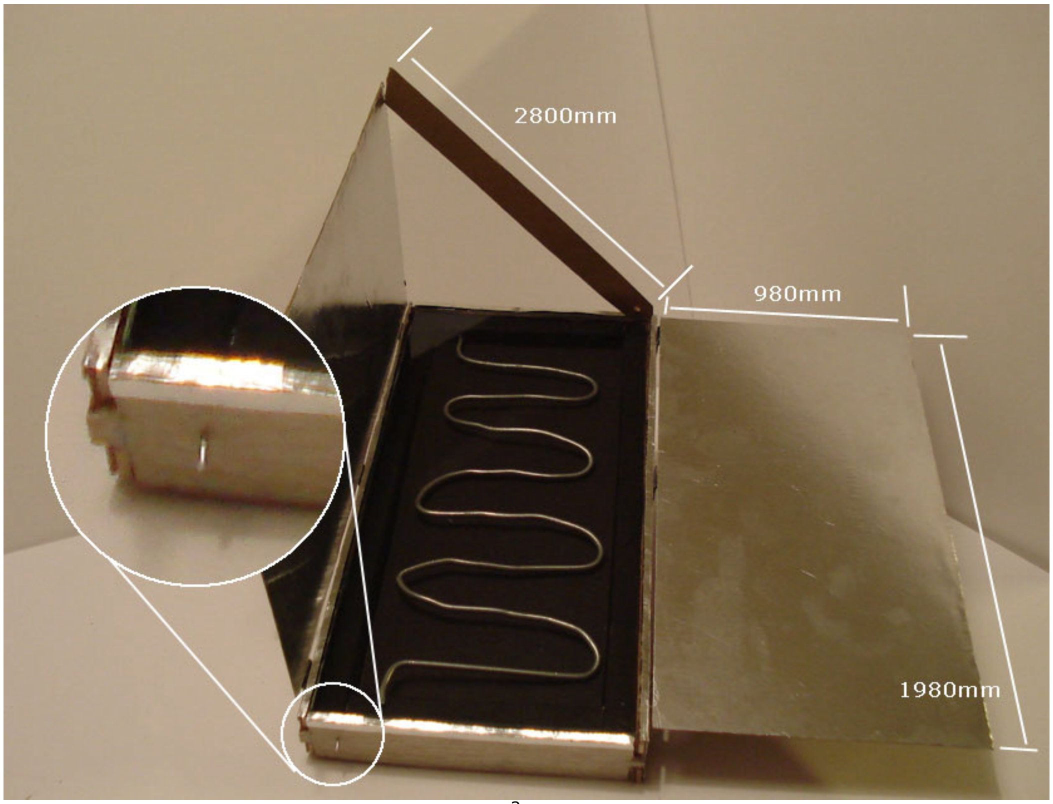

Illustration C.2.1: 2 m^2 receiver with reflectors

See Annex F.7 for measurements of the tubes inside the receiver. Also see Annex H for more drawings and building plans for the receiver.

C.2.1.2 Reflectors

Reflectors are chosen to amplify the energy in the receiver. In this chapter the material, the angle of the reflectors and the positioning of the solar kitchen during the day is discussed.

Reflectors can be made out of different materials:

- Aluminum foil OR
- Polished aluminum OR
- Mirrors OR
- highly reflecting polyester foil[L18]

It is very difficult to get any reflection material in Ethiopia, that is why the reflector will become very expensive. According to the director of Selam's Children Village, mirrors are available and cheap. The choice is made to use mirrors because of this reason. However, the reflectors can be of any above mentioned material. If a cheaper material is found, this material can be used as well.

The illustrations below show the angle of the reflector. This is the angle in which they will reflect the most sun-beams (see illustration C.2.2).

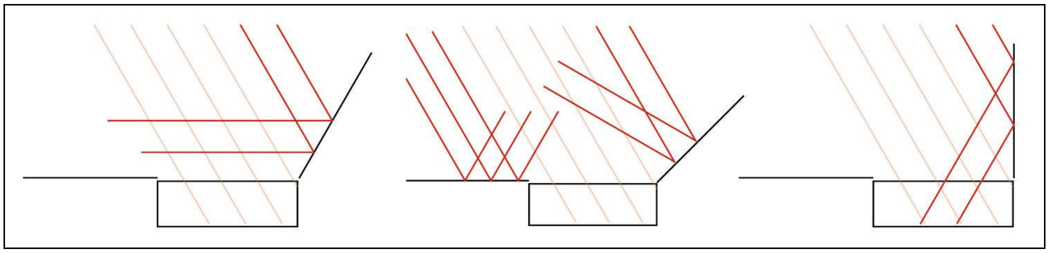

Illustration C.2.2: Different angles of reflector: right 60°, 45° and 90°.

In the illustration above one can see that only one angle will contribute to the heating in the box, this is the 90° angle. By placing the left reflector in an angle it will only be in the way of the sun-beams and not reflect any beam into the box.

The angle of the sun during the day can be seen in Illustration C.2.4. Their will not be sufficient sun before 8h and after 16h, therefore the Solar Kitchen can only be used between 8h and 16h. However, the system has to charge first before it can be used. See Annex F.1.

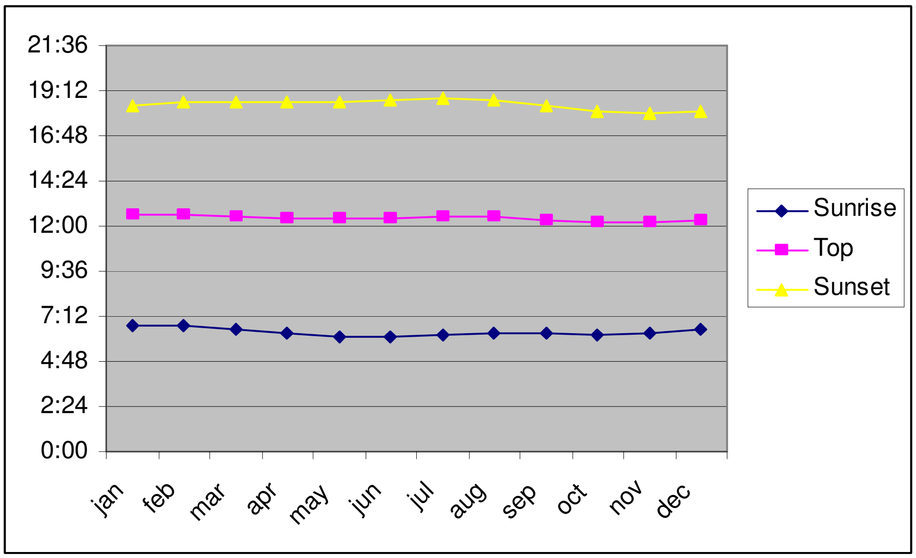

Illustration C.2.3: Sunrise and sunset in Addis Ababa, Ethiopia[L21]

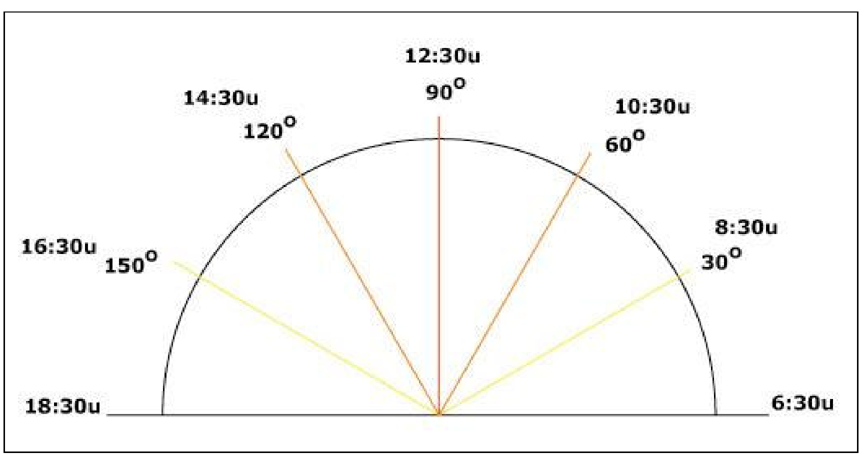

Illustration C.2.4:Position of the sun + hours in general, Addis Ababa

In the illustrations below the angle of the sun-beams during the day is shown.

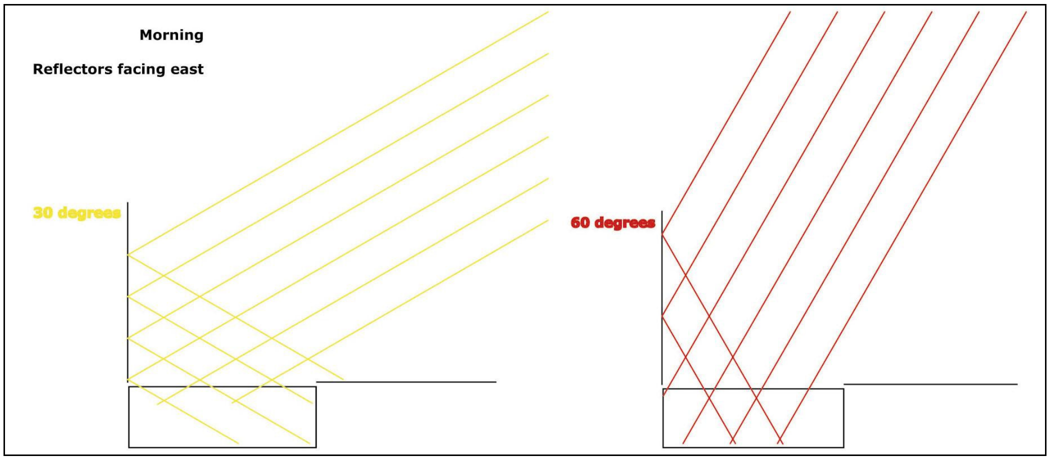

Illustration C.2.5: Morning, reflectors facing east

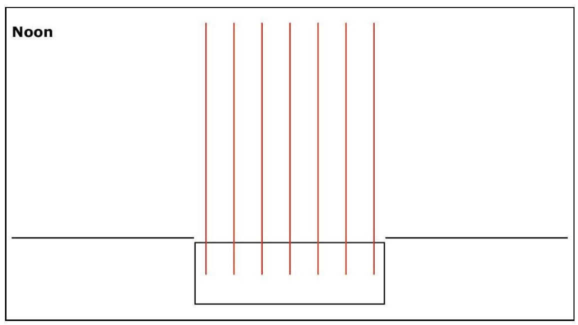

Illustration C.2.6: Noon, reflectors do not contribute

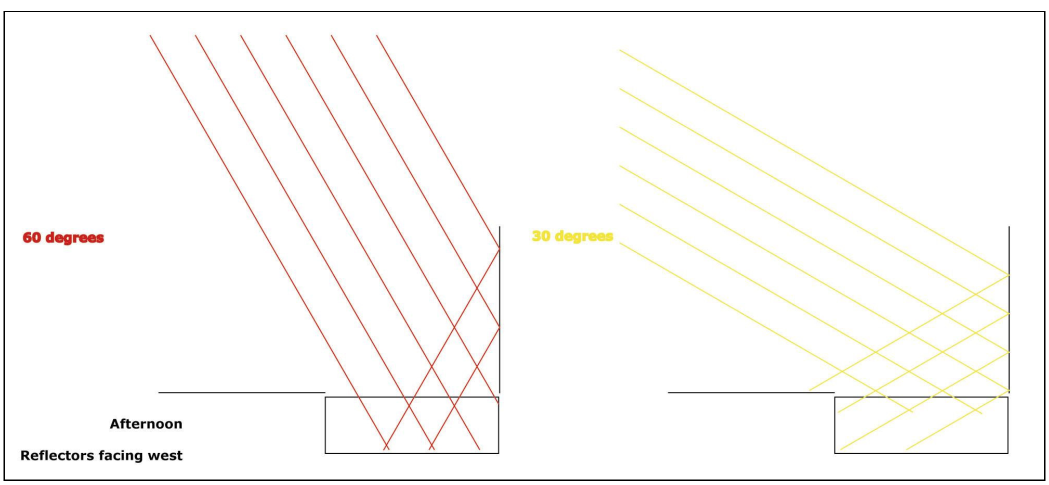

Illustration C.2.7: Afternoon, reflectors facing west

To support the heat convection (see Chapter C.1.1) the receiver should stand in an angle, this is 15°[L17]. The angle is determined by the place where the receiver is positioned on the earth. The receiver should always stand perpendicular to the sun-beams. For Ethiopia, which is practically situated at the equator, this is negligible, because the angle to support the heat convection is larger.
Another important positioning aspect is that the top of the receiver should be directed to the north. This way the reflectors are directed, when folded out, to the

west (left) and east (right). This is also shown in the pictures above. When the receiver is directed like this, it will collect the most sun-beams.

To be able to keep the reflectors in this position and prevent them from falling, the reflectors should be fixed. They should be able to be fixed in an 90° angle, but also horizontal next to the receiver. Several options are possible:

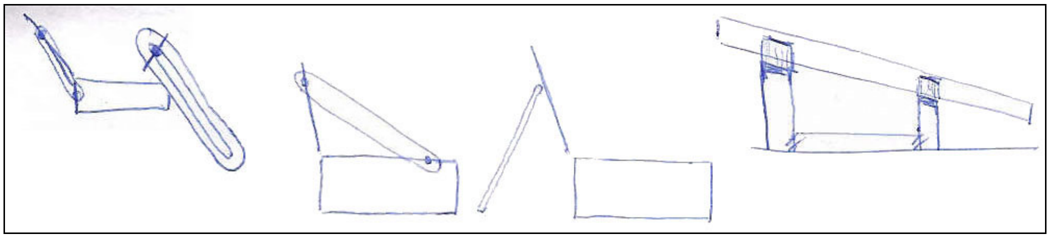

Illustration C.2.8: options for fixing the reflectors

If a 180° angle is necessary a wooden frame is used to support the reflectors. This can also function as an handle to open the reflectors. For the 90° position inward support beams are used. The reflector has to be fixed in an upright position and should not fall to the right or the left. To fix the beams screws are used. See Annex H for more information.

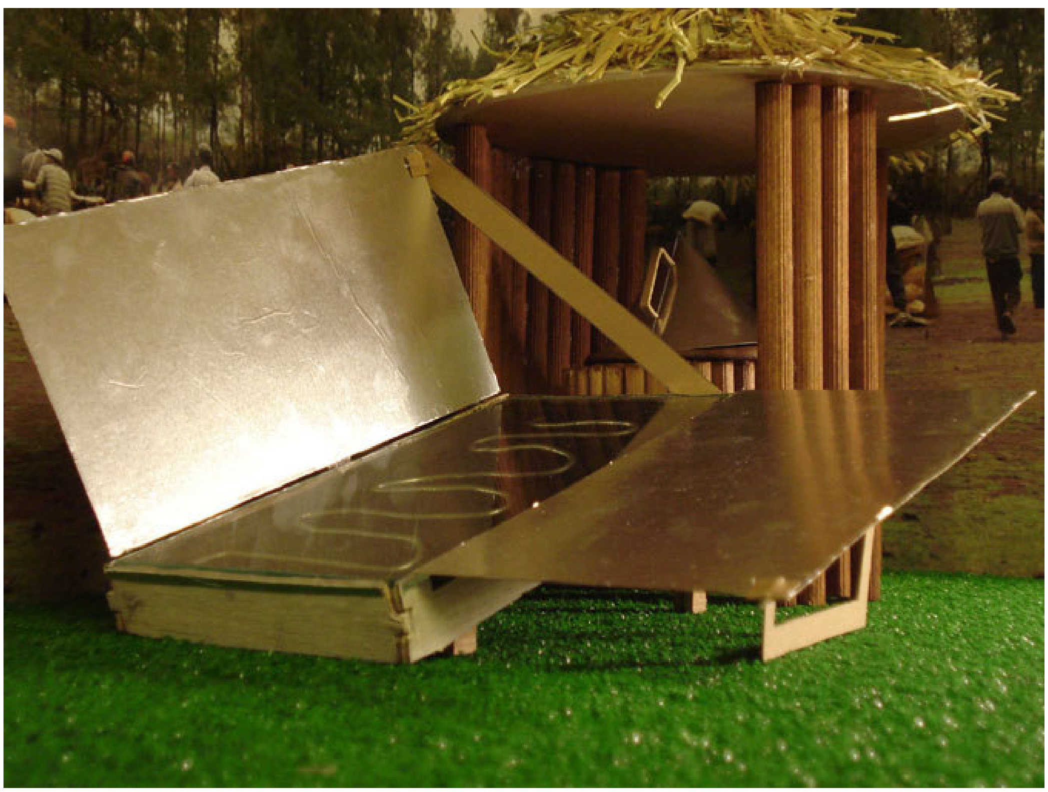

Illustration C.2.9: Fixation of reflectors

C.2.2 Conduction

In this chapter all the aspects of the conduction in the Solar Kitchen will be discussed: the use of oil, transportation of the heat, insulation to prevent heat loss, heat storage and expansion caused by the heat.

C.2.2.1 Oil

The heat conduction will take place through oil. However, not any oil can be used. The maximum temperature of the system is also determined by the choice of oil, so a suitable oil should be found to be used as heat transportation. Oil is a good fluid to use, because it can contain high temperatures without breaking down. A vegetable oil is cheap and can be made in Ethiopia itself. Synthetic oils are expensive in general. Some qualities it should have: it must be able to reach temperatures above 250° C without breaking down or boiling. With heat loss of the system, it has to produce a temperature of 220° C.

- Peanut oil: the Schwarzer model uses peanut oil, however, the smoke point (the point at which it will break down) is 231° C[L5].
- Sunflower oil: this vegetable oil has a smoke point of 246° C, this is enough for use in the Solar Kitchen system.
- Safflower oil: the smoke point of safflower oil is 265° C[L5]. Also, Ethiopia is the fourth producer of Safflower oil in the world, this indicates that it is easy to get by[L6]. This oil is chosen as transmitting fuel.
  According to the Food and Agriculture Organization of the United Nations[L15] Ethiopia was the 7th producer of Safflower seeds in 2005.

C.2.2.2 Transportation

As can be seen in illustration C.1.2 the oil must be transported from the sun-beam receiver, where it gets its temperature, to the heat storage and the baking plate. This can only be done by tubes, because the system should be a closed loop all the time. This way the oil can circulate and heat equally.
The best material for tubes is metal. This material will not break easily (like glass) or melt (like a synthetic material, plastic). The ideal metal is a metal which has the suitable thermic conduction: when it has to absorb or radiate energy it should have a thermic conduction which allows that, also the other way around. While absorbing or radiating energy the thermic conduction should be high, like copper (390 J/(sm°C))[L14]. While transporting the hot oil, as little heat as possible should be lost. A low thermic conduction is in order, steel has this: 14 J/(sm°C)[L14].

The heat loss for every meter of metal tube which is "outside" (not in the receiver): it radiates <u>253,04 J/s</u>. (see annex F.2) However, the loss should be interpreted as the energy loss per meter of tube without any insulation. The actual heat loss is the radiation of the tube, also including the radiation of the surroundings, sun heat etc, which adds energy to the tubes, and the insulation.

C.2.2.3 Insulation

To reduce the heat loss insulation should be installed. This way the heat loss can be minimized. Because no ordinary insulation can be used, because of the expense, a natural insulation should be found. This insulation can also be used for insulation of the heat storage.
Some options for natural insulation:

Material	**Heat transfer coefficient**[L22]
Clay	1,3 W/m.K
Clay (5-10%) with straw (90-95%) in it[L13]	0,08 – 0,09 W/m.K
Cork	0,039 W/m.K

Table C.2.1

Other natural insulation materials are also possible. However, all have a higher Heat transfer coefficient than the three mentioned above. If one chooses according to the Isolations values of the material, one should choose cork. However, this material is very expensive.

All of these materials have to be placed in an empty space, inside a double layered tube, which should be created. This costs a lot of money; therefore these options have a large disadvantage. However, there is one option that does not have this problem: clay with straw. Both materials are available in Ethiopia, and no outer layer is necessary, since the clay holds the straw together. This method is used for insulating houses as well. Insulating with clay and straw is chose.

To preserve the heat, the transportation tubes should be as short as possible. While implementing the Solar Kitchen, the length of the tubes should be made as short as possible.

C.2.2.4 Heat storage & Expansion

Heat storage
A problem occurs during the baking of the injera. When one pours the batter over the baking plate, this will cool down immediately. It will take a while before the oil is heated enough again. In the meantime people will have to wait before they can bake again. When baking a lot of injera in a row, this will not be practical. A solution for this problem is storing the heat. The heat storage:

- heats more oil at the same time; the system can immediately use new, hot, oil, and the user can immediately bake a new injera.
- will make it possible to control the temperature of the baking plate. Without heat storage the baking plate is heated all the time, by storing the heat elsewhere, the user can control the flow of hot oil and therefore turn off or turn down the temperature.
- An additional advantage is that people will be able to cook at any time, as long as the oil stays hot. This means that people will be able to cook after the sun is set, with solar energy.

Expansion
Another problem which occurs with a closed system is that it changes while heating the system. When heating, the oil and the metal expand, the overpressure caused by the oil will cause the system to break. To prevent this, a expansion tank is necessary.

The change of volume when heated is 6 liters, see Annex F.3 and Annex F.4. This can be placed under the baking plate, by not fully filling the oil storage under the baking plate. (leaving an empty place of at least 1,1 cm) See Annex F.4 for more explanation.

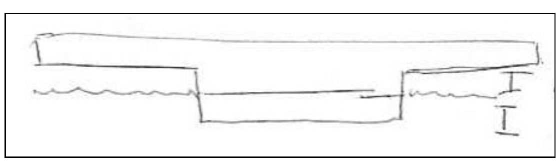

Illustration C.2.10: Expansion tank

C.2.3 Heating

C.2.3.1. Baking plate

The baking plate, made out of clay, is heated with the hot oil. This is one of the parts where the system is different from the Schwarzer model. In the Schwarzer model, the oil runs through tubes which are fixed on the cooking pot. With the Solar Kitchen a baking plate will be used, the plate is heated with the oil.

If the same method as the Schwarzer model is used, see illustration C.2.11, a problem occurs: the heat convection cannot take place. There is simply not space enough for the hot and cold oil to separate. Also, the angle of the tube cannot be sufficient to create a fluid flow. Besides, by placing the tubes in an angle, the baking plate will have a lower temperature when the tube has a larger distance from the top of the baking plate.

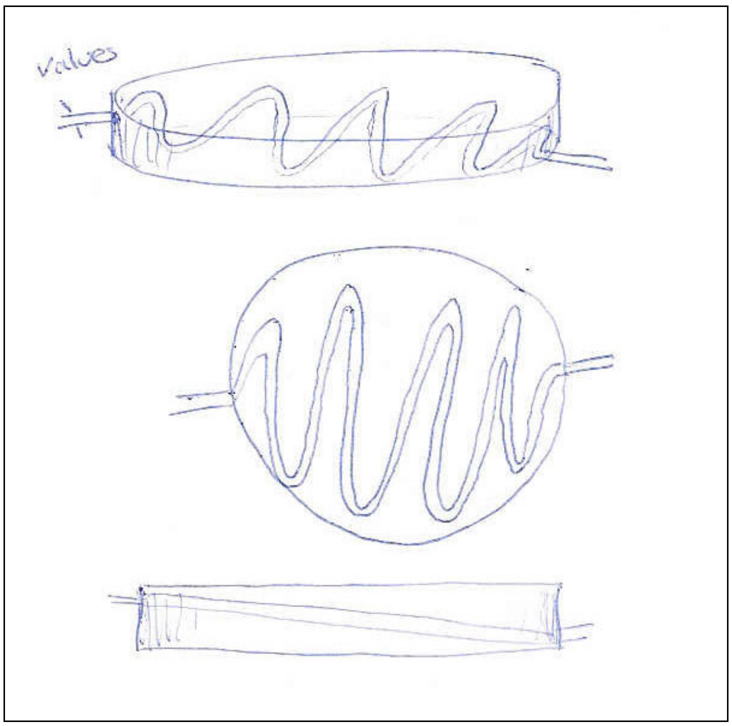

Illustration C.2.11: Tubes in a angle in the clay

The best way of heating the baking plate is to place the baking plate directly onto the heat storage barrel, see illustration C.2.12. This way the heat convection can take place, because the hottest oil is always at the top of the barrel. The colder oil descends easily. However, the problem with this idea is that one cannot control the heat. All the hot oil is against the baking plate, so the baking plate will always be the temperature of the hottest oil.

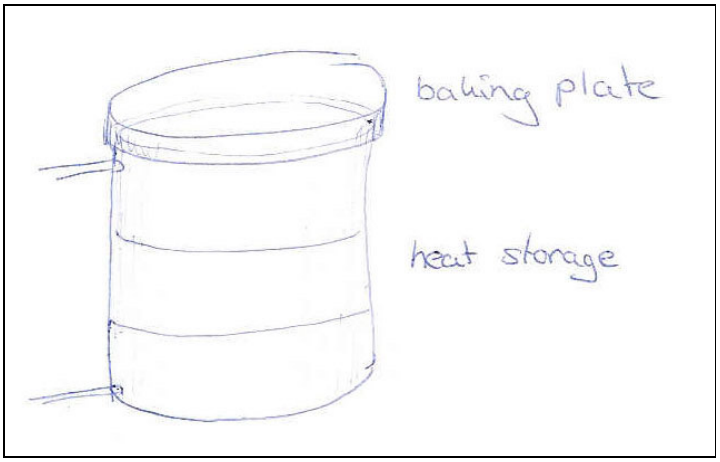

Illustration C.2.12: Baking plate on a oil barrel (heat storage)

The best way, while still being able to control the heat, should be a separate heat storage, with a smaller heat storage which has its own temperature and heats the baking plate. However, the smaller heat storage (active heat storage) cannot be too big, because the stored cold oil will decrease the temperature of the hot oil top a great deal.

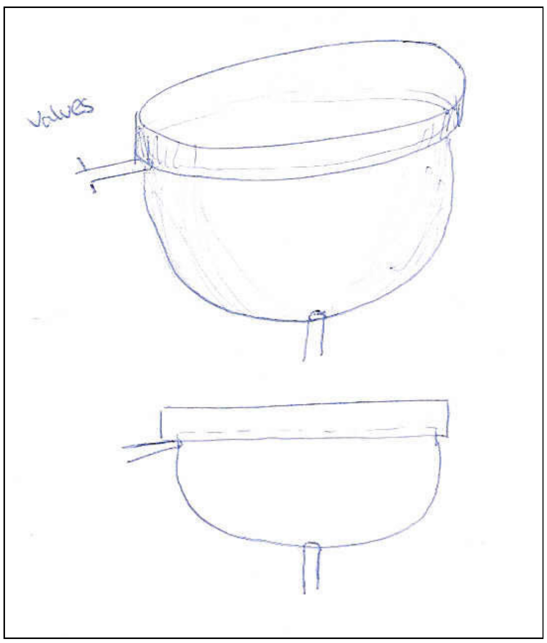

Illustration C.2.13: Baking plate on small heat storage

When using this option, all the demands are met: the baking plate is heated equally, the heat convection can take place and the heat can be controlled. Also, the heat goes to the baking plate in the most direct way, which has the least heat loss. However, the oil cannot be 100% directly against the clay, because it will absorb the oil. To prevent the clay from breaking, for instance a metal plate with high thermic conduction, could separate the oil and the clay baking plate.

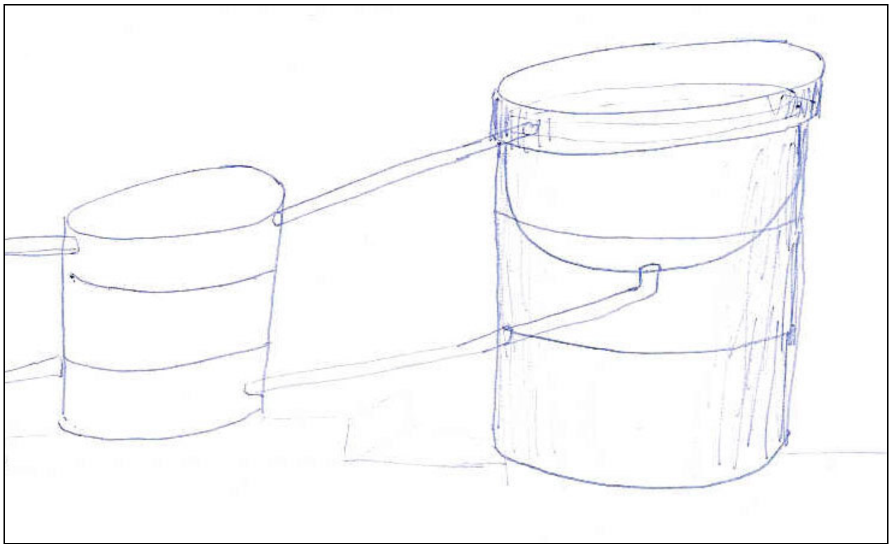

Illustration C.2.14: Baking plate on oil barrel for support

However, with a metal plate between the clay and the oil, there will be a lot of heat loss. A method should be used where the clay can be placed directly in the oil. To prevent the clay from falling apart, a protective layer should be applied on the clay baking plate. A good solution is glaze. This way, the clay will be protected from the hot oil. The glace should be baked onto the clay, while the clay is baked too. Both materials should get an temperature of 1100°C in the oven.

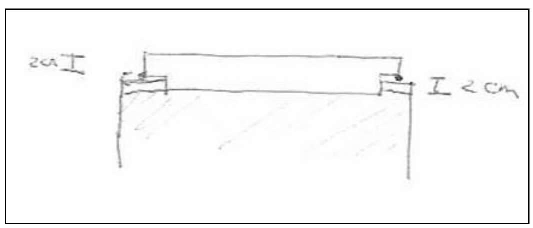

Illustration C.2.15: Plate in oil, separated by glaze

This method is also used in a Moroccan pot called Tagine. The pot is made out of clay and glaze. The glaze protects the clay by making it water proof.

Illustration C.2.16: Moroccan clay pot with glaze

The question is how long it takes the oil to reach 260°C in the sun in Ethiopia. This way it can be calculated whether it is realistic to heat oil with the sun. ***Keep in mind, that the amplifying factor of the receiver (solar box + reflectors)***

is still unknown. This factor reduces the time that is needed to heat the oil to 260° C.

From the calculations in Annex F.1 it can be concluded that is not possible to heat the necessary amount of oil when using a heat storage. The minimum is a storage of 157,08 liter. This will take up to 4h21m to heat, this is too long. If a heat storage is used, the volume should be larger to make it effectively. However, the heating time will increase. Due to this a heat storage can not be used. When looked at the heating time, one can see that a small amount of oil can be used to keep the heating time reasonable. A new design is made for a smaller "heat storage", which is located directly under the baking plate. In order to use this, the system should get hot in a short time. The baking plate can not be hot all day long, because it will not last long if this is done. Therefore, the system should be turned on and off.

With a heat storage separated from the baking plate, valves can be used to stop the circulation of the oil and therefore stop the heating of the baking plate. However, without a heat storage which is separated from the baking plate, valves cannot be used. The only way to stop the system from collecting more heat is to close the receiver (cover it with the reflectors).
When someone wants to bake, she should open the receiver an hour in advance (see annex F.1). After baking she should close it again to maintain the quality of the oil and the baking plate for a longer time.

The heat storage cannot be used as long as the receiver cannot receive more solar energy. The consequence of this decision is that people will have to change their ways of baking injera: ***it will take a bit longer before the injera is baked well. This has to be accepted in order to use the solar kitchen***.

In the table below can be seen that a temperature of 217°C can be achieved with the heat loss calculated. See Annex F for the calculations.

Heat IN (per hour)		**Heat OUT (per hour)**	
Solar energy	260°C	Tubes	4,87°C
		Storage	37,16°C
		Baking plate radiation	217,97°C
	260°C		260°C

Table C.2.2: baking plate radiation

C.2.3.2. Temperature measurement

In the Solar Kitchen there are two points at which the temperature should be known. First of all, the temperature should be known in the heat storage barrel. The temperature should not get higher than the temperature at which it will set fire[L9]. Therefore the temperature should be measured, and when the temperature gets too high, the sun collector should be closed. (reflectors should close the solar box). Secondly, the temperature of the baking plate should be known. When it is lower or higher than the required temperature (220° C), the temperature can be controlled by the valves.
Of course a simple thermometer can be implemented in the system. However, most people are illiterate and can therefore not understand the temperature.
Some other solutions:

- LAZOLA[L18] uses a metal which expands at higher temperatures. By wedging the end of this material, the top moves with the temperature in a radius. A certain distance can be calibrated to tell a certain temperature. An area which is "good" can be displayed.

- A thermometer with a needle can be used. Instead of the numbers, colors are used. Around 220° C, for the baking plate, can be indicated in the middle of the color range. Too high is red, too low is blue.
- The expansion tank can also be used for measuring the temperature. The level of the oil can give information about the temperature. Each temperature has its own height, when calibrating this, one can see each temperature on the expansion tank.

All options are expensive and require a lot of training; still these options cannot measure the temperature of the baking plate. A more local solution has to be found to be able to measure the temperature of the baking plate.
When searching for this solution Ton Putt[C27] of WOT told about a natural solution which is used in Spain. To see if an oven is hot enough, people throw pine tree needles into the oven. When these needles start burning, the oven is ready for use. A similar solution should be found in Ethiopia.

C.2.4 Total design

In this chapter the total design will be discussed. All the choices have been made, so a total design can be presented. A mockup has been made, by using pictures of the mockup a few things will be told.

Illustration C.2.17: Total design

In image C.2.17 the total design can be seen. The receiver is 2m^2 and has two reflectors of both 2m^2. It stands in an angle of 15°. To be able to absorb as much

as possible the metal is painted black. This way the metal absorbs solar beams and transports it to the tubes via conduction.
The baking plate, together with its oil reservoir (storage), are stored in the baking plate casing. The isolation is also hidden in this casting.
To make the baking more comfortable for the women, the baking plate is covered by a hut. A fourth of the wooden wall is facing west, it creates shadow in the afternoon. During midday the room creates a shadow as well. To be able to replace the oil, two tabs should be installed. One at the lowest point of the receiver to empty the system. And one tab near the baking plate, at the highest point of the system. This one is for refilling the oil.

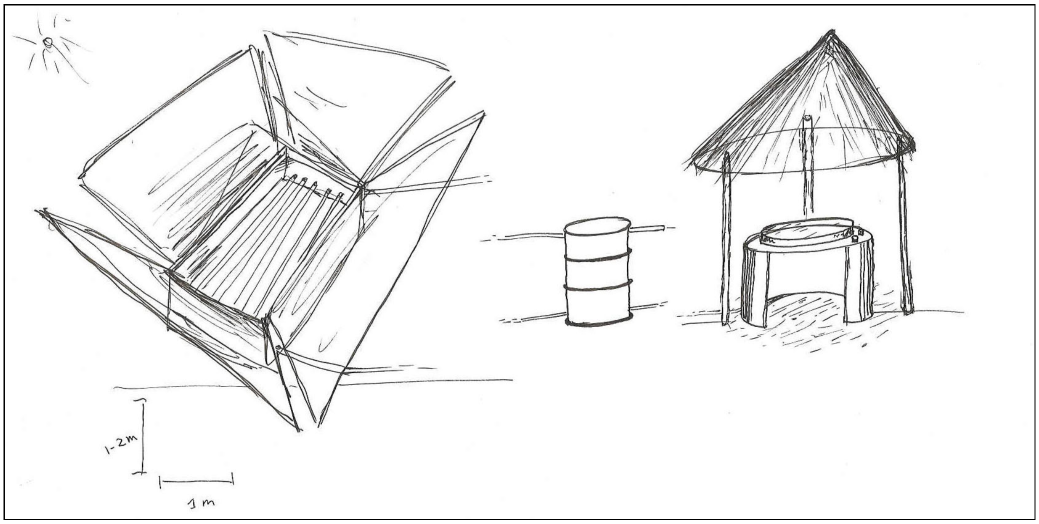

Illustration B.2.18: Receiver, barrel (storage) baking plate (in a hut)

The hut is made in the same way the huts are in Ethiopia at this moment, these can be seen in the collage in Illustration A.4.2. The receiver design is pure a result of form follows function. The outside has to be white, to radiate as little as possible. The cover is the same cover as is used now, see Illustration C.2.19.

Illustration C.2.19: left to right; closed, half open, open, cover on baking plate

More drawings can be found in Annex H

Chapter C.3 Costs of material

To be able to calculate a price for the Solar Kitchen, it should be known what the materials cost. A list with different materials can be found in Annex E. Below are estimates of the price.

Wood:	€ 20,98
Insulation layer:	€ 5,-
Metal sheet	€ 25,-
Tubes	€ 69,57
Glass plate	€ 25,-
Tube fixing plates	(out of metal sheet)
Reflector 2x	€ 50,- (mirror)
6x Hinge	€ 12,-
Support beams & holders	€ 10,-
4X Foundation blocks	(out of wood for support beams)
Oil Reservoir	(out of metal sheet)
Clay	€ 30,-
	-------- +
	€ 247,55

This is an indication of the price for the main parts. Trunks and straw are not included. Keep in mind that this is the price to make the Solar Kitchen in The Netherlands. The prices are from an expensive store, so even in The Netherlands, one can make this cheaper. The costs for wood, clay and mirrors will be lower in Ethiopia. For metal and the tubes will it be higher.

Chapter C.4 Conclusion

In this final chapter the conclusions will be discussed. Does the Solar Kitchen meet the demands? What has to be done after this research? Those question will be answered here.

C.4.1 List of demands

The list of demands will be discussed here, especially why a demand is met or not.

U1: <u>The solar kitchen should be of acceptable size</u>

The receiver of the Solar Kitchen is relatively large. However, because the receiver will be placed outside, this should not be a problem. Because it is low to the ground, it will not be in the view of the people.

Partially met

U3: <u>should be able to be at a high temperature (220° C) for a long time</u>

The Solar Kitchen is able to achieve high temperatures. If the user opens the reflectors in time, the oil will be heated enough after an hour to be able to cook.

U4. <u>The cooker should produce less smoke than stoves which are used now.</u>

The Solar Kitchen does not produces any smoke, since it does not use any wood or other material to burn.

U6. <u>They should be able to make the same amounts of food as they do now</u>

The amount of sun beams determine whether the Solar Kitchen will be working for a long time. Since Ethiopia has a lot of sun during the day, this will not be a problem.

P1: materials should be accessible in Ethiopia.

All used materials are accessible in Ethiopia. However metal and tubes are more expensive then other chosen materials.

P3. The size of the sun-beam receivers should not be out of proportion

The receiver is big, but acceptable. However, without this size, the Solar Kitchen will not work.

Partially met

A1. the costs should not be more than 100 - 200 euros

It is likely that the costs will be lower in Ethiopia. There fore the costs will be under 200 euros.

A2. users should not get blinded while using the Solar Kitchen.

Since the reflectors are placed away from the baking plate, the user can not get blinded while using the Solar Kitchen.

A3. The users should be able to maintain the Solar Kitchen

With proper training, and by using the different tabs, the user should be able to maintain the Solar Kitchen.

Partially met

A4. The cooker should use less wood

The Solar Kitchen does not use any fuel wood

A5. The method of baking injera should not be any different

Because no heat storage can be used, the method of baking is a bit different. Only in the time of baking is a difference, this has become longer. The rest is the same.

Partially met

A6. The clay baking plate of the current stoves have a diameter of 90 – 100 cm. It's about 2 cm's thick

The diameter is 100cm.

A7. it should be practical, and the users should think that as well

Since only the heating source has changed, the method of baking is the same (only a little longer). Therefore it can be said that it is still practical.

C.4.2 Conclusion

The question that was raised by SUPO every time was whether it would be technically possible to design a injera bakery on solar energy. The most important aspects were costs and culture. By looking at chapter C.4.1, the list of demand, it can be said that the answer to SUPO's question is yes! Almost every demand is met, only four have partially been met. These are especially not totally met, because of choices that had to be made. Without these choices the Solar Kitchen would not work properly.

Even though still a lot has to be done before a solar kitchen can be implemented in Ethiopia, the first part of the journey toward that goal has been a success.

C.4.3 Recommendations

As said in C.4.2 some demands were not met because choices had to be made. Some of them were made based on assumptions. In this chapter some recommendations will be made to how this project should be continued:

Trial and error or analysing:
A choice has to be made about what the next step will be. The two options are "trial and error design" or analysing and "redesign". Because trial and error design will get very expansive in this case, it is recommended to start analysing the purposed system first. When analysing, one should be calculating the actual heat losses and make realistic calculations about the final baking temperature. After the redesign, one should start testing a prototype in Ethiopia or in The Netherlands (if the weather allows it)

Heatstorage:
The possibilities and necessity for a heat storage should be researched deeply. The expectation is that a heat storage will benefit the system, but is what way? This should be figured out.

Receiver:
The most crucial part of the Solar Kitchen is the receiver. By improving this by looking more closely to the choice of material and insulation, the Solar Kitchen can get more effective.

Bio Energy:
The Solar Kitchen is only a solution when there is sufficient solar radiation. When this is not the case, the Solar Kitchen can not be used. For the days that this is the case a alternative should be provided. By implementing a bio energy solution in the Solar Kitchen, the user can choose between solar energy or bio energy.

Target group test:
Before implementing the Solar Kitchen on a bigger scale, the bakery should be tested with the target group. This way, one can see whether it is accepted and practical. With these results the Solar Kitchen should be redesigned.

List of abbreviations
Annex A - H

List of abbreviations

AU: African Union

DDA: Donkey for Development Association

ECA: Economic Commission for Africa

GTZ: Gesellschaft für Technische Zusammenarbeit

SCI: Solar Cookers International

SUPO: Stichting voor Urbane Projecten in Ontwikkelingslanden, Association for Unban Projects in Development countries.

UNDP: United Nations Development Program

WOT: Werkgroep OntwikkelingsTechnieken, Working goup Techniques for development countries.

Annex A: Research Proposal (dutch)

Definities

Enjera: bij de meeste maaltijden wordt "Enjera" als basis gebruikt. Enjera is een soort pannenkoek, gemaakt van de graansoort teff. Deze pannenkoek wordt gegeten met verschillende soorten sausjes. Correctie schrijfwijze onbekend, kan ook geschreven worden als: enjerra of injera.

Solar Kitchen: werkingsprincipes van een gehele zonne keuken. Dus de zonne opvang onderdelen, eventuele versterking, geleiding naar bakplaat en bakplaat zijn gezamenlijk de Solar Kitchen. De bekisting etc wordt hierbij niet meegeteld.

Actoranalyse

De Stichting voor Urbane Projecten in Ontwikkelingslanden, SUPO, is in Nederland opgericht in 1977. Het betreft een kleine stichting die diverse lokale partners ondersteunt in enige landen in Afrika. Sedert 2000 betreft dit vooral een bijdrage voor het opzetten van centra voor kansarme kinderen en het bevorderen van het gebruik van zonne-energie voor de bereiding van maaltijden in de urbane en rurale omgeving. In de periode 2006-2008 hoopt SUPO deze activiteiten voort te kunnen zetten in Burkina Faso en een nieuw programma te kunnen starten in Ethiopië. Deze opdracht richt zich met name op de voorbereiding van dit nieuwe programma in Ethiopië.

Projectkader

In de hoofdstad Addis Ababa zijn de kosten voor fossiele brandstof erg hoog. Circa 80% van de bevolking in Ethiopië woont op het platteland. Meestal moeten vrouwen ver lopen om hout te sprokkelen in een wijde omgeving rond hun dorp. Rond 1950 was Ethiopië voor circa 40% bebost, thans is dat nog maar 3%. Hout is een schaars goed geworden. Bovendien is de voortschrijdende ontbossing een ernstig gevaar voor het wegspoelen van vruchtbare grond. De dreiging van hongersnood ligt ieder jaar op de loer. Het gebrek aan voedsel heeft in de voorbije jaren duizenden mensenlevens geëist.
Zonne-energie, biogas en biodiesel kunnen in de komende jaren een belangrijke bijdrage leveren voor de energievoorziening voor de huishoudens in de urbane en rurale omgeving.

Opdrachtomschrijving

Een groot deel van de bevolking van Ethiopië heeft weinig, maar een ding hebben ze in overvloed: zonlicht. Zou het niet beter zijn voor dit deel van de bevolking om niet meer elke dag vele uren kwijt te zijn om hout te sprokkelen? Zou de bevolking in de steden niet beter af zijn als ze minder geld zouden besteden aan de aankoop van hout en houtskool op de lokale markt? Het antwoord is natuurlijk een volmondig ja! Een van de manieren om dit te bereiken is het gebruik van hout te beperken. Het gebruik van de zon als energiebron komt dan in beeld. Op welke wijze kan zonne-energie effectief worden benut?
De opdacht is als volgt: ontwerp een "solar kitchen". In de *solar kitchen* zullen een aantal vrouwen uit het dorp Enjera maken, welke voor de rest van het dorp beschikbaar gesteld zal worden (waarschijnlijk tegen betaling).

Het doel is om de *solar kitchen* te laten vervaardigen in Ethiopië, daarom kunnen alleen materialen gebruikt worden die daar aanwezig zijn. Tevens moeten de kosten (op dorps niveau) zo laag mogelijk zijn.

Doelstelling

Het onderzoek is een praktijkgericht onderzoek, omdat het gebruik zal maken van bestaande theorieën en een ontwerp als eindresultaat zal hebben. Daarom is het ook een ontwerpgericht onderzoek. Het probleem is reeds gesignaleerd, maar er is wel een diagnostische fase wenselijk om inzicht te krijgen in het probleem. Op basis hiervan wordt een programma van eisen opgesteld wat de leidraad zal worden voor het ontwerp. Dit ontwerp zal uiteindelijk een pakket van technische tekeningen zijn, die in Ethiopië gebruikt zal worden bij de productie van het ontwerp.

De doelstelling van het onderzoek is het ontwerpen van een Solar Kitchen, waarmee "enjera" gebakken kan worden, door te analyseren aan welke eisen en functies deze solar kitchen moet voldoen en zo een ontwerp, waarvan ook een prototype, te maken welke na testen de correcte ontwerptekeningen als eind resultaat zal opleveren.

De doelstelling is *nuttig* omdat dit ontwerp een toevoeging is in de strijd tegen de armoede in Ethiopië. Hierdoor zullen mensen minder, tot geen, geld uitgeven aan brandhout. En hierdoor zal men niet meer 6 – 7 uur per dag hoeven te zoeken naar hout, men houdt dus tijd "over" voor persoonlijke ontwikkeling.

De doelstelling is ook *uitvoerbaar* in de gestelde tijd, omdat er al zeer veel bekend is op dit gebeid. Door naar Ethiopië te reizen en door een congres met betrekking tot dit onderwerp te bezoeken, zullen nog meer contacten worden opgedaan en zal er meer informatie met betrekking tot de context gevonden worden. Tevens zijn er bij aanvang reeds vele vraagbaken en informatie punten beschikbaar.

Tevens is de doelstelling *eenduidig* omdat het duidelijk is wat het resultaat moet worden. Daarnaast staat de hoofdfunctie van het ontwerp beschreven in de doelstelling.

De doelstelling is *informatierijk* omdat het ontwerp traject hierin beschreven staat. Tevens staat er in wat het precieze eindresultaat is.

Vragen

Om bovenstaande doel te kunnen bereiken zijn een tweetal reizen ingepland. Het doel van deze reizen is om sneller meer informatie te kunnen vergaren. De eerste reis zal naar Ethiopië gaan. Hier zal een groot deel van het onderzoek gedaan worden. Na de reis naar Ethiopië zullen een aantal vragen beantwoord moeten kunnen worden:

Q1: In welke context zal het ontwerp gaan werken?
- 1.1 Wie gaan het gebruiken?
- 1.2 Waar zal het gebruikt worden?
- 1.3 Waar zal het nog meer voor gebruikt worden, naast het bakken van enjera?

Q2: Aan welk programma van eisen moet het ontwerp voldoen?
- 2.1 Wat zal de functie precies worden?
- 2.2 Aan welke eisen moet het voldoen voor de gebruikers?
- 2.3 Aan welke eisen moet het voldoen voor de producenten?
- 2.4 Aan welke eisen moet het voldoen voor de gerelateerde stichtingen?

Q3: Welke temperatuur moet bereikt worden om de "enjera" goed te kunnen bakken?
- 3.1 Wat is "enjera"?
- 3.2 Hoe wordt het gebakken?

3.3 Hoe wordt het gegeten?

Q4: Wat wordt in Ethiopië nu gedaan om de situatie te verbeteren?
- 4.1 Hoe ver zijn de ontwikkelingen m.b.t. het ontwerp van een solar kitchen in Addis Ababa? (specifiek: samenwerkende instellingen)
- 4.2 Welke Solar alternatieven worden er nu al geïntroduceerd?
  - 4.2.1 Van welke werkingsprincipes maken deze gebruik?
- 4.3 Welke voordelen heeft de Solar Kitchen t.o.v. de huidige situatie?

De tweede reis zal naar een congres in Granada, Spanje gaan. Dit congres gaat over Solar Cooking. Een onderwerp dat past bij deze opdracht. Hier zullen veel mensen aanwezig zijn die zich bezig houden met het ontwerpen van Solar Cookers. Tevens doen zij onderzoek naar manieren om de armoede, m.b.t. voedsel, in Afrika te verminderen. Na de reis naar Granada zullen een aantal vragen beantwoord moeten kunnen worden:

Q5: Welke producten zijn op dit moment al werkzaam?
- 5.1 Wat is er nu technisch mogelijk?
- 5.2 Van welke werkingsprincipes wordt nu gebruik gemaakt?
- 5.3 Wat zijn de nieuwe ontwikkelingen?

Q6: Hoe kan een Solar Cooker worden ingezet om armoede m.b.t. voedsel, te verminderen?

Na dit deel zal het gehele vooronderzoek afgerond zijn. Na deze fase zal worden gewerkt aan concepten.

Q7: Welk ontwerp zal uiteindelijk getest worden?
- 7.1 Wat zijn de eisen en wensen aan het eindontwerp?
- 7.2 Welke concepten zijn er?
- 7.3 Welk concept voldoet het beste aan het programma van eisen en wensen?
- 7.4 Wat is de detail werking van het gekozen concept?

Onderzoek materiaal

Hierbij zal per deelvraag worden aangegeven welk onderzoeksmateriaal gebruikt zal worden.

Q1: In welke context zal het ontwerp gaan werken?

1.1: Werkelijkheid → observatie
Personen → ondervraging: interview, face-to-face
1.2: Werkelijkheid → observatie
Literatuur → inhoudsanalyse
1.3: Personen → ondervraging: interview, face-to-face

Q2: Aan welk programma van eisen moet het ontwerp voldoen?

2.1 Werkelijkheid → observatie
Personen → ondervraging: interview, face-to-face
2.2 Personen → ondervraging: enquete, face-to-face
2.3 Personen → ondervraging: interview, face-to-face
2.4 Personen → ondervraging: interview, face-to-face

Q3: Welke temperatuur moet bereikt worden om de "enjera" goed te kunnen bakken?

3.1 Literatuur → inhoudsanalyse
Media → internet
3.2 Literatuur → inhoudsanalyse

Media → internet
3.3 Literatuur → inhoudsanalyse
Media → internet
Werkelijkheid → observatie

Q4: Wat wordt in Ethiopië nu gedaan om de situatie te verbeteren?
4.1 Werkelijkheid → observatie
Personen → ondervraging: interview, face-to-face
4.2 Personen → ondervraging: interview, face-to-face
Literatuurstudie → inhoudsanalyse
4.4 Resultaat

Q5: Welke producten zijn op dit moment al werkzaam?
5.1 Personen → ondervraging → interview, face-to-face
Personen → congres
Literatuurstudie
Media → internet
5.2 Personen → ondervraging → interview, face-to-face
Personen → congres
Literatuurstudie
Media → internet
5.3 Personen → ondervraging → interview, face-to-face
Personen → congres
Literatuurstudie
Media → internet

Q6: Hoe kan een Solar Cooker worden ingezet om armoede m.b.t. voedsel, te verminderen?
Personen → ondervraging → interview, face-to-face
Media → internet

Q7: Welk ontwerp zal uiteindelijk getest worden?
7.1 Documenten → uit eigen onderzoek een PvE opstellen
7.2 Uitwerking
7.3 7.2 toetsen aan 7.1
7.4 Uitwerking

Onderzoeksstrategie
Dit onderzoek zal een diepgaand onderzoek zijn, aangezien er een specifieke doelgroep onderzocht zal worden. Tevens zal er een kleine groep "concurrenten" onderzocht worden.
De analyserende fase van dit onderzoek zal een kwantitatief karakter hebben. Hierin zullen vooral survey's de overhand hebben. Maar er zal ook een kwalitatief onderdeel zijn, aangezien ook literatuurstudies een onderdeel zijn van dit onderzoek.

Knelpunten
Het belangrijkste knel punt is dat er te veel moet gebeuren. Er komen zeer veel, interessante, aspecten kijken bij dit onderzoek. Het is daarom van groot belang dat de planning strikt wordt nageleefd, en dat de doelstelling goed in de gaten wordt gehouden. Alleen zo, kan er niet te veel afgeweken worden van het onderzoeksdoel.

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Annex C: Contacts

C1 :
Gullilat Abera
Director of *Donkey For Development Association (DDA)*
DDA was set up in 1998, but in the two years before that the idea was already present. Unfortunately, it took about two years to make DDA an official NGO. Current "Donkey For Development" project consists of the following: women get a donkey if they are willing to work on the land for a certain amount of hours. On this land they have to plant trees to prevent erosion. They also have to pay one birr a month to pay for a guard. His job is to protect the tree siblings which have just been planted. Unfortunately, this man does not do his job well, that is why the trees of the current project are not growing as they should. Fortunately the project worked in another village. 200 Women are involved in the current project. To prevent the trees to be eaten by sheep, goats and donkeys, DDA is planting Cactuses that should work as a fence, hopefully the animal will not pass these cactuses so that the tree siblings will be able to grow.
The women will have advantage in different ways. First of all, they will all own a fertile piece of land on which trees and other plants will be able to grow. They can sell the trees that grow on the land to each other or other corporations, they can decide for themselves whenever to sell a tree. However, it is a must to plant two new trees for every tree that has been cut down. They can also use the trees themselves, for construction, selling or fuel, but they must pay for this tree as well. This money for the trees goes to a community bank account, this is used for maintaining the piece of land, and the profit is divided among the women.

C2 :
Negewo Hailu
Contact at *Gende Gorba Peasant Association*
The Gende Gorba Peasant Association is a union of all the farmers of Gende Gorba. This association acts as a spokesman for these farmers in all relevant cases. They also arrange common things together: storage and distribution of fertilizer for instance. Besides this, the association is also a place where farmers come together and discuss all the current topics.
Besides the farmers (men), the women also use the peasant association as a place to come together and discuss several topics. The usages of solar cookers could be one of those topics.

C3:
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Horn of Africa Environment Programme
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Old Airport Zone
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Addis Ababa
Ethiopia
+ 251 (0) 11 37 111 00
jc.poley@minbuza.nl
www.netherlandsembassyethiopia.org

C4:
Tim Veldman
Ethiopian Steel Profiling and Building Cooperation (ESPBC)

This is a steel plant which was set up by the Dutchman Tim Veldman. At this moment 64 people work at ESPBC. On average they earn 1 birr a day, which is a lot considering the Ethiopian standard. ESPBC has existed for 3 years and makes steel profiles, blocks and wooden cabinets.
The father-in-law of Tim Veldman has a steel plant in the Netherlands, but he wanted to set up a steel plant in a developing country. The money for this went to an association, which is shareholder of ESPBC. The profits do not have to go back to the Netherlands, but should be invested in Ethiopia.
0911 40 56 38
011 4334771
espbc@ethionet.et

C5:
Solar Bereket
011 646 73 07 (office)
0911 22 (or 88) 51 31 (mobile)
solarber@yahoo.com

C6:
David R.
Selam Technical & Vocational Center
This orphanage grew out to be a technical educational centre for Ethiopian orphans. They experiment with a few solar solutions here.
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C7:
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C8:
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Rift Valley Children and Women Development Association
Program manager
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Rift Valley Children and Women Development Association is a governmental association. Their work aims at five main points: food security, education, health, environment and HIV/aids.

C9:
Gezahagn
Gezahagn10@yahoo.com
0911 38 85 65 (last 5 could be a 3)

Maker of an automatic injera baker and a double-sided baker.

C10:
Solar Serve
Hans van Beek
Project Advisor

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Da Nang, VietNam

hansnl@dng.vnn.vn
www.vietnamsolarserve.org

Solar Serve is an organization which tries to promote Solar Cookers in Vietnam. They mostly implement solar ovens made out of materials bought at the market in Vietnam itself.

C11:
RSD, Solar Water, RSD Rosendahl System
Monika Seidel

Office Munich
Schleissheimer Str. 38
D – 80333 Muenchen
Germany

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www.rsdsolar.de

RSD makes solar water distillation systems.

C12:
Foundation Solar Cookers for Development Countries
Gerard Jörg

De drie morgen 23
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gjorg@casema.nl
033 – 4808044

Gerard Jörg has a solar promotion project and fabrication project in Gambia.

C13:
Foundation Solar Cooking Eritrea- Netherlands (SCEN)
Clara Thomas
Chairwoman / Project manager

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The Netherlands

Cookit.ned@wanadoo.nl
www.solarcookingeritrea.nl

Since 2004 SCEN has implemented the CooKit in Eritrea.

C14:
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Washington, D.C. 20520

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This employee of the US Department of State tries to promote the use of solar energy in the US government.

C15:
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Jim Scott
Project Director

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www.solarcooking.org/bkerr

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Taylor, AZ 85939 USA

This center promotes a sustainable living and a life in harmony with the natural world. They do this among other things with a through the wall solar oven.

C16:
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C17:
Sunfire Solutions
Crosby Menzies
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Crosby Menzies is making a continental network for Solar Cookers: Solar Cookers for Africa.

C18:
Solar Household Energy, Inc.
Louise Meyer

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USA

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www.she-inc.org

This non-profit organization has developed the Hot Pot, a black and glass pan which is used in a CooKit to prepare a dinner faster.

C19:
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Writer of the book *Solarkocher*[14].

C22 :
Solea
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Solar Consultant in Spain from Canada.

Solea is a consulting organization specialized in climate change, renewable energy and CDM.

C23:
Marije ter Beke
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Dutch Industrial Design student

C24:
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The maker of a paper parabolic cooker.

C25:
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Xavier Devos makes a parabolic cooker out of mirrors and wood only.

C27:
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Annex D: Inquiry /interviews

To get an better image of the target group, several households have been interviewed. A small number of questions have been asked with regards to cooking habits, way of living, energy sources, etc. The interviews were taken via a translator. Below are the questions plus the results of two households. These two households are from Gende Gorba. To get a better image, more questionnaires will be made. Different associations will do this in the coming month: two households in Ziway and two households in another village in Oromia.

The questions
Some of the questions have been deleted while working on the interviews. Therefore, the numbers of the questions will not be complete.

1. How often a day do you use the stove?
2. Besides baking injera, what else do you use it for?
3. How do you make your stove safe?
4. Has someone ever got hurt by using the stove?
5. How long does it take before it gets hot?
6. X
7. How many meals do you prepare a day?
8. In general, how many injera does one meal contain? And other elements?
9. For how many people do you cook every day?
10. Which energy source do you use?
11. Where do you get this energy source?
12. How much time do you spend a day to get this?
13. How much money do you spend a day to get this?
14. X
15. What is bad about your stove?
16. What is good about your stove?

Extra question

7. What is your income?
8. How do you earn your income?
9. What are you expenses?
10. Where do you spend it on?
11. How many people live in your village?

Result 1
This woman was using a wood saving stove for baking injera. This is also used for making bread and for cooking water for tea and coffee. Besides this she also uses a traditional stove for other pans that do not fit on the wood saving stove.

1. Every 3 or 4 days. It depends on how much she needs. Usually she starts baking more injera or bread when she is almost out of injera or bread.
2. Bread and injera. On the chimney she boils water and makes Watt (the sauce that is eaten with injera)
3. The stove is very hot for a long time. Until it is cold, no children are allowed to come near the stove. It is a house rule.
4. No, it is safe this way.
5. 10 minutes
6. X
7. 3 times a day.
8. 3 people in the family. In one day: 1 bread in the morning, 1 bread during the day and 1 bread in the evening. She does not eat too much injera,

because it is too expensive. When she, and her family, eat injera, they eat just one. This is also because it is too expensive to eat more. She does not have land to earn a bit of money, her husband or father is not a farmer.

9. 3
10. Stow and Cow dung
11. She searches during the day, searching on the roads where herds have walked, or walking behind herds and taking the cow or horse dung. In the rainy season this is very difficult, because fewer herds walk to the land.
12. 2 – 3 hours a day
13. not relevant
14. X
15. Nothing is wrong
16. Everything is good. The new stove does not use much fuel and produces less smoke. Also, one can do a lot on this stove once it is warm.

Extra questions:

7. / 8. She does not have much income. Her husband drives a horse taxi, the income of which is variable. In general he earns 5- 10 birr a day, but the bigger part of this goes to the food etc. of the horse. Only after 3 – 5 birr he makes a profit.

9. / 10. Food, horse, clothes and children.

11. 1975

During the conversation an extra question was asked:
What if we made a cooker which does not use any fuel? What would you think of that?
While the question is asked she looks very serious, at the end of the question she is smiling and answers: everything that works better is better! It would save a lot of time.

Result 2
This woman was also using the wood saving stove for baking injera. But when this interview was taken, she was using an traditional stove to make coffee. The result was that a lot of smoke and ashes were in the "kitchen" (also dining room).

1. Two times a week. She bakes about 15 injera every time.
2. Mostly bread and injera. Besides that she sometimes uses the injera stove for boiling water for tea or for making watt. In that case she puts the pan on the clay to boil the water. Problem with this is that the pan has to be big enough (in radius), otherwise the clay will break.
3. She doesn't have older children, only a baby, so by using a cover it is safe enough.
4. No
5. The wood saving stove takes 5 minutes to get hot, the old one took about 15 minutes.
6. X
7. Three meals a day.
8. It depends on the amount of money she can spend on it, and what she can get in the village. It can vary from cabbage, spaghetti, macaroni, bread, injera, meat, vegetables, etc.
9. Two: her husband and herself, but she also has a baby.
10. Cow dung, straw, horse dung, sometimes a bit of wood, but these are just some sticks she finds on the road.
11. She gets the dung of her own land, she has horses and oxen.
12. No time, own land.
13. None
14. X

15. No negative points.
16. Positive points about the wood saving stove are: it uses less fuel, there is no smoke, when it is hot it is very quick so one can make many injera, the chimney can be used for boiling water at the same time.
    With respect to the old stove: when the wood is burning in a good way, there is no smoke. Usually it is not burning the right way.

Extra questions:

7. It varies, in the summer 20 – 30 birr a day. But now it is rainy season, so the income is much lower. It is not possible to save in the summer for the rain season, because the costs for maintaining the horse (which generates income) are very high.
8. Her husband has a horse taxi. The maintaining of this horse is very expensive.

9./10. Food, maintaining the horse, household (tea etc).

11. Same village, so 1975 people.

In this conversation the extra question was also asked:
What if we made a cooker which does not use any fuel? What would you think of that?
She thinks about it for a while and also starts smiling. She would be very happy if she would be able to use such a thing. She is always happy with things and people who help her, as long as she knows how they work.

Annex E: Costs

Source: Praxis. 2 august 2006

Mirrors	
120 x 45cm, 5,4 Kg	€ 24,50
70 x 55cm, 3,8 Kg	€ 17,29
Wood (244 x 122cm)	
Chipboard, 9mm	€ 6,49
Chipboard, 15mm	€ 9,79
Chipboard, 18mm	€ 10,49
MDF, 9mm	€ 11,99
MDF, 12mm	€ 12,89
MDF, 18mm	€ 18,49
Plywood, 9mm	€ 34,99
Plywood, 12mm	€ 44,99
Plywood, 15mm	€ 57,95
Plywood, 18mm	€ 67,95
Tubes	
Red Copper, 3m, d=12mm	€ 11,55
Red Copper, 3m, d=15mm	€ 15,75
Red Copper, 3m, d=22mm	€ 23,19
Cut-off cock, 12x12mm	€ 5,69
Cut-off cock, 15x15mm	€ 5,99
*Hinge*s	
60 x 60mm	€ 2,29 - € 7

Annex F: Calculations

F.1 Heating time and amount of oil

Solar flux in Ethiopia: 5,7 kW/m^2 [bereket]

$$Q = mc\,dT$$
$$\int Q\,dt = mc(T-T_0)$$
$$\Delta t\,Q = mc(T-T_0)$$

Q = total heat transfer, kJ
m = mass, kg
c = specific heat, kJ/kg.K
T = temperature, K
t = time, s
η = efficiencyreceiver
ρ = density : 920 kg/m^3

$$Q = mc(T-T_0) / \Delta t$$

$$m = \Delta t.Q / c(T-T_0)$$

$$Q = \text{solar flux Ethiopia X surface area (A) X } \eta$$

A_p = 1,60 (surface of the entire plate + the tubes), η = 0,40

To get a clear idea about how much liter oil can be used, several different hours are tested to see what the outcome is.

If:
Δt = 1h = 3600s
m_p = 33,16 kg
V_p = <u>36,05 liter</u>

If:
Δt = 2h = 7200s
m_p = 66,33
V_p = <u>72,10 liter</u>

If:
Δt = 3h = 10800s
m_p = 99,49
V_p = <u>108,14 liter</u>

If:
Δt = 4h = 14400s
m_p = 132,65 kg
V_p = <u>144,18 liter</u>

Heating time with heat storage

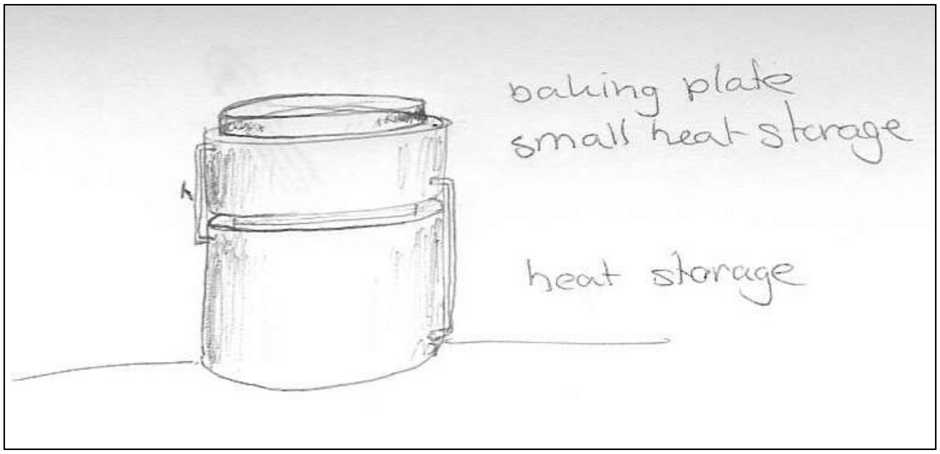

Illustration F.1

The small heat storage is the storage which heats the baking plate. The hot oil is stored in the heat storage. When the valve is opened, the hot oil can go from the heat storage to the baking plate. The height of the small heat storage is 1 dm, the height of the heat storage can vary starting from 1 dm.

The volume of the solar kitchen with a heat storage of 5 dm height is:

$V_{\text{small heat storage}} = \pi r^2 h = \pi(5)^2\ 1 = 78{,}54$ liter
$V_{\text{heat storage}} = \pi r^2 h = \pi(5)^2\ 5 = 392{,}70$ liter

$V_{\text{total}} = 78{,}54 + 392{,}70 = 471{,}24$

The amount of oil used in the Solar Kitchen with heat storage is 471,24 liter. The heating time is:

$$\Delta t = mc(T-T_0) / Q$$

m = 433,54 kg
47 062 s = <u>13h4m</u>

Heating time without heat storage

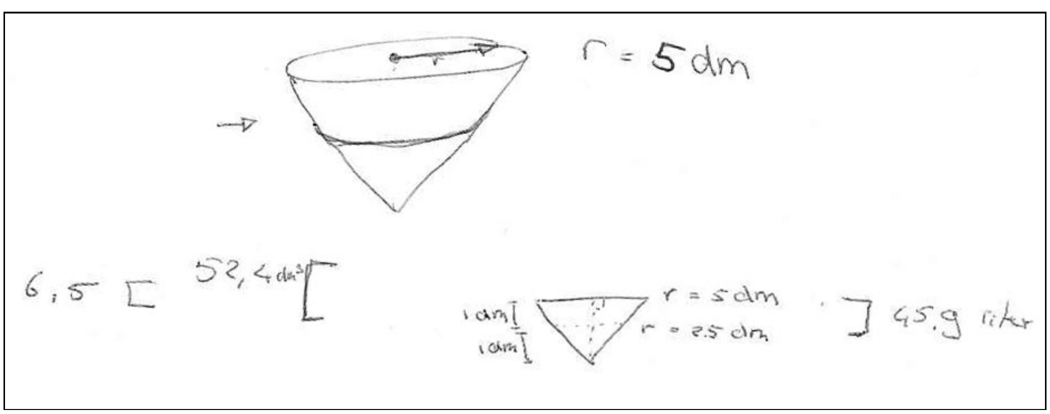

Illustration F.2: Oil reservoir

V_1 = (r=5; h=1,1) = 28,80 liter
V_2 = (r=0,5; h=0,1) = 0,03 liter
__________ +
27,77 liter, with all oil in tubes: 35 liter => 32,2 kg

Δt = 3495s = 58m

F.2 Heat loss; per meter outside system

Stefan – Boltzmann:

$$Q_{emit} = \varepsilon\sigma AT^4$$

A: $2\pi rh$, r = 11.10^{-3}, h=1 A = 0,06912 m^2 (radiation surface)
ε = copper: 0,17, stainless steel: 0,17, general: 0,8 – 0,08
σ = $5,67.10^{-8}$
T = 260 + 273 = 533K

Q = 316,30. ε
ε = 0,17 => Q = 53,77 J/s
ε = 0,8 => Q = 253,04 J/s

Steel tube radiates 253,04 J/s

Clay/straw insulation is used. Heat transfer coefficient: 0,08 W/m.k
Insulation layer is 2cm = 0,02m

0,08x260x*0,02*=0,416 J/s

= 1497,6 J/h

Q = cmΔT

c = specific heat clay: 880 J/kg.K
m = V_{tube} = $\pi r^2 h$ = $\pi(11.10^{-3})^2 1$ = 0,00038 m^3 = 0,3496 kg

Per hour:
1497,6 = *880 X 0,3496 X ΔT*

ΔT = 4,87°C

F.3 Expansion

$$\Delta V = \beta V_0 \Delta T$$

ΔV : change of volume caused by temperature
β : expansion coefficient
V_0 : start volume
ΔT : change of temperature

The total volume of oil in the system is: V = 35 liter

Temperature rising, in the best case: 20°C -> 260°C : ΔT = 240°C

Expansion coefficient of olive oil: $0,72 . 10^{-3} K^{-1}$

The change of volume is: $\Delta V = \beta V_0 \Delta T = 0,72 . 10^{-3} \times 35 \times 240$ = 6,048 liter

F.4 Expansion location

The expansion tank will be placed under the baking plate. In this section are the exact dimensions calculated of the expansion tank.

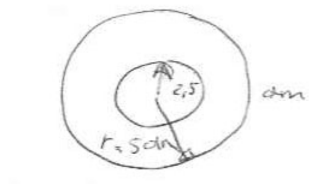

Illustration F.3: underside baking plate

$I_1 = \pi r_1^2 h = \pi(2,5)^2 h = 19,96h$
$I_2 = \pi r_2^2 h = \pi(5)^2 h = 78,54h$

$I_2 - I_1 = 58,91h$

$58,91h = 6,5$ liter
- ⇨ $H = 0,11$ dm $= 1,1$ cm

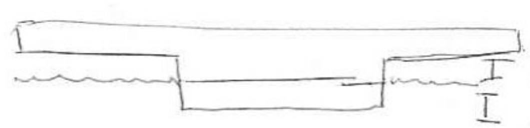

Illustration F.4: Expansion location and volume

F.5 Total system

Heat IN: Solar Energy
$5,7 \text{ kW/m}^2 * 1,60 * 0,4 = 3648$ J/s

Heat OUT: tubes: see F.2

Heat OUT: storage

Surface of storage:

$A_1 = \pi r(r^2 + h^2)^{1/2} = \pi 0,5(0,5^2 + 0,2^2)^{1/2} = 0,8459 \text{ m}^2$
$A_2 = \pi r(r^2 + h^2)^{1/2} = \pi 0,25(0,25^2 + 0,1^2)^{1/2} = 0,2115 \text{ m}^2$
$A_3 = \pi r^2 = \pi(0,25)^2 = 0,1963 \text{ m}^2$
$A_1 - A_2 + A_3 = 0,8307 \text{ m}^2$

$$Q_{emit} = \varepsilon\sigma A T^4$$

$\varepsilon = 0,8$ (for steel)
$\sigma = 5,67.10^{-8}$
$T = 260 + 273 = 533K$

Q = 3041,07 J/s (without insulation)

Clay/straw insulation is used. Heat transfer coefficient: <u>0,08 W/m.k</u>

Insulation layer is 2cm = 0,02m

0,08x260x*0,02*=0,416 J/s

= 1497,6 J/h

$Q = cm\Delta T$

c = specific heat clay: 880 J/kg.K
$V_{cone} = 1/3\ \pi\ r^2\ h$
$m = V_{cone} = V_1 - V_2 = (1/3\ \pi\ (0,5)^2\ 0,2) - (1/3\ \pi\ (0,25)^2\ 0,1) = 0,0458\ m^3$

Per hour:
1497,6 = *880 X* 0,0458 *X* ΔT

$\Delta T = 37,16°C$

Heat IN (per hour)		**Heat OUT (per hour)**	
Solar energy	260°C	Tubes	4,87°C
		Storage	37,16°C
		Baking plate radiation	217,97°C
	260°C		260°C

F.7 Length, surface area and volume tubes

Used are diameter 22mm red copper tubes. The minimal distance from the zigzag tube to the receiver sides is 150mm, this space is needed for insulation. The width of the zigzag tube is 700mm, including the curves with a radiation of 50mm. Maximum height is 1700mm. See Illustration C.2.1.

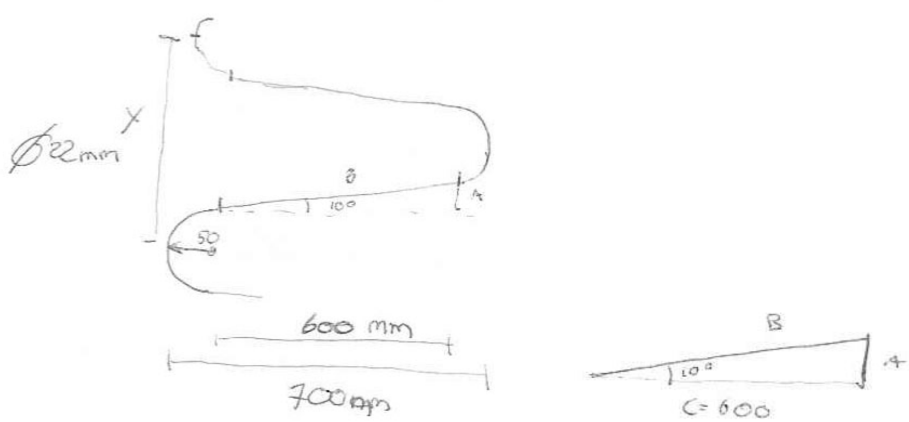

Illustration F.5a & b: size of curve

The unknown length A and B can be calculated with the known angle. The length A will contribute in calculating the number of curves as shown in Illustration C.2.1. Length B will contribute in calculating the total tube length and therefore the volume of the needed oil.

Tan α = A/600 => A = 600.tan.10° = 105,8 mm ≈ 106mm

$\cos \alpha = 600/B \Rightarrow B = 600/\cos.10° = 609{,}3 \approx 609mm$

$x = 2x50 + 2x106 + 100 = 412$ mm

Amount of curves like Illustration C.2.1 = 1700/412 = 4,13
=> 4 times a cuve

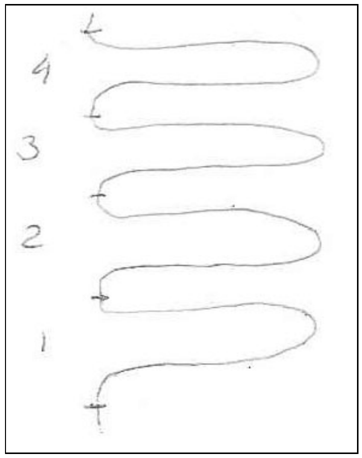

Illustration F.6

Outline length curve = radius.2π = $50x2\pi = 100\pi \approx 314mm$

Total length tubes = 4 x 314mm
8 x 609mm
------------- +
6128mm = 6,128m

Volume tube inside receiver (V_{r1}) = $\pi.r^2.h$
r = 11mm
h = 6128mm
= V_{r1} = 2329453,3 mm^3
= 2,32 . 10^{-3} m^3
= 2,32 dm^3 = 2,32 litre

Volume tube in insulation in receiver (V_{r2}) = $\pi.r^2.h$
r = 11mm
h = 2x150mm
= V_{r2} = 114039,8 mm^3
= 0,11 . 10^{-3} m^3
= 0,11 dm^3 = 0,11 litre

$V_r = V_{r1} + V_{r2}$ = 2,32 dm^3 + 0,11 dm^3 = 2,43 dm^3 = 2,43 litre

Surface in the sun in receiver (only top surface) = ½ .2π.r.h
r = 11mm
h = 6128mm
S_r = 0,21 m^2

Perpendicular surface in the sun = S_{pr} = 22mm x 6128mm
= 0,13 m^2

Metal sheets surface = (1000-2x70)mm x (2000-2x70)m =
= 860mm x 1860mm =
= 1,60 m^2

Annex G: Safflower oil profile

Safflower Oil Profile (organic)[L19]
Botanical Name- *Carthamus tinctorius* Origin- Mexico Extraction- Expeller pressed, and organically refined. **Specifications** Color- Faded yellow/golden Odor- Characteristic Free Fatty Acids- <0.5 Peroxide Value- <1.0 Non-Saponifiables- Saponification Value- 185-198 Iodine Value- 85-95 Specific Gravity- 0.900-0.925 Refractive Index - 1.465-1.475 **Fatty Acids** Oleic- 75.33- 80.00% Palmitic- 4-9% Linoleic- 12-16% Linolenic- <1

Safflower Oil Costs (organic)[L20]
INCI Name: Carthamus Tinctorius (Safflower) Seed Oil Gallon: $ 20,93 = 3,785 litre = € 16,37(15 august 2006) => € 4,32 per litre

Annex H: Drawing and building plans

This chapter shows the main building plans / drawings of the Solar Kitchen. First the receiver will be shown, then the baking plate and at last the hut build around the baking plate.

Receiver

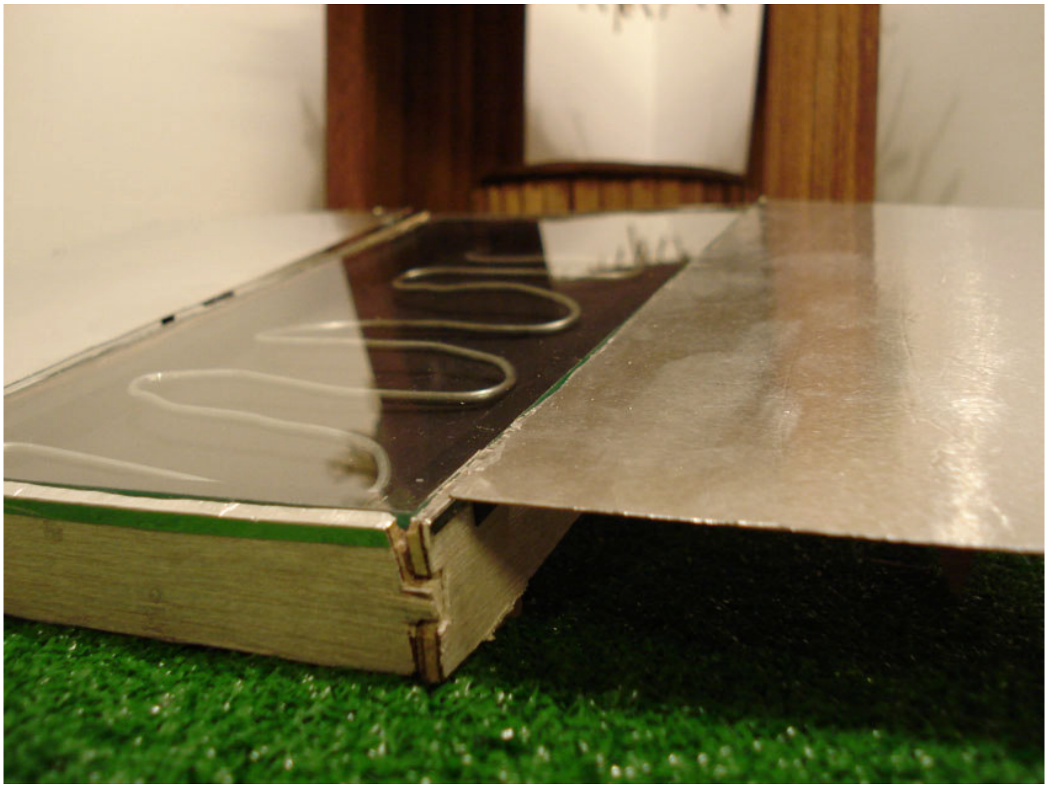

Illustration H.1: overview receiver

The parts of the receiver are:	Illustration:
- 2x Front plate	H.3
- 2x Side plate	H.4
- Bottom plate	H.5
- 2x Large inside insulation support plate	H.8
- 1x Small inside insulation support plate	H.8
- Insulation layer	
- Metal sheet	H.6
- Tube	H.7
- Glass plate	H.9
- Tube fixing plates	H.10
- 2x Reflector	H.15
- 6x Hinge (for reflector)	
- 2x Support beam (for reflector)	H.15
- 2x Support holder (for reflector)	H.16
- 4x Hinge (for support holder)	
- 4X Foundation blocks	H.11

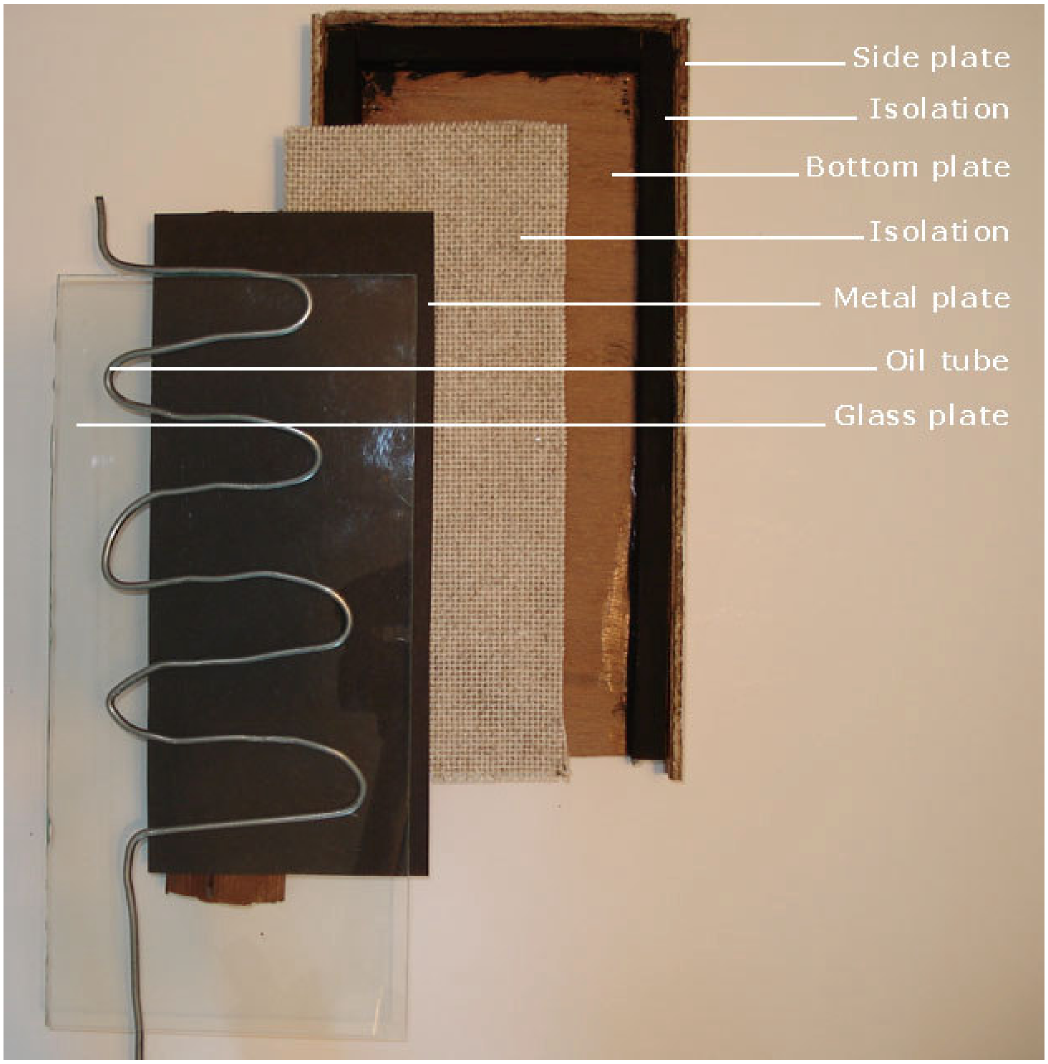

Illustration H.2: parts of receiver

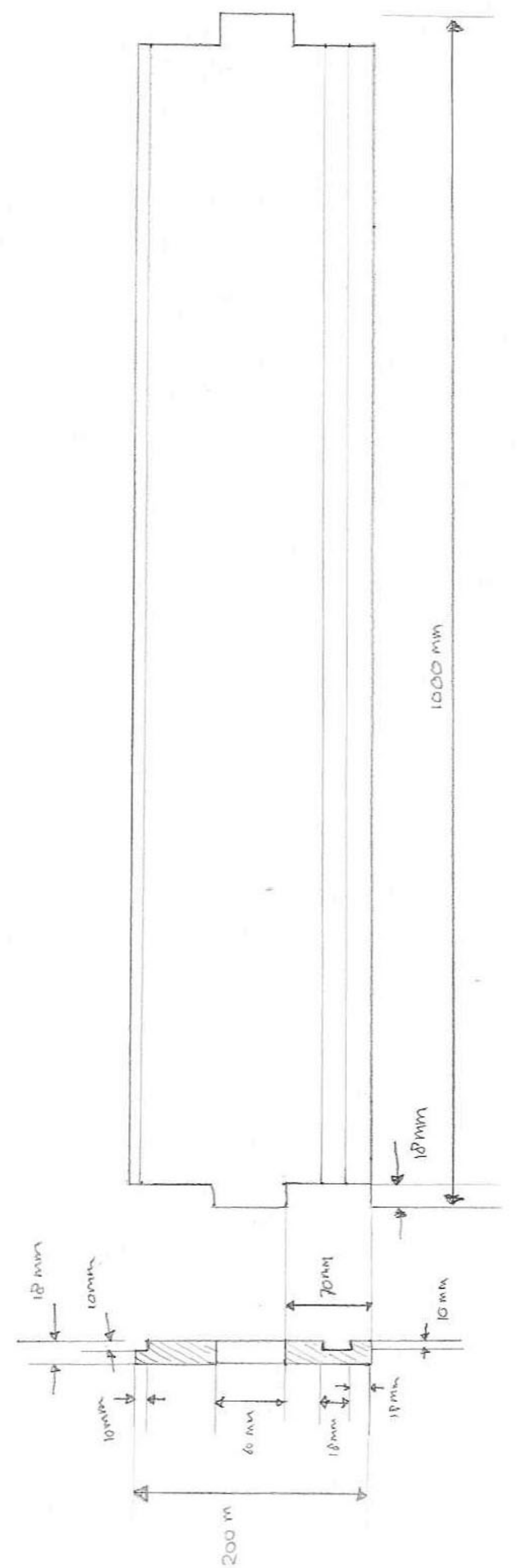

Illustration H.3: Front plate

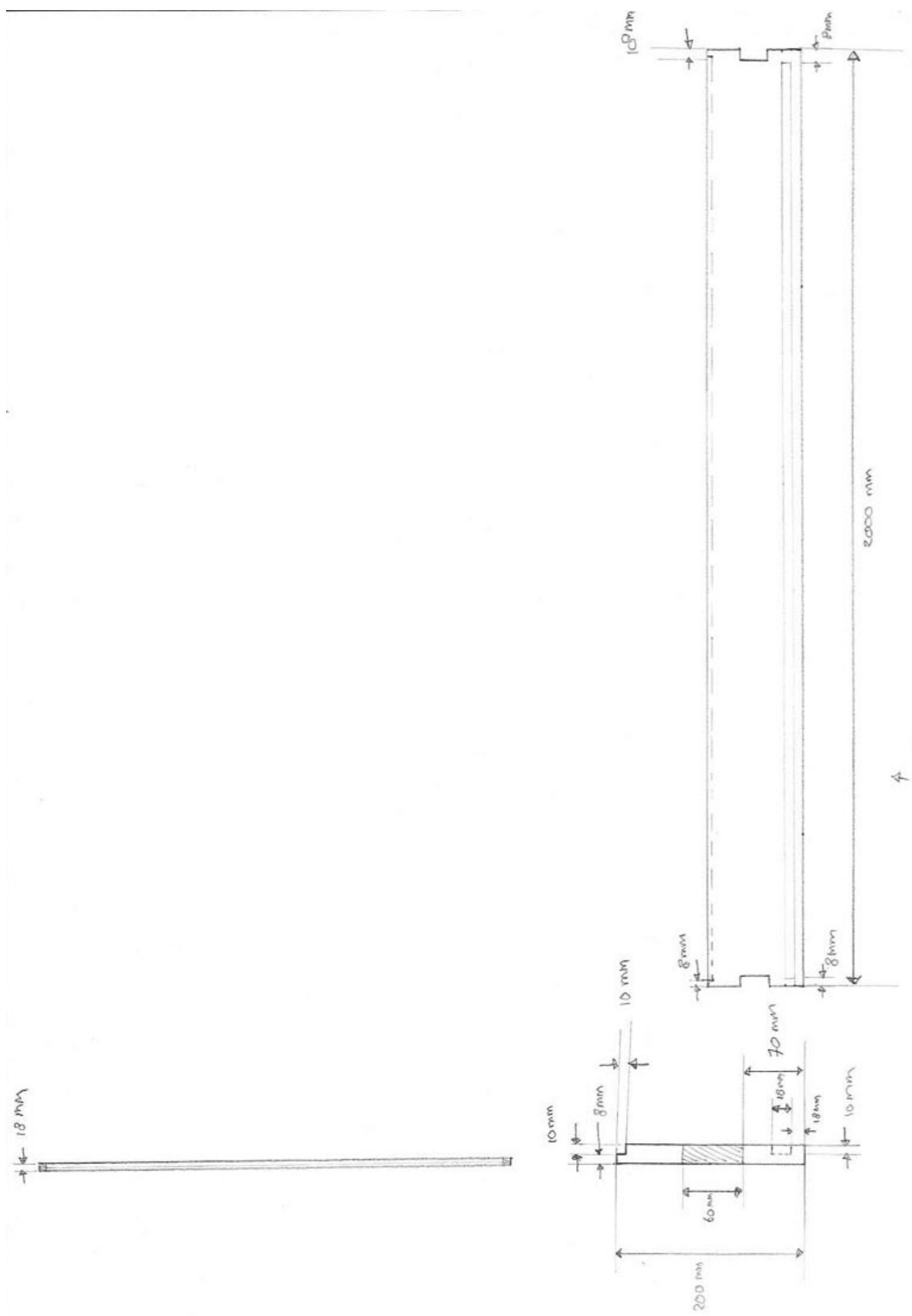

Illustration H.4: Side plate

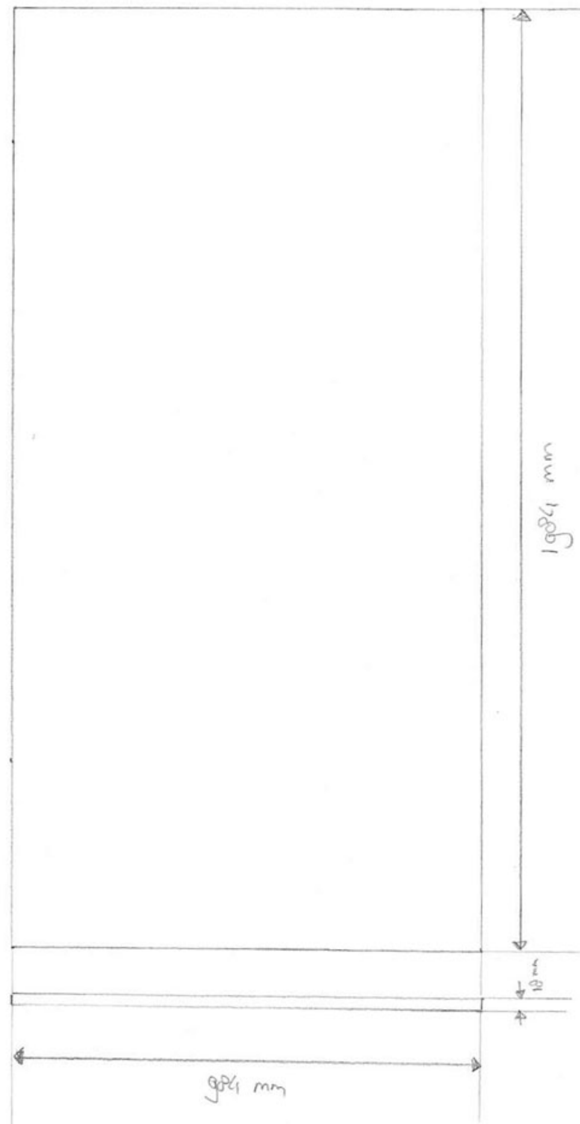

Illustration H.5: Bottom plate

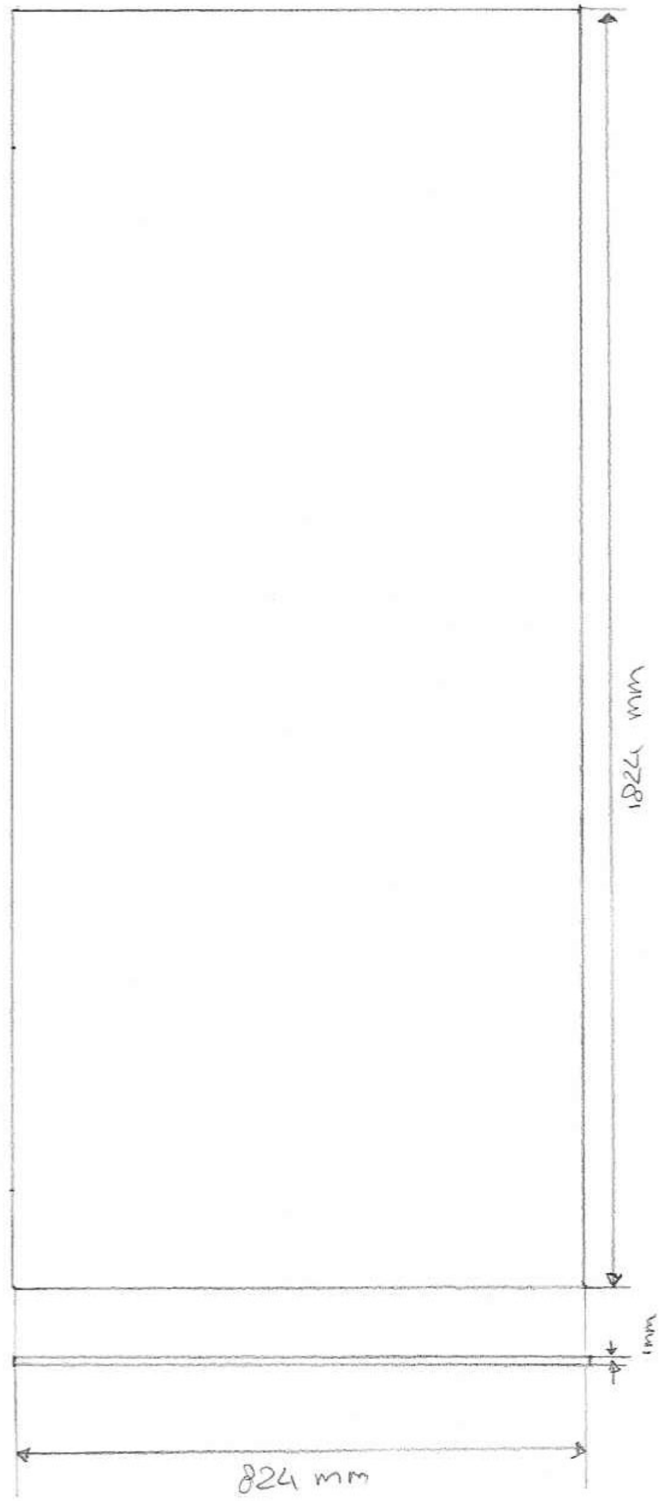

Illustration H.6: Metal plate

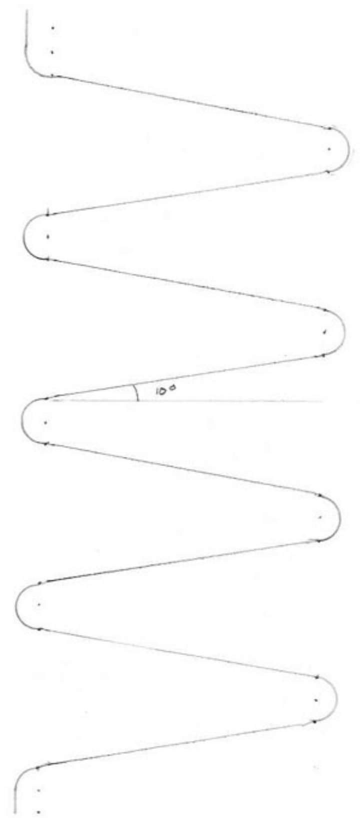

Illustration H.7 Tube outline, d=22mm

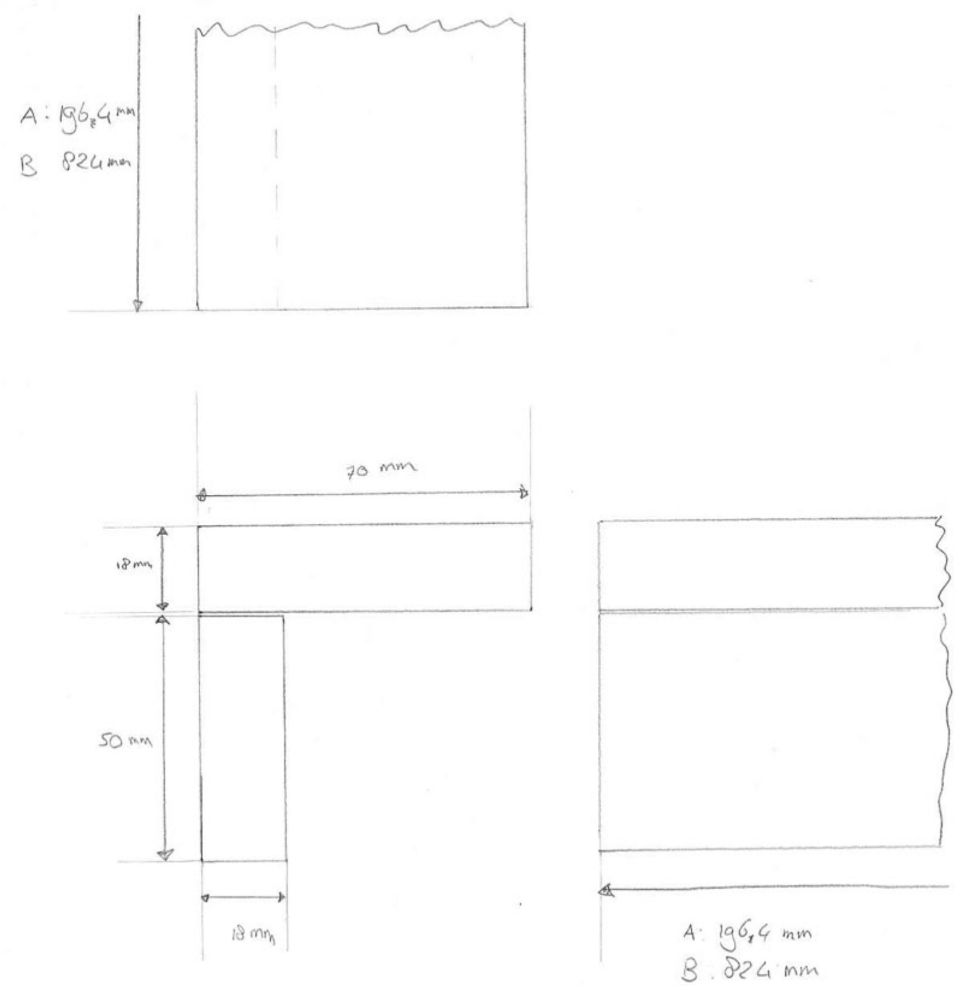

Illustration H.8: Inside insulation support plates

A: Large inside insulation support plate
B: Small inside insulation support plate

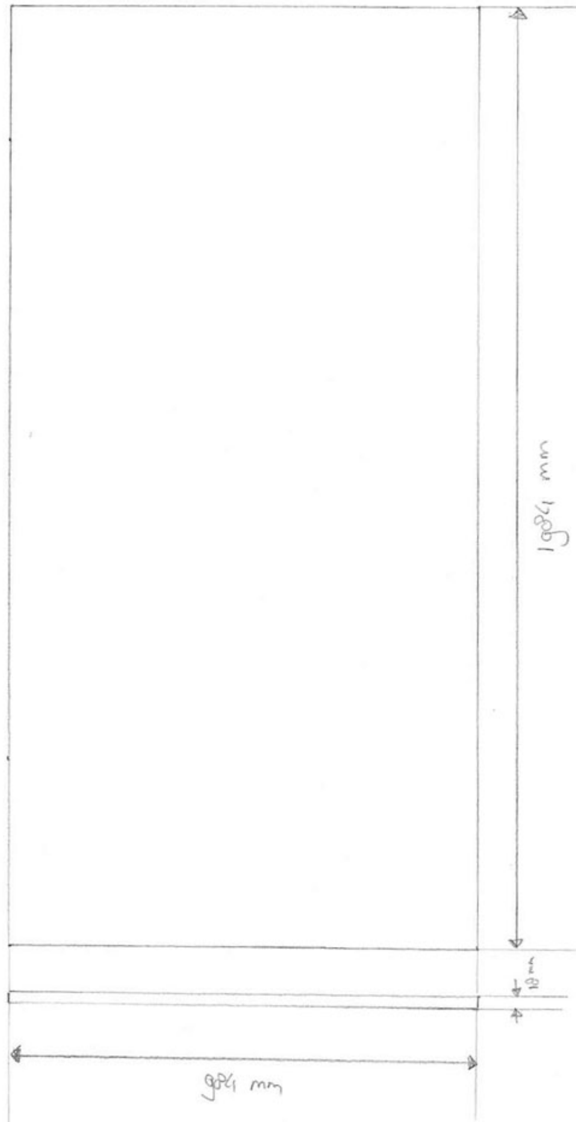

Illustration H.9: Glass plate

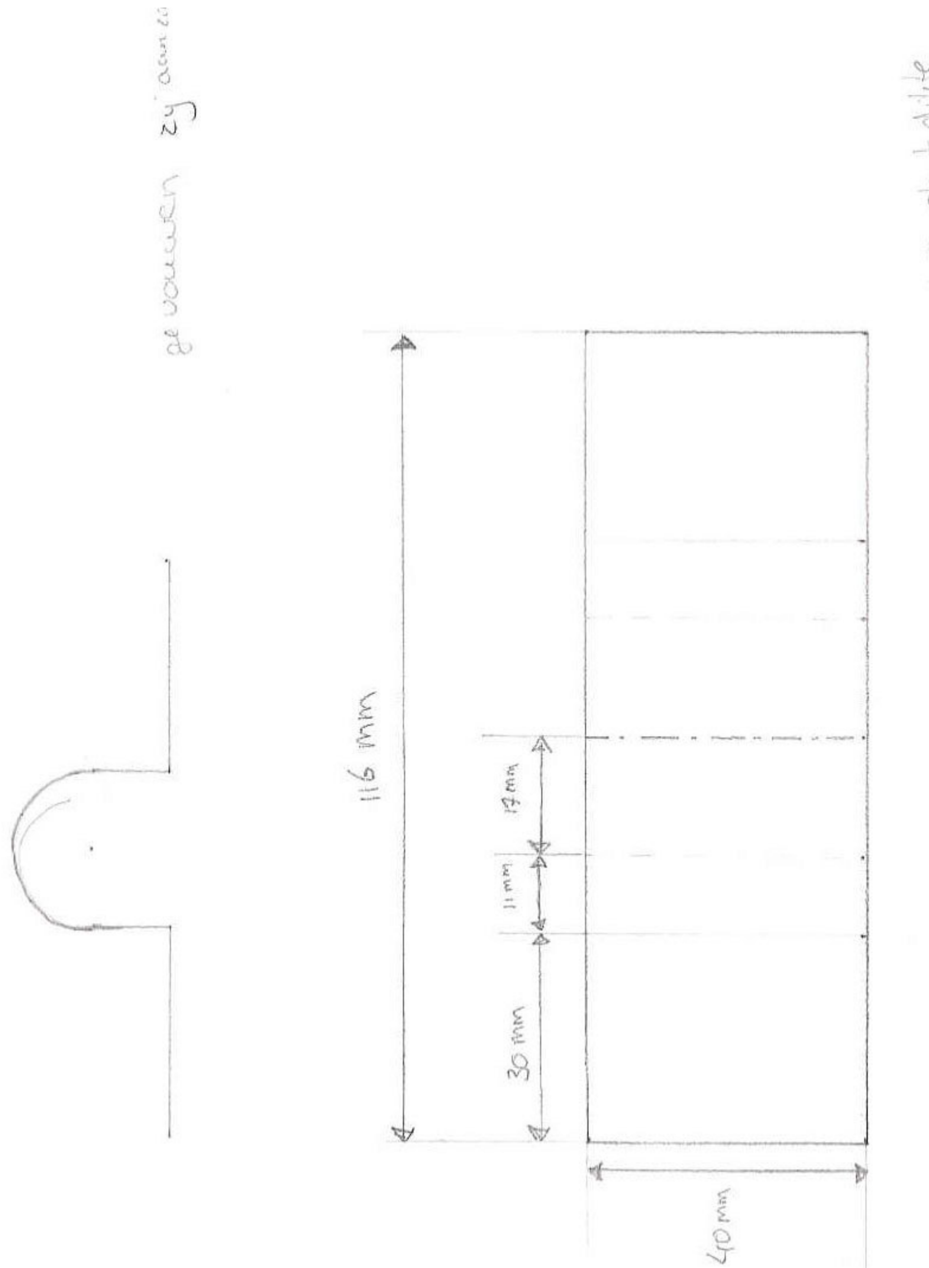

Illustration H.10: Tube fixation plates

These plates fix the tube to the metal sheet.

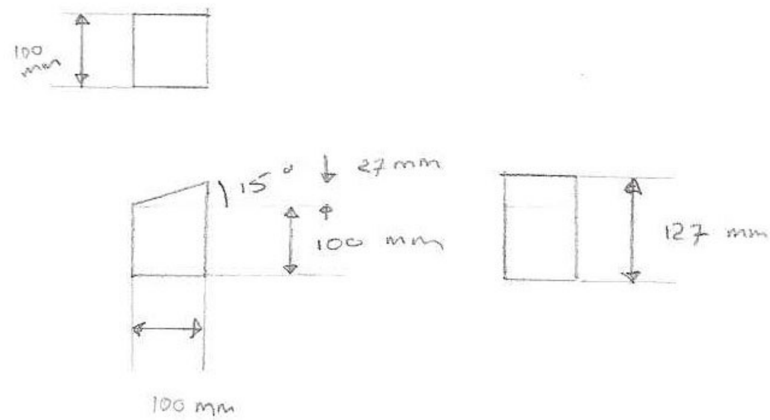

Illustration H.11: Foundation blocks

These blocks are necessary to place the receiver in an 15° angle. Two small ones in front, as drawn above, and two larger ones. The larger ones are 50cm higher then the ones above.

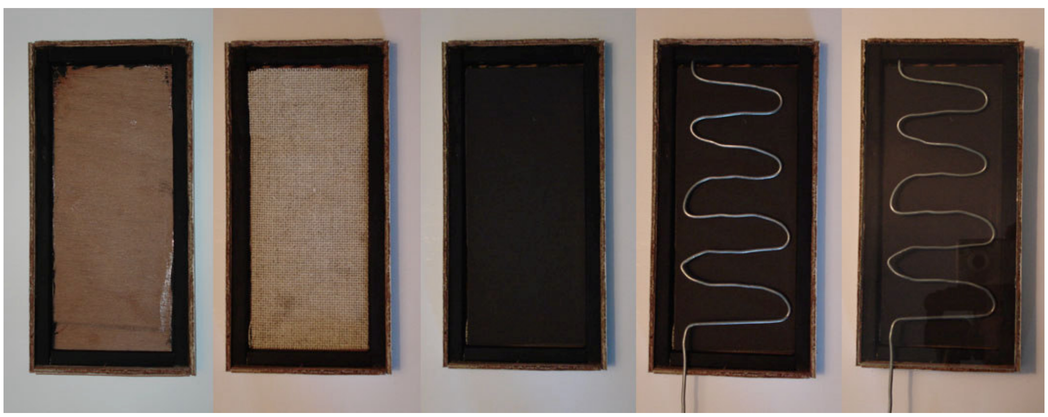

Illustration H.12: top view of different layers in receiver

Illustration H.13a: front view of different layers in receiver

Illustration H.13b: front view of different layers in receiver

Illustration H.13c: front view of different layers in receiver

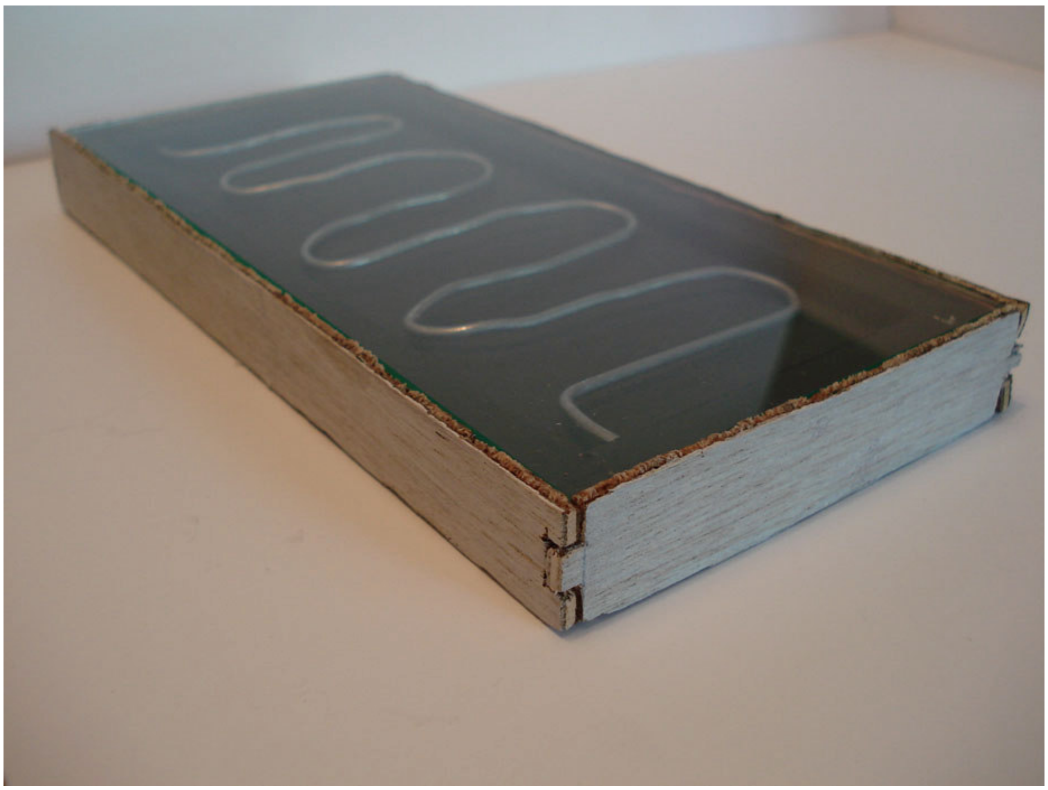

Illustration H.14: total view of receiver (without reflectors)

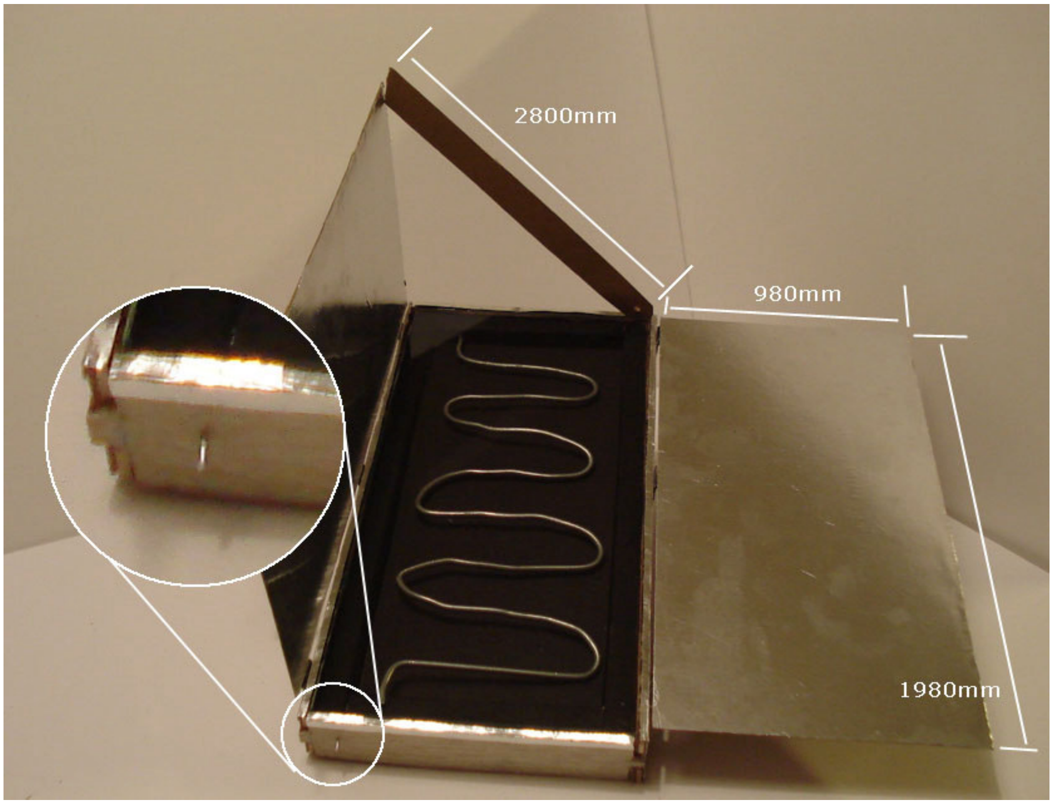

Illustration H.15: receiver with reflectors + support beam

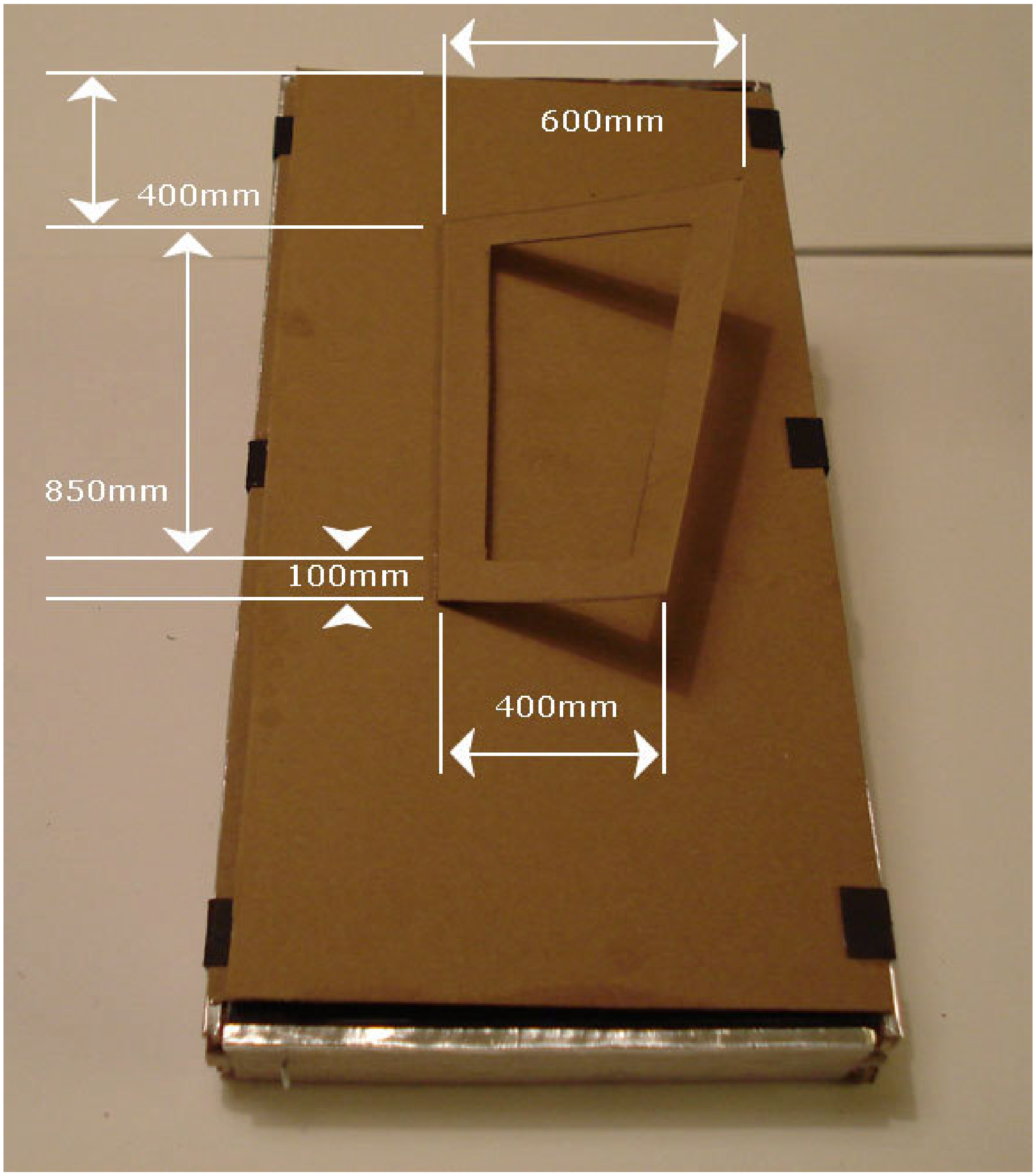

Illustration H.16: Measurements of support holder for reflector

Baking Plate Casing

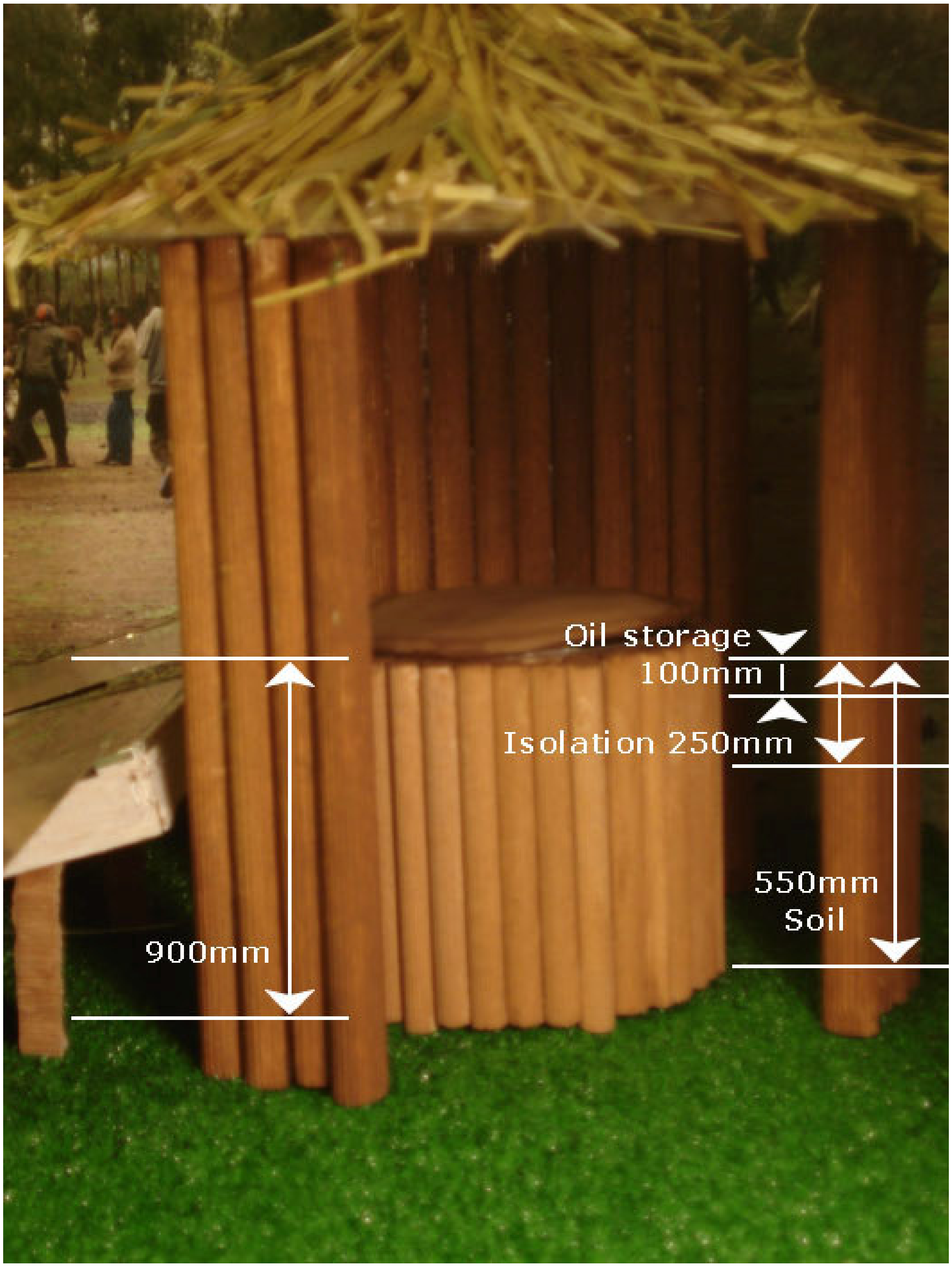

Illustration H.17: measurements of baking plate casing

Parts of the Baking plate casing are:	Illustration:
- Soil	
- Isolation (straw with clay)	
- Oil storage	H.19
- Trunks	
- Baking plate	H.18

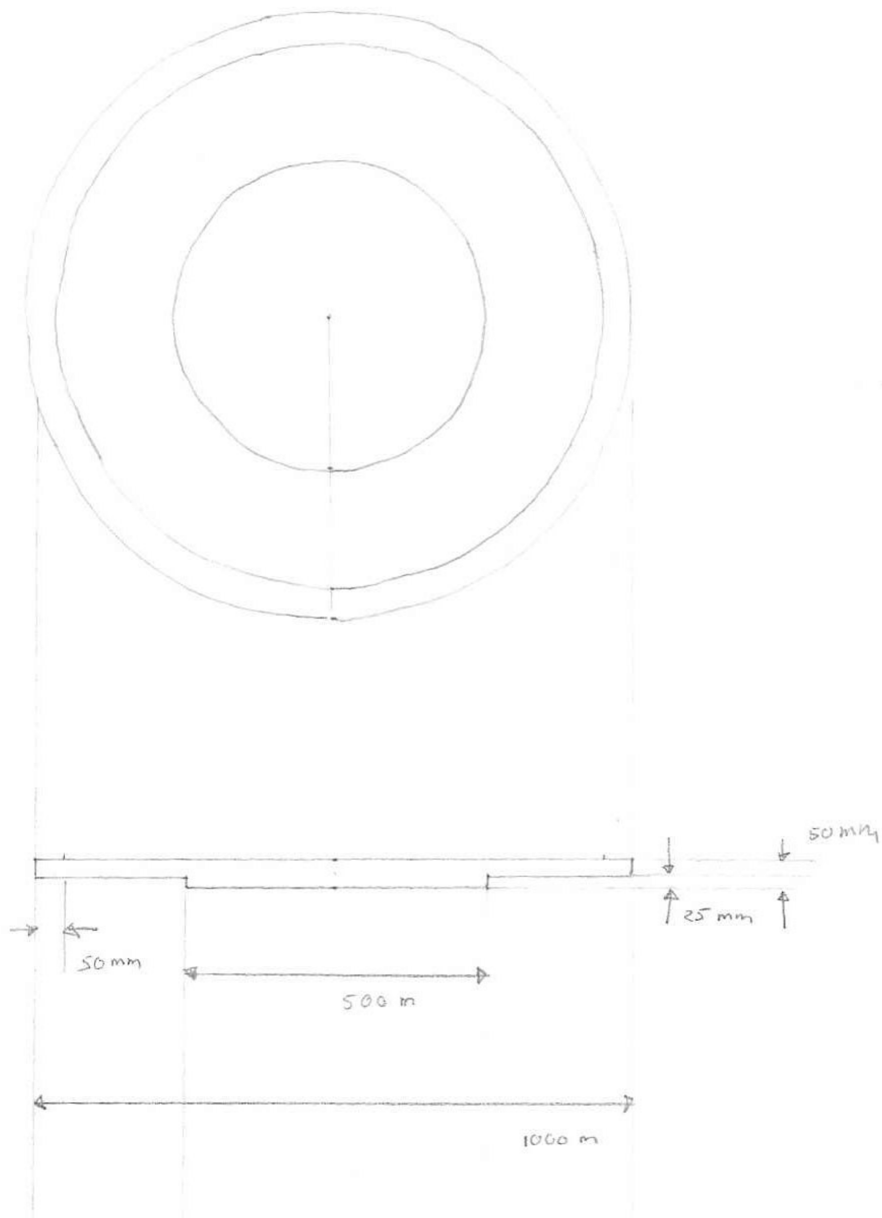

Illustration H.18: Baking plate

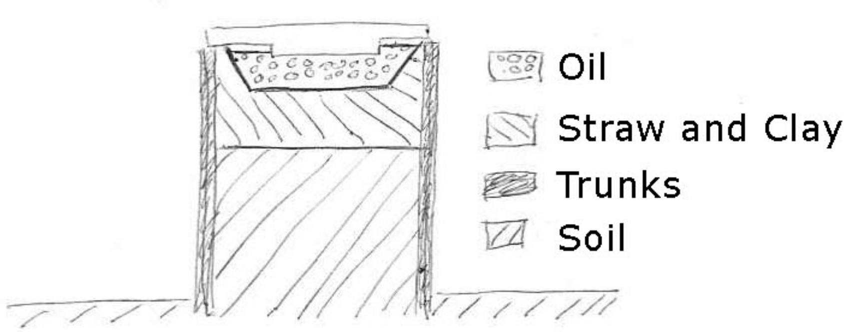

Illustration H.19: Casing layers

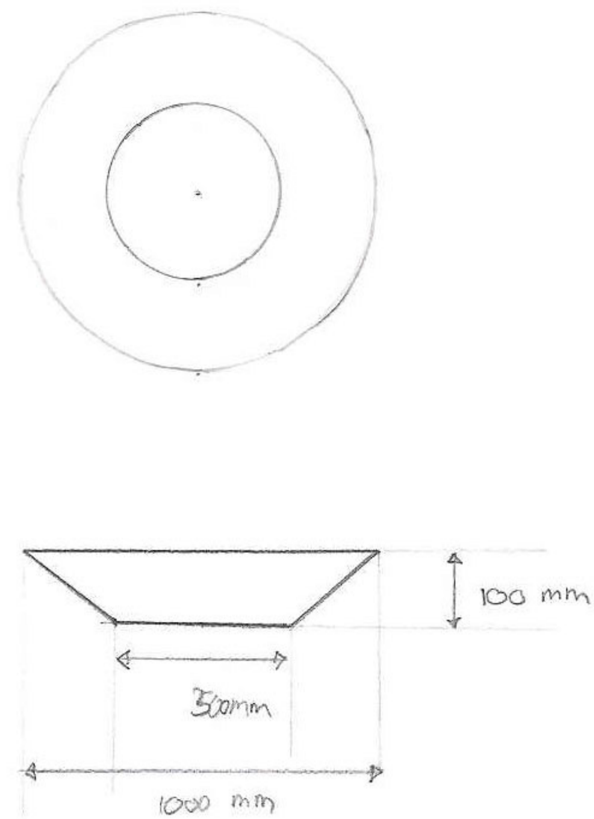

Illustration H.20: Oil Storage

Illustration H.21: Different layers of Baking plate casing

Hut around baking plate

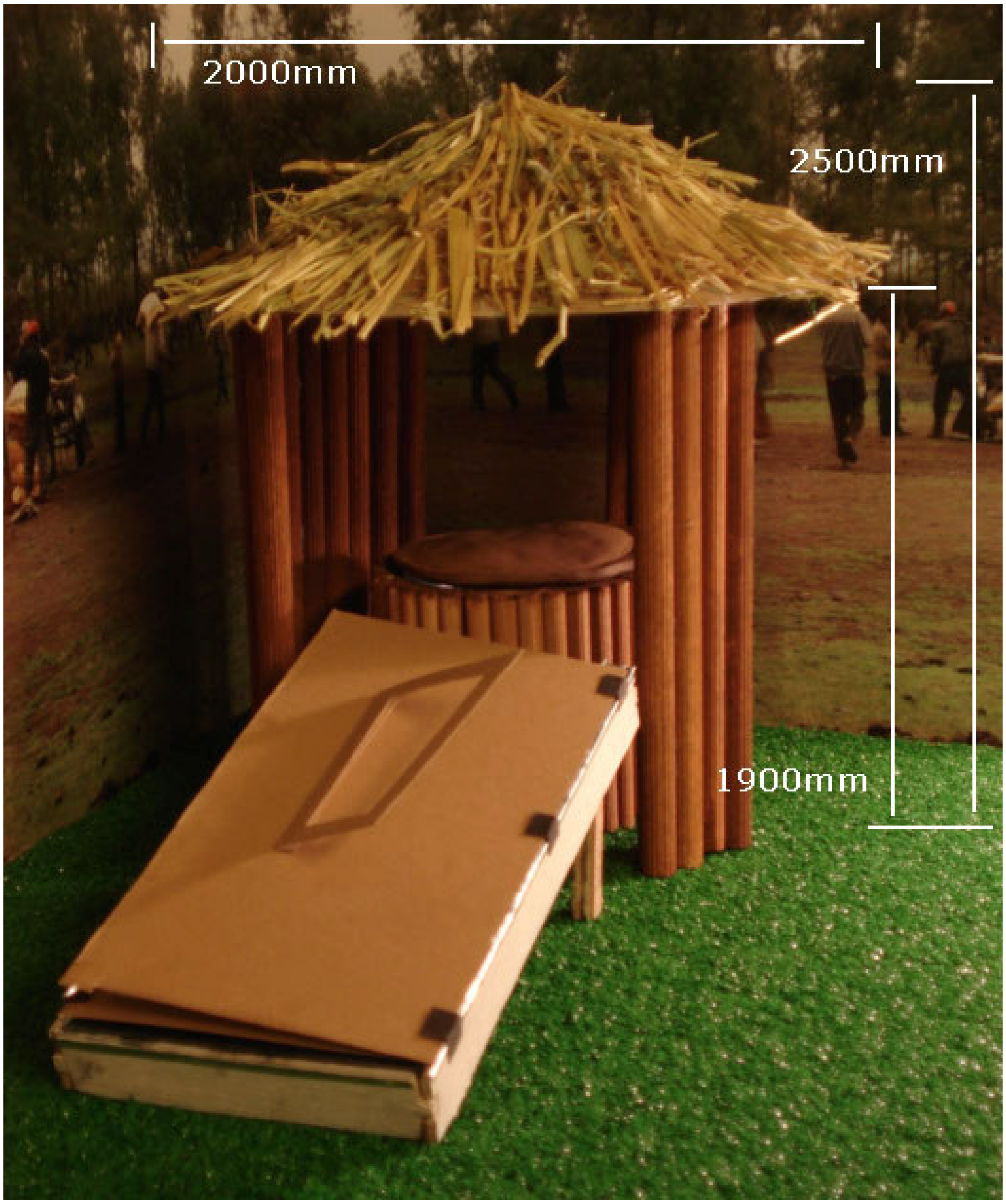

Illustration H.22: Measurements of hut around the baking plate

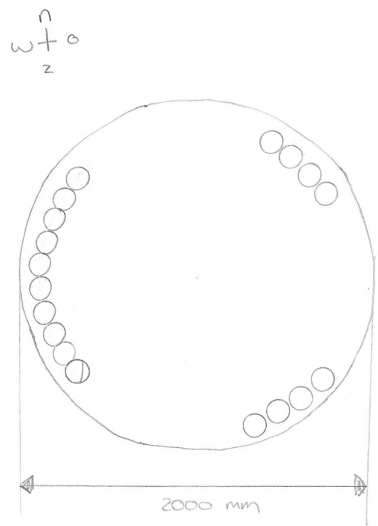

Illustration H.23: location of trunk of the hut

The largest part of the trunks are facing west, to create shadow onto the baking plate in the afternoon.