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Plan and design of a solar water heating system

A Matura-Paper by

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1. Introduction

In summer 2010 a group of students (myself included) from the Stiftsschule Einsiedeln went to Namwala High School[1], our associate school in Zambia. Down there we visited the country and the school, and we were confronted directly with their problems. This was when I realized that my Matura-Paper should be something useful in order to specifically help these people.

After visiting the company "Suntec" in Lusaka the idea came to me for a Matura-Paper which combined my interests in solar energy and the aim of helping the students at the Namwala High School: a solar water heating system for the kitchen to heat up water and save electricity and money.

I especially want to thank Mr. Van Der Weijden who advised me during the preparation of my Paper; Mr. Beat Oettiker who helped me come up with the idea for my Paper and supported me with information and suggestions; Mr. Amos Makasa who delivered the data necessary from Namwala; Mr. Bruno Schläpfer and the "Ernst Schweizer AG" which provided us with advice and delivered information; Mr. Jean-Lucien Gloor and Christine Lobmaier who corrected my Matura-Paper and helped me out with my English.

The goal of my Matura-paper is the planning and designing of a solar water heating system for the Namwala High School in Zambia. This includes the development of construction plans and a realistic initial cost estimation for the project.

The plan will take the sanitary installations into account which are already at the Namwala High School.

I am going to study the main solar heating techniques available, and recommend which one would be the optimal installation for Namwala in consideration of the price, the quality and the effort to install them in Zambia. This project could really help the school to be independent from the big electricity firm ZESCO and save a lot of money.

I also want to try to get firms specialized in solar energy solutions to realize the potential of the strong African sunshine and to be more active in Zambia.

The reasons why solar energy is used in Switzerland are the desire to protect the environment and the energy needs at isolated places where the access to the public electricity network is hindered or even impossible (for example on an isolated mountain cabin).

The reasons for the use of solar energy in Zambia are very different.

Most of the people in Zambia are very poor and live from subsistence farming in the countryside. They are far away from civilization as we know it with running water and electricity. They use wood to cook and heat their homes because this is the only suitable material they can find in nature (not having to pay for it) to help them perform these simple acts of living. This is of course bad for the environment. To clear forests leads to soil abrasion, desertification and destroys natural environments which leads to the reduction of plants and animal diversity.

[1] http://www.namwala.stift.ch/index_de.shtml

Who could blame them? It's perfectly understandable that this is the only option to survive for these people. This is why it is important to help them wherever we can. With simple things like solar cookers, the people of Zambia can be helped to a better lifestyle without destroying nature.

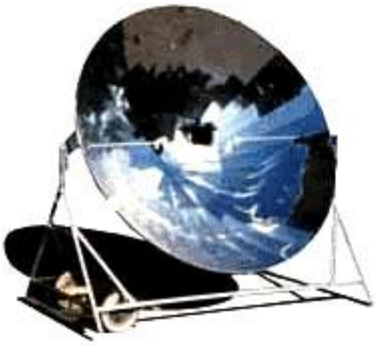

Image 1: Solar cooker

And this is why I want to start this project with my Matura-Paper. If it gets realized it will not only help the pupils and the school of Namwala to save money, but these people will hopefully realize that such simple things as systems to heat up water, even if it is just a wooden box with a glass cap, can do much in Africa to help.

But this is not the only reason why people should generally invest in solar energy in Zambia and Africa. Zambia is currently a third world country and does not have a lot of money but this will not remain forever. A lot of countries in Africa are making huge progress in social, technical and ecological development and so is Zambia. Its politics are stable and the people are willing to learn and are thankful for help as long as we do not try to force them to think exactly like the western world. But they understand that there are not only big corporations who exploit the land and its resources, but there are also people who care and want to help. The solar energy domain is a perfect example. There is already a firm in Zambia which sees its purpose as bringing solar energy to Zambia. Its name is Suntec and it is located near Lusaka, the capital of Zambia. The Suntec people have realized the great potential of solar energy in Zambia. The market is completely open at the moment. ZESCO, the big electricity company, has a monopoly on electricity provision and keeps increasing its prices. People can't afford to pay these prices anymore and will surely be happy to have an alternative. Why not give them an alternative with solar energy?

I think everyone agrees that with what has happened in the world lately, the oil crisis and so on, we can say that renewable energies are increasingly necessary and one of these main energies is solar energy. Now where would be the best place to install solar energy gathering systems? Why not Africa where the sun intensity is high and much can be done with little money?

Although the profit might not be initially great the market of solar energy will rise in the next few years. And with the acceleration of the energy transport research the demand for solar energy from Africa will rise. Now is the right time to start working on the corresponding basic infrastructure.

I hope that the reasons for investing in solar energy in Africa have been clarified in this introduction and also that this project will help start a group of western solar energy firms caring to develop renewable energy solutions in Africa.

2. Solar energy potential and comparison of solar techniques efficiency between Switzerland and Zambia [1]

An introduction to the potential of solar energy based on calculations of the sun intensity will be made first. A comparison of solar techniques efficiency between Switzerland and Zambia will follow.

2.1. What is solar energy and what are the criteria to calculate it

The solar energy related values in the following graphics will be re-estimated or taken directly from the information sources listed in the References. It is therefore important to understand how to generally estimate the sun intensity on different places on the earth.

The solar energy values are average rather than exact values. To understand why, we need to look at how these values are calculated and on which assumptions the calculations depend.

2.1.1. Definition

Solar energy is defined as follows: ***the amount of energy produced by the nuclear fusion processes in the sun which reaches the earth in form of electromagnetic radiation.***

Measurements over the years have shown that the solar radiation is constant and the averaged insolation on the upper edge of the earth atmosphere is **1'367 W/m^2**. This is also known as the solar constant. So if the sun radiation is constant everywhere on the edge of the atmosphere, why is it warmer in Zambia than it is in Switzerland for example? And how about the seasons?

The answers to these simple questions will be given in this chapter.

1 **http://www.klett.de/sixcms/list.php?page=miniinfothek&miniinfothek=Geographie+Infothek&article=Infoblatt+Entstehung+der+Jahreszeiten, 03.01. 2011**
http://de.wikipedia.org/wiki/Sonnenenergie#Abh.C3.A4ngigkeit_der_Strahlungsleistung_vom_Einfallswinkel, 03.01.2011
http://www.atmosphere.mpg.de/enid/2__Stadtklima/-_Strahlung_42e.html, 2.6.2011

2.1.2. Angle of the sunrays

The first criterion for the sun insolation is the **angle of the sunrays**. Because of the spherical surface of the earth the intensity of sunrays depends on the latitude. This picture illustrates why this is so. The incident angle of sunrays is smaller near the equator (90°) than at the middle latitudes. This phenomenon causes the sunray bunch which hits the earth through a greater angle to also be distributed on a greater surface than the bunch with the smaller angle. (The green line which symbolizes the earth surface is shorter near the equator than over the middle latitudes) The same amount of energy coming from the exact same bunch of sunrays will be distributed on a larger surface which reduces the sun intensity at the middle latitudes.

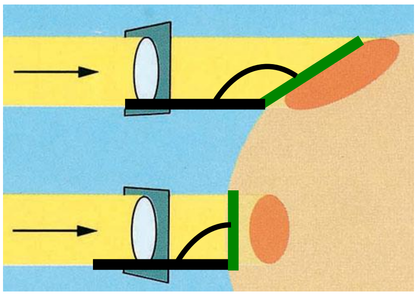

Image 2: Angle of sunrays

The logical conclusion is: the greater the incident angle, the smaller the amount of sun energy per unit of surface.

This is also known as Lambert's law and can be described by this formula:

$\mathbf{J = J_0 \times \sin(\varphi)}$

J is the intensity of the radiation at an incident angle φ ; J_0 is the intensity at a vertical angle.

With this simple theory we can basically explain the climate differences on earth because solar energy is deposited as heat on the earth surface. The energy from the sun warms up the earth and causes the different climates.

Now what about the seasons? To explain them, we need one more piece of information about the earth:

The earth axis is inclined with respect to its orbit around the sun which leads the incidence angle to change when the position of the earth around the sun changes. While the incidence angle does not change much near the equator, it does change substantially at the middle latitudes. This leads to different periods of low or high sun intensity which are called seasons. Summer is the period with a small angle and a high sun intensity. Winter is the period with a larger angle and low sun intensity.

The picture below illustrates why days in summer are longer than in winter. The arrows point respectively to the winter (blue) and summer (red) season on the southern or northern hemisphere. During summer, the northern respectively the southern hemisphere tilts with respect to the sun which makes the surface on the hemisphere enlightened by the sun greater and the days longer.

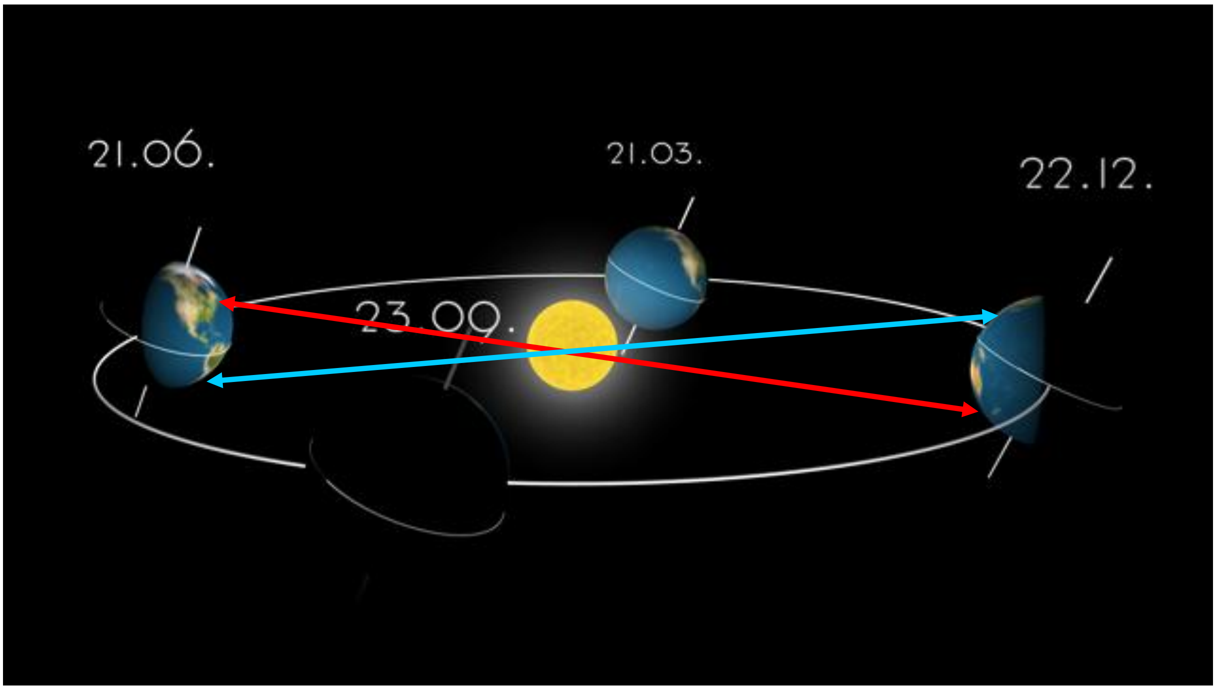

Image 3: Seasonal insolation

Important to our subject is to know that except at earth's equator, the sun intensity is not constant over the year which means that in winter due to the shorter daytime and lower sun intensity less solar energy will be available than in summer. This winter period reduces the average level of solar energy over the year. Also worth noticing is that the average incidence angle of the sun radiation during the year is always going to be smallest near the equator where the position of the earth on its orbit around the sun does not change the incidence angle much.

In conclusion, the place on earth with the most solar energy will always be near the equator.

Even though this is the most important criterion it isn't the only thing to consider.

2.1.3. Absorbtion and reflection of solar energy through the atmosphere

A second important criterion is the **absorption and reflection of the solar energy through the atmosphere**.

As already mentioned before, sunlight consists of electromagnetic waves and these waves get reflected and absorbed by different things in the atmosphere and by the atmosphere itself. Water droplets or dust can absorb or reflect sun waves and hinder them from reaching the earth surface with their full power. The sunlight waves even get absorbed directly by the air itself which gains energy and heats up. The external cover of the atmosphere is hit by a more or less constant value of energy. This value is called the **solar constant** and can change slightly over the year due to the different distance of the sun to the earth in winter and summer and due to the fact that the Earth’s orbit around the sun is not perfectly circular. The solar constant is defined at about 1365 to 1372 W/m^2. But this energy never reaches the surface of the earth because much of it is absorbed by the atmosphere.

2.1.4. Weather

The third most important criterion is the **weather**. Clouds hinder sunlight from hitting the earth’s surface or diffuse it, which reduces the solar power noticeably. Countries with high cloud cover and rainfall are hindered from using the full solar energy potential which would be available on their latitude.

2.1.5. Conclusion

The amount of available solar energy cannot be calculated exactly due to too many interacting criteria.

For example: the small radiation angle near the equator is responsible for a high solar energy level; this causes high temperatures near the equator; high temperatures lead to high water evaporation on the earth surface; water evaporation leads to increased air humidity; water droplets in humid air absorb and reflect sun energy and cause clouds which hinder the sunrays from hitting the earth and so forth and so on.

The following picture shows the complexity of the process of solar energy hitting the earth:

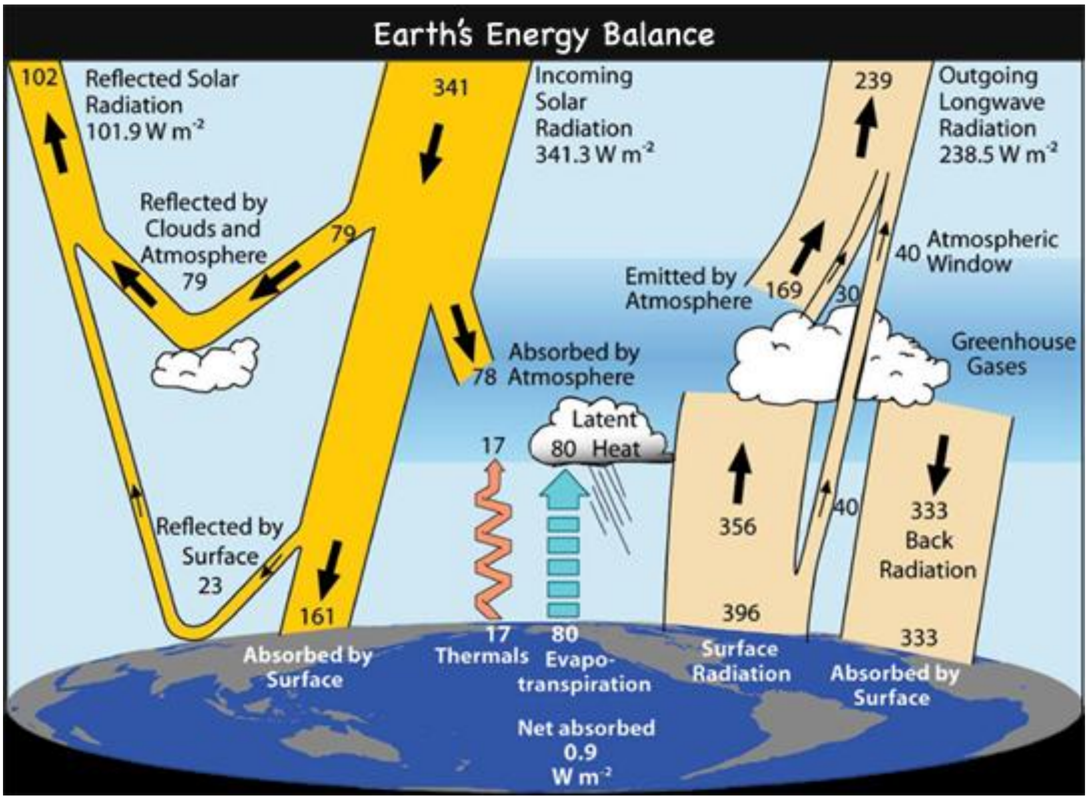

Image 4: Energy balance

The values shown on this figure are average values measured over 2 years. They give a good approximate value and help us to get a rough overview of the allocation of the intensity of solar energy on different places of the earth. We cannot trust them entirely to predict where exactly the most sun energy will be deposited on the earth surface but we can use them to draw general rules:

- Because of the smaller incidence angle there will always be a higher sun energy level near the equator than on the middle & high latitudes.
- Because of the smaller incidence angle near the equator the track length of the sunrays through the atmosphere will always be shorter than at middle latitudes and the sun energy absorption and reflection by the atmosphere will consequently be smaller. → The amount of solar energy hitting the earth will therefore be higher near the equator than at middle & high latitudes.
- Because of the longer daytimes there will always be more sun energy deposited on the earth surface in the hemisphere for which the current season is summer.
- The solar energy hitting the earth surface will always be smaller than the solar constant of 1'367 W/m^2 because even when the incident angle is 90° and there are no clouds, the atmosphere still absorbs and reflects a part of this energy.

- Solar energy levels in altitude will always be greater than the solar energy level at the same latitude at sea level because the sunrays track through the atmosphere is shorter in altitude and so there is less absorbtion and reflection (this and in addition the snow reflecting and thus reenforcing sunshine, is why you get tanned faster while skiing; the reflection effect also comes from the water surface on lakes or at sea).
- Regions with low rainfall will always have a higher amount of available solar energy than regions at the same latitude with high rainfall → The more clouds the less solar energy.

2.2. Comparison of solar techniques efficiency between Switzerland and Zambia

It is clear that there is a difference of insolation between Switzerland and Zambia, but how big is it really?

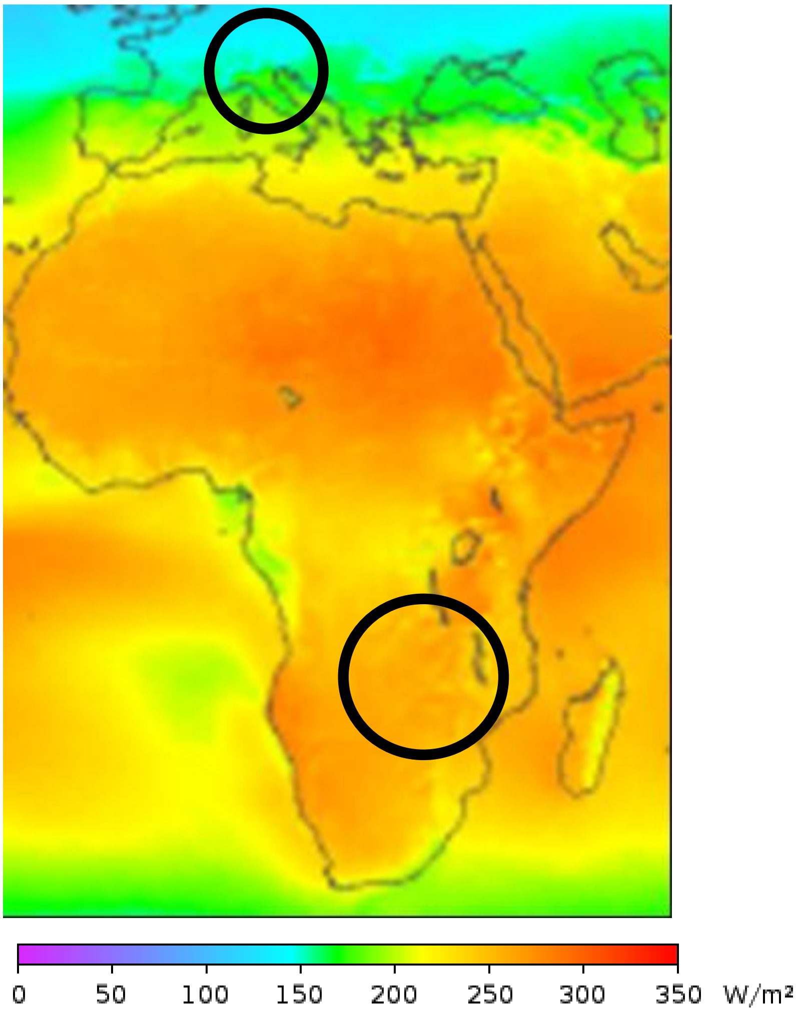

Image 5: Insolation accord

This map shows the amount of yearly average solar energy per day in W/m^2 also taking the average clouding conditions into account (this average value therefore takes into account the average cloud cover during the year, the difference in insolation during the 24 hours day and night period, and during the seasons of the year).

The sizable difference in insolation between Switzerland and Zambia can clearly be seen on the picture.

This can be explained easily with the solar energy considerations of section 3.1.5:

With an average latitude of 14° south Zambia is much closer to the equator than Switzerland with its average latitude of 47° north. That makes its incidence angle for sunrays much smaller than the corresponding one for Switzerland which augments its sun intensity and shortens the track of the sunrays through the atmosphere. This leads to a substantially larger amount of solar energy in Zambia.

The map shows that Switzerland has a yearly average daily solar energy value of about $175W/m^2$. For Zambia the corresponding value is about $275W/m^2$. That makes the insolation in Zambia about 1.6 times larger than the insolation in Switzerland. In spite of this, solar technology is used a lot more often in Switzerland although the electric power supply system is much better than in Zambia.

3. Technical study

3.1. Energy cost savings

How can we save energy and lower the electricity costs at Namwala High School? The answer is simple: three times per day, a lot of water needs to be heated up for cooking to a water temperature of ca. 97 °C (Namwala is located at an altitude of about 1000m). The headmaster of Namwala High School collected the data on how much water is heated up per day for us. Here is the result:

570l need to be heated in the morning

785l need to be heated at noon and in the evening

Therefore 2140l of water need to be heated up by approximately 87 °C daily (in estimation of a water temperature of 10 °C out of its source).

It is possible to save a lot of energy and money if we already heat the water to be used to 90 °C before cooking. At the current electricity prices (02.06.2010) which are about 18'000'000 K (4000 US $) monthly and 180.00 K (0.04 US $) per kWh[1] the costs are too high for the school.

How much electricity for heating water would be left to pay after this project?

We can heat up all the water necessary for the cooking, even the amount for the morning, because the boiler conserves the heat very efficiently. Thus we can heat up 2140l of water up to 90 °C daily. Assuming that the water has a temperature of 10 °C out of its source 2140l have to be heated up by 80 °C (This is the minimum we would want to achieve)

How much electricity does it need to heat up one liter of water by 1° C?

[1] **http://www.zesco.co.zm/APPROVED%202010-11%20TARIFFS.pdf, 02.06.2011**

$C = 4.18\ J / (g \times °K)$ [1]

$\rho = m / V$, $m = \rho \times V$ $1l = 1dm^3$

$m = (1\ kg/dm^3) \times (1dm^3)$

$m = 1kg = 1000g$

$\Delta T = 1°C = 1°K$

The amount of energy required to increase the temperature of 1 liter of water by 1°C is thus:

Energy = $E = C \times m \times \Delta T$
$E = 4.18\ J/(g\ °K) \times 1000\ g \times 1\ °K$
$E = 4180\ J$, $1\ J = 1\ Ws$
$E = 4180\ Ws$
$E = (4180\ Ws) / (3600\ s/h)$
$E = 1.161\ Wh$

$\underline{\underline{E = 0.00116\ kWh}}$

To heat up 1 liter of water by 1°C consumes 0.00116 kWh.

To heat up 2140l of water by 80°C consumes 0.00116 kWh × 2140 × 80 = 198.6 kWh

At this point it has to be said that the water temperature of 10°C is an approximation. 1°C colder or hotter water to begin with would result in a change of 2.5 kWh per day.

199 kWh a day is equal to 5958 kWh a month. 5958 kWh x 180 K is equal to 1’072’440 K which is 228.9 US $ (31.03.2011; 1 ZMK = 0.000213447 USD). This may not seem to be a lot but in Zambia it is. For a year the amount of money saved becomes: 2746.8 US $

At the current exchange rate, this is about 2515 CHF (31.03.2011; 1.00 CHF = 1.09225 USD). With this amount of saved money per year, one can for example

- Finance 8 scolarships (300 CHF or 327.6 US $)
- Purchase 101 new desks (25 CHF or 27.3 US $)
- Purchase 126 new chairs (20 CHF or 21.8 US $)

What is the best method to achieve this? Solar panels. I’m now looking for a simple design which the students could even make themselves.

[1] **Source:**
http://www.wasser-wiki.de/doku.php?id=wasser_eigenschaften:waermekapazitaet:start , 04.04.2011

3.2. Solar panels

How do solar panels work?

The technology is very simple and even though there are many different types of panels their principle is always the same.

The cold water from the boiler needs to be heated up with solar energy. Lead a non-freeze liquid through a few plates collecting the energy of the sunrays (in this case in the form of heat resulting from the solar energy deposited in the plates). This hot liquid can get up to 200 °C. Thereafter, the hot liquid is led back to the boiler in which cold water resides. The liquid transfers its warmth to the cold water, heating it up and completing the water warming cycle.

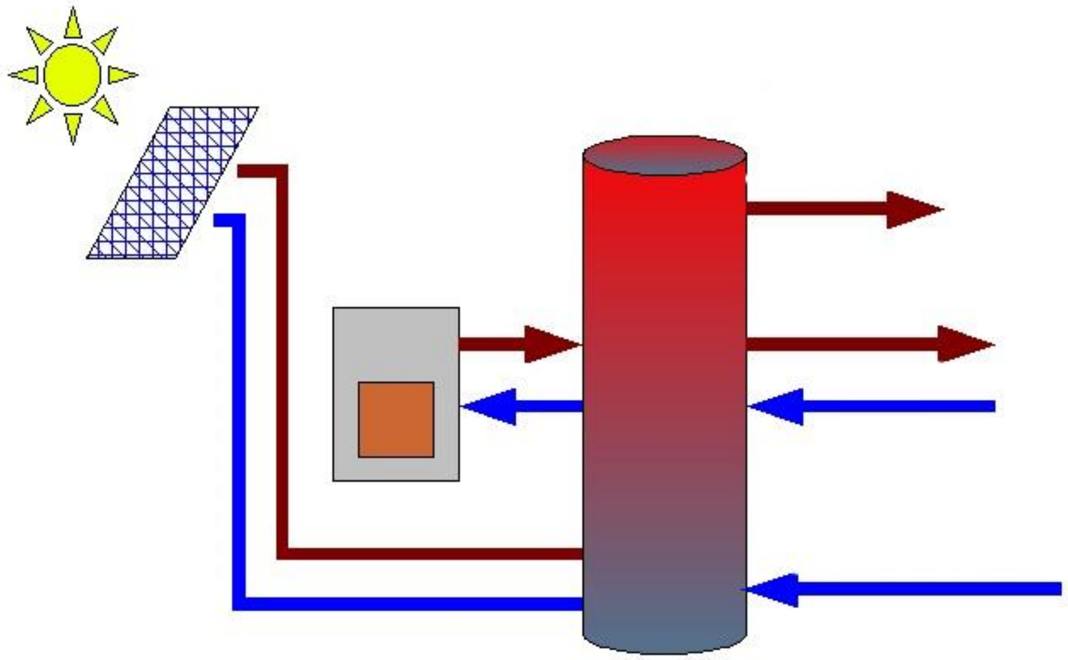

Image 6: Solar water warming cycle

In order to warm up the heat transfer liquid we will make use of the heat-trapping ability of glass or plastic. There will always be one to two layers of glass or transparent plastic to trap the heat. The objects carrying the liquid can either be a box (the cold liquid coming in from the bottom and the warm liquid getting back in to the top) or a flat collector plate made of a good heat-conducting material like metal. A collector plate can additionally be painted with a heat absorbing special paint or simply black paint.

With this very simple system using the direct energy of sunlight water can be heated up to 80 °C which can help to kill germs in the water and even cook.

3.3. Which type of solar panels should be used?

Considering the goal to produce hot water for cooking (in order to save part of the energy needed to heat the water in the cooking pots with electricity) the logical conclusion is that liquid-type panels should be used for this project.

There are other questions which have to be solved concerning the choice of the panel type. How should we make the panels? Is this the best solution? Wouldn't it be easier to just buy the panels instead of constructing them ourselves?

In order to answer these questions, a comparison of three different panel types will be made: one entirely hand-made, one partly hand-made and one bought from a specialized company producing liquid-type panels. A comparison of the three alternative solutions will be made as a basis to make the final selection.

3.3.1. Japanese solar heating tray

The first panel type considered is a handmade **"Japanese** solar **heating tray"**

The manual to build one was found in the book "**how to build a solar heater by Ted Lucas**"[1]

The concept is simple: a wooden tray lined with a thick sheet of black polyvinyl plastic.

Cold water will come into the tray through an "inlet tube" at the bottom of the tray, the water will heat up and rise, the superfluous hot water will flow off through an "outlet tube" near the top of the tray. The cover plate of the tray will consist of 2 sheets made of transparent plastic or glass to get the required greenhouse effect for the heating (the air space in between the 2 layers make sure that there is less moisture condensing on the underside of the sheet which reduce the scattering of sunshine by the development of water droplets due to the moisture).

The advantage of this system is its simplicity. It is easy to self-make it but this can also be a disadvantage. A self-made system is more prone to mistakes and instability.

Another advantage is that it is cheap due to the fact that one only needs to pay for the materials and the shipping costs but not for the production itself. Because the construction of the panel isn't strictly prescribed, we could adapt things like the dimensions to our personal needs. A clear disadvantage is that the water can only be heated to about 55 °C. This is way below the aimed 80 °C. To assure a fluent water circulation, a water pump must be included in the system.

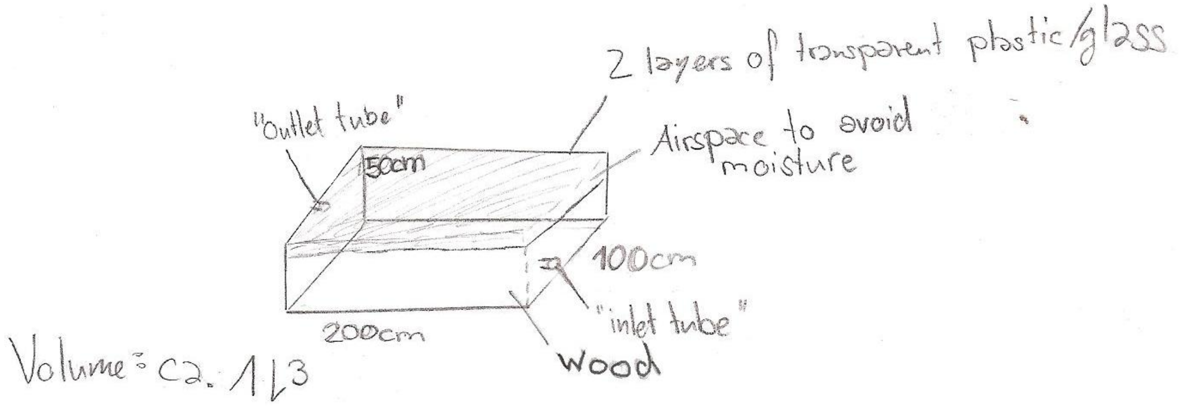

Image 7: Japanese solar heating tray

[1] **Lucas Ted, How to Build a Solar Heater a complete guide to building and buying solar panels, water heaters, pool heaters, barbecues, and power plants, Pasadena - Calif. : Ritchie , 1975**

3.3.2. Semi-handmade plate with a machine-made collector plate

The second panel type considered is a **"semi-handmade plate with a machine-made collector plate".**

The idea for this system comes from a 15 year old project of Mr. Van. Der Weijden, in which he installed a water heating system for a mountain cabin with his former students. They used this "semi-handmade plate" design because they needed a thermo siphon heating system (a system of water circulation which is activated by the natural convection flow of hot and cold water) given that they had no electricity to power a pump for the water circulation. The efficiency of this plate design is reasonably high and the installation and manufacturing was not too expensive.

This plate design is in form of a box (similar to the "Japanese heating tray") consisting of 4 layers. The first one is a simple wooden bottom plate (the side panels are also made of wood) followed by an insulation layer on which the collector plate is reclined to avoid heat loss towards the ground. On top of the box is a closing glass (or plastic) layer for the required greenhouse effect. The trapped heat will indirectly heat up the water by heating the collector plate first. In so doing there will not be any moisture underneath the glass/plastic layer (considering that the water is "trapped" in the collector plate and cannot condense under the transparent upper layer) and the efficiency loss caused by the light scattering of water droplets composing the moisture will no longer be a problem.

The advantage of this system is that it can heat water up to 80 °C if correctly built (**This value is an estimation)**. It may also be cheap if the firma "Rüesch Solar AG" sells us the collector plate with some reduction like they did 15 years ago. Of course this design is not as flexible as the "Japanese heating tray" because the collector plate drives us to certain predefined dimensions. To assure a fluent water circulation, it will be necessary to attach a water pump to the system.

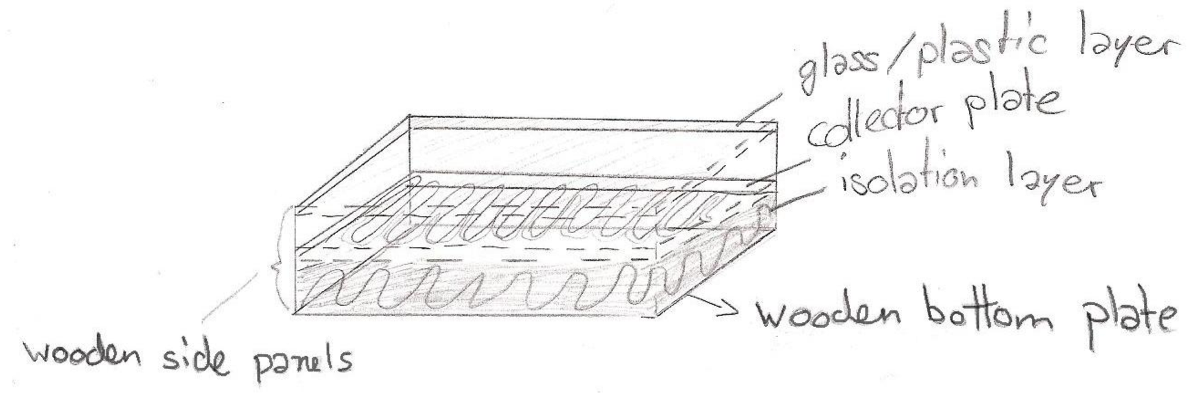

Image 8: Semi handmade plate

3.3.3. Prefabricated solar panels

The third panel type considered is to buy **prefabricated solar panels** from a company, preferably from one of the companies which is already represented by the firm "suntec" in Lusaka.

The recommended system is the "L series 2" system which is sold by a firm called "Edwards" [1]

These systems already contain a solar collector and a boiler. The seller (suntec) claims that the system is very reliable. Two main system dimensions are available with an optional third. Firstly a system for 180l, secondly one for 305l (and thirdly one for 440l) The corresponding suntec prices are 1850 USD and 2500 USD, which is very expensive.

Even though the quality would be assured in such a case, the system is still very expensive and limited in its utilization because of its proportions.

3.3.4. Comparison

A comparison of the three alternative systems gives the following results:

System	**Costs or Price**	**Water heating ability**	**Quality**	**Logistics**
Japanese heating tray	Cheap (material costs only)	Low (50 °C)	Depending on students	Complicated (gathering all the material)
Semi handmade plate	Likely to be intermediate (details missing)	High	Good	Easy
Bought prefabricated panel	Expensive	High	Good	Easy

At this point the necessity came up to discuss our problems and questions with a professional in this domain. For this purpose we arranged a meeting with Mr. Schläpfer, head of Ernst Schweizer AG, which is a company specialized in solar energy. [2]

[1] **www.edwards.com , 04.04.2011**
[2] **Power Point to this meeting in the annexes**

The following conclusions could be drawn:

First of all it was clear from the beginning is that the first alternative, the "Japanese heating tray", is not efficient enough for our purpose and can be excluded.

The problem is the decision between the second and the third alternative solutions. The following arguments have to be considered.

Semi handmade plate	**Bought prefabricated panel**
Pros:	
• Favorable price	• Assured efficiency
• Active co-operation with the people of Zambia and transfer of knowledge	• Easy installation and logistics
Cons:	
• Efficiency partly depending on the construction of the people in Zambia	• Expensive price
	• Less knowledge transfer necessary

In light of the points considered above, the decision is rather difficult. It seems appropriate to ask the crafts teacher and the janitor of the school if they feel capable of constructing the "semi handmade plates" and are prepared to do this.

We asked Mr. Schläpfer for his personal opinion about the panel construction and we concluded that we want an efficient, long lasting product for our project and that this couldn't be achieved by a handmade construction.

However we will keep in mind the idea of the handmade collector because a transfer of knowledge to Zambia about the constructions of such panels was one of my main goals. The idea came up to try to construct just one of those panels in Zambia and test it, to validate if such a project based only on handmade collectors would even have been realizable and also to transfer some knowledge about the functioning of solar panels.

3.3.5. Recommendation

Following several discussions to review the various relevant factors, a decision was made to select the third or the second alternative "Bought prefabricated panels" / "semi handmade panels", the definite conclusion will be taken in a discussion with the people of Zambia.

4. Planning and design of the system

This section summarizes the actual planning to buy industrial collectors from a company.

4.1. How many Panels are necessary?

Generally you can say that (in Switzerland) one square meter of solar panel gives you about 50l of hot water. This is what one person in a household in Switzerland usually consumes every day. In our case we can't use this rule of thumb because the water for the school in Zambia will only be needed for cooking but will need to be as hot as possible.

We handed over the available information to Mr. Schläpfer (yearly insolation in Zambia and the amount of water used per day) which he used to calculate the amount of panels needed for this project.

The results showed that 45-50 m^2 of collector surface is necessary in our case; this is equivalent to 20-25 collectors (model FK2-H4 with a collector surface of 2.3 m^2 per piece sold by the Ernst Schweizer AG)

After the evaluation of the graphics provided by Mr. Schläpfer for the numbers of collectors required, we decided to design a system with 25 collectors in order to maximise the benefits.

4.2. Where will they be placed?

In this chapter two issues have to be solved: the placement of the solar panels and of the boiler.

4.2.1. Solar panels

In the framework of a project which started in August 2009[1], solar photovoltaic panels are currently being installed in the Namwala High School. The janitor decided to install them on the roofs of the buildings. This is not due to a lack of room elsewhere but because of the risk of vandals damaging the panels or even of people stealing them. It seems likely that the collectors should also be placed on the roofs. But there is a question whether the old roofs of the Namwala High School are strong enough to hold the collectors' weight. It has to be taken into consideration that the construction of the panels in this project will be heavier than the photovoltaic panels which are being installed now.

If the decision is taken to put the collectors on the ground, which seems more logical, the concerns of the janitor have also to be considered. Therefore it is necessary to plan protection measures like for example barbed wire in order to keep vandals and thieves off the panels.

[1] **http://www.namwala.stift.ch/sites_1_de.shtml, 04.04.2011**

What also has to be considered is the angle of the collectors. According to Mr. Schläpfer the angle needed for the system to work properly at the latitude of Zambia is 15°. If the collectors were placed on the roofs this would not need any further arrangements because the roofs are already tilted. If the collectors were placed on the ground, the construction would have to be such as to lean the collectors at a 15° angle to assure proper functioning of the collectors. This would need a onetime angle adjustment at time of the construction.

4.2.2. Boiler

According to Mr. Schläpfer the boiler must be able to contain the daily use of water or a reserve of 40l per square meter of solar panel. For 25 collectors of each 2.3 m^2, the water capacity of the boiler has to be at least 1000l. The daily use of water in Namwala is 2140l. This leads to a boiler capacity of at least 2140l. The question now is where to put it. If the dimensions allow this it would of course be best to put it in the kitchen or nearby but this has to be taken care of during the actual realization of the project.

5. Procurement of the needed goods and initial cost estimation

In this chapter an approximate estimation of the costs will be made. This will allow to plan the required financial and material resources and to simplify the seeking of donations to allow the realization of this project. The goods procurement will only be made for the prefabricated panels because the procurement of the goods for the "semi-panels" would need further clarification with the people in Zambia.

5.1. Procurement of the goods

Due to the collaboration with the Ernst Schweizer AG firm and with his director, Mr. Schläpfer, the material will likely be purchased in Switzerland and shipped to Zambia.

5.2. Initial cost estimation

Mr. Schläpfer gave us a list of the prices for all the planned system components:

„ Sonnenkollektor Typ FK2-H4“ (ab 15 Stück) Fr. 1‘052.- pro Stück

Nachwärmspeicher 800 Liter aus Edelstahl (Typ A) Fr. 4‘772.-

Solarspeicher 1200 Liter aus Edelstahl (Typ A) Fr. 6‘289.-

Plattenwärmetauscher 42 kW gelötet Fr. 1‘139.-

[…]

Solarspeicher 1200 Liter aus Edelstahl (Typ B)
mit eingebauten Glattrohrwärmetauscher 5.6 m2 Fr. 8‘866.-

Solarspeicher 1500 Liter aus Edelstahl (Typ B)
mit eingebauten Glattrohrwärmetauscher 7.0 m2 Fr.10‘707.-„[1]

An approximate cost estimation only is needed at this stage. The actual buying decisions will be taken when the project is actually realized.

Our system complex consists of 25 solar panels, a boiler and pipes. We also have to consider the shipping and duty costs and the sales tax. The costs for solar panels and the boiler don’t constitute a problem. The pipes are problematic because it’s unclear where the panels and the boiler will be placed; consequently, we don’t know how many meters of pipe will be needed. We only need to consider the export duty from Switzerland because the Namwala High School can import goods free of tax. The sales tax for these goods is at a level of 8% [2]

This gives:

Solar panels:	25 x 1‘052.-	=	26‘300 -.
Boiler: (depending on which one)		=	10‘000-. – 15‘000-.
Pipes (rough cut estimate):		=	1’000-.
Shipping: (estimated)		=	2’000-.
Sales Tax: (8%)		=	3144-. - 3544
Total:		=	42’400-. – 47’800-.

The whole project will cost between 42’400 and 47’800 CHF.

[1] Source: PDF-„Vorprojekt“ in the annexes
[2] Source: http://www.kmu.admin.ch/themen/00256/00268/index.html?lang=de, 02.04.2011

With an estimated value of 200-. For the "semi-handmade panels" we can also make a comparative calculation for those ones:

Solar panels:	25 x 200-.	=	5'000-.
Boiler: (depending on which one)		=	10'000-. – 15'000-.
Pipes (rough cut estimate):		=	1'000-.
Shipping: (estimated)		=	2'000-.
Sales Tax: (8%)		=	1440-. – 1840-.
Total:		=	19'400-. – 24'800-.

We can see that the construction with the "semi panels" is much cheaper than the one with the prefabricated panels so a consideration during the actual planning will definitely be worth it.

5.3. Time till profit

This chapter will be ended with the calculation how much time it would take to actually tear a profit out of the project.

With the estimated savings of 2515 CHF per year, it would take approximately 17 to 19 years to recoup the approximate costs of the project with the "prefabricated plates" or 8 to 10 years fot the project with the "semi-plate", which is long in both cases. This is why seeking donations to finance the project is very important. If donations can be found to cover the project investment costs, the project benefits could be enjoyed by the Namwala High School as soon as the project realization has been completed.

6. Summary

First of all the introduction explains the motivation of this Paper as a useful and helpful project at the Namwala High School in Zambia to save electricity and money and gives thanks to all who assisted. The origin of the idea, the exact aim and the social and ecological aspects of this paper are explained.

In section 2, the potential of solar energy and the technical basics of solar energy are explained. This includes a short definition and illustration of solar energy; three criteria to calculate the energy of the sun and a conclusion saying that the calculations regarding solar energy are always difficult and often imprecise. A few guidelines for the related calculations are provided.

There is also a comparison of the efficiency of solar energy between Switzerland and Zambia showing that it's always higher in Zambia than in Switzerland.

Following the introductory part, section 3 of the Paper describes the technical study beginning with an explanation of the main idea and a calculation of its benefit.

This is followed by a description of three alternative solutions for solar panels ("Japanese heating tray", "Semi-handmade plate" and "Prefabricated solar panels") which could be used in this project. The general operating mode of each of the three types of panels is explained and their advantages and disadvantages are listed up. The next points are a comparison of the three alternatives and the decision-making.

The third alternative, "Bought prefabricated panels" was recommended.

In section 4, the actual planning begins: questions about the design of the system, as well as the number of panels, the dimensions and placement of the panels and of the boiler are considered.

The Paper concludes with an initial cost estimation in section 5 and this summary in section 6.

The total cost of the project will be between 19'400-. and 24'800-. or between 42'400-. and 47'800-.

With the estimated savings of 2515 CHF per year, it would take approximately 8 to 19 years to recoup the approximate costs of the project, which is very long. This is why seeking donations to finance the project is very important. If donations can be found to cover the project investment costs, the project benefits could be enjoyed by the Namwala High School as soon as the project realization has been completed.

7. Independence Confirmation

I hereby affirm through my signature that I wrote the submitted paper autonomously, without external help and without other than the declared auxiliary material. All sources, released or unreleased, of which parts were taken over analogously or literally were marked as such. The paper has not been taken over from a foreign paper made within the scope of a past survey.

Date & Place: Signature:

8. Annexes

Images:

- **Image 7: Solar cooker**
  „*http://www.solarserver.com/upuploa/pics/lexikon_solarkochernatur_kultur.jpg*
  (*04.04.2011)*

- **Image 8: Angle of sunrays**
  http://www.klett.de/sixcms/media.php/76/strahlungsenergie.jpg
  (03.01.2011)

- **Image 9: Seasonal insolation**
  http://www.scientific-beginner.de/geographie/Jahreszeiten/Jahreszeiten0816.png
  (03.01.2011)

- **Image 10: Energy balance**
  http://www.agci.org/classroom/images/trenberth_energy.png
  (05.01.2011)

- **Image 11: Insolation accord**
  http://upload.wikimedia.org/wikipedia/commons/d/db/Solar_land_area.png
  (03.01.2011)

- **Image 12: Solar water warming cycle**
  http://www.ofen-undkaminbau.de/assets/images/Solar-Wasser.jpg
  (04.04.2011)

- **Image 7: Japanese solar heating tray**
  Gloor Christelle
  (Wollerau, 22.10.2010)

- **Image 8: Semi handmade plate**
  Gloor Christelle
  (Wollerau, 22.10.2010)

Sources:

- ***http://www.atmosphere.mpg.de/enid/2__Stadtklima/-_Strahlung_42e.html***
  (020.6.2011)

- ***http://de.wikipedia.org/wiki/Sonnenenergie#Abh.C3.A4ngigkeit_der_Strahlungsleistung_vom_Einfallswinkel***
  (03.01.2011)

- ***http://www.edwards.com***
  (04.04.2011)

- ***http://www.klett.de/sixcms/list.php?page=miniinfothek&miniinfothek=Geographie+Infothek&article=Infoblatt+Entstehung+der+Jahreszeiten***
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- ***http://www.kmu.admin.ch/themen/00256/00268/index.html?lang=de***
  (02.04.2011)

- *Lucas Ted,* **How to Build a Solar Heater a complete guide to building and buying solar panels, water heaters, pool heaters, barbecues, and power plants**
  (Pasadena - Calif. : Ritchie , 1975)

- ***http://www.namwala.stift.ch/index_de.shtml***
  (04.04.2011)

- ***http://www.namwala.stift.ch/sites_1_de.shtml***
  (04.04.2011)

- ***http://www.wasser-wiki.de/doku.php?id=wasser_eigenschaften:waermekapazitaet:start***
  (04.04.2011)

- *Gloor Christelle,* **Power-Point presentation of the Meeting with Mr. Schläpfer**
  (22.02.2011, Hedingen)

Heisses Wasser für Namwala

Ein Projekt, entstehend im Rahmen der Partnerschaft der Stiftsschule Einsiedeln und der Namwala High School in Namwala Sambia als
Maturaarbeit von Christelle Gloor, begleitet von Johannes Van Der Weijden.

Heisses Wasser für Namwala

Ziele:

• Das Bewusstsein für solare Energie in Afrika stärken und die Möglichkeiten wahrnehmen frühzeitig darin zu investieren und damit Menschen zu helfen

• Eine aktive Kooperation zwischen der Schweiz und Sambia in Sachen solare Energie schaffen

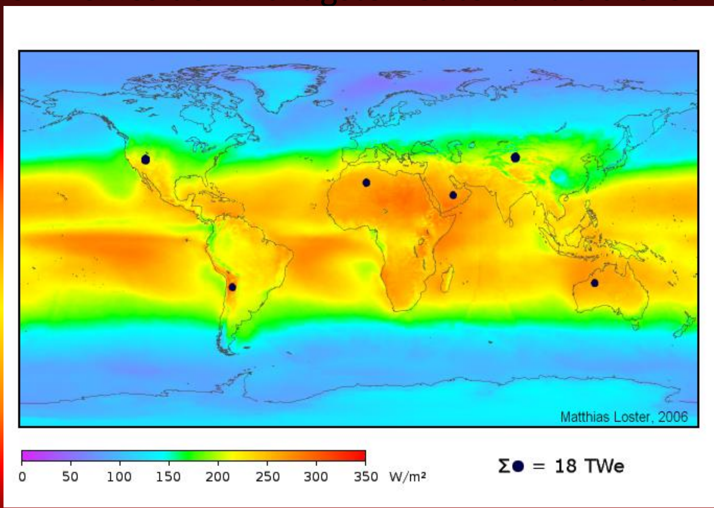
• Der Namwala High School die Möglichkeit schaffen mit diesem Projekt Geld zu sparen und der Unabhängigkeit des monopolistischen Stromproduzenten ZESCO einen Schritt näher zu kommen

Heisses Wasser für Namwala

Solare Energie in Afrika

Afrika als sonnenreicher Kontinent → Energiequelle

Energie → eines der wichtigsten Güter und sichere Investition



Heisses Wasser für Namwala

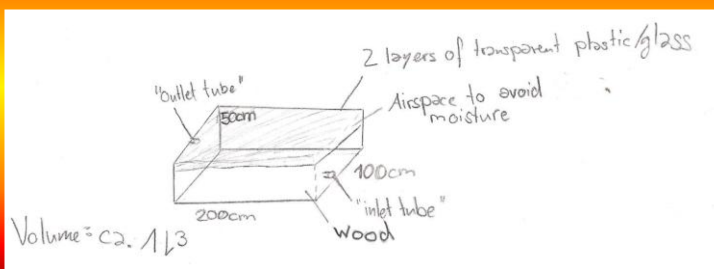
Solare Energie in Afrika

Humanitäre Aspekte der Sonnenenergie in Sambia:

- Konkurrenz für die monopolistische Stromversorgung und somit finanzielle Unabhängigkeit

- Umweltschutz (Prävention von Haushaltsbedingten Waldrhodungen, Desertifikation & Artensterben)

Beispiele: Solarkocher, simple Heizwannen für warmes Wasser



Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

3 x (4x225l + 4x135l) Wasser muss am Tag auf ca. 97°C aufgeheizt werden (1000m Höhe).

→1140l Wasser um 82 °C (15°C morgens)
→ 2x 1140l Wasser um 72 °C (25 °C tagsüber)

Idee:
Geld sparen indem wir das Wasser schon auf 80 °C vorheizen.

Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

Strompreise:
(2.6.2011) → 18’000’000 K (4000 US $) im Monat /180.00 K (0.04 US $) pro kWh.

Morgen vernachlässigen → 2x 1440l Wasser auf 80 °C aufheizen (2x 55 °C → von 25 °C auf 80 °C)

Um1440l Wasser um 110 °C zu erhitzen braucht man184 kWh.

Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

<u>184 kWh am Tag sind 5520 kWh im Monat.</u>
<u>5520 kWh x 180 K = 993’600 K = 206.3 US $</u>
<u>Dies entspricht 2475.6 US $ im Jahr.</u>

Dies entspricht **7.75** Stipendien im Jahr
oder **93** neuen Schulpulten
oder **116** Stühle

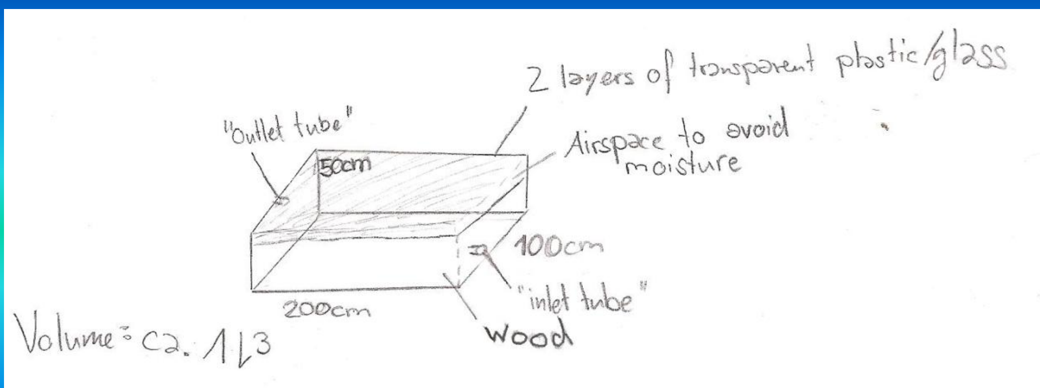
Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

Möglichkeiten für Kollektoren:

1. „japanese heating tray“



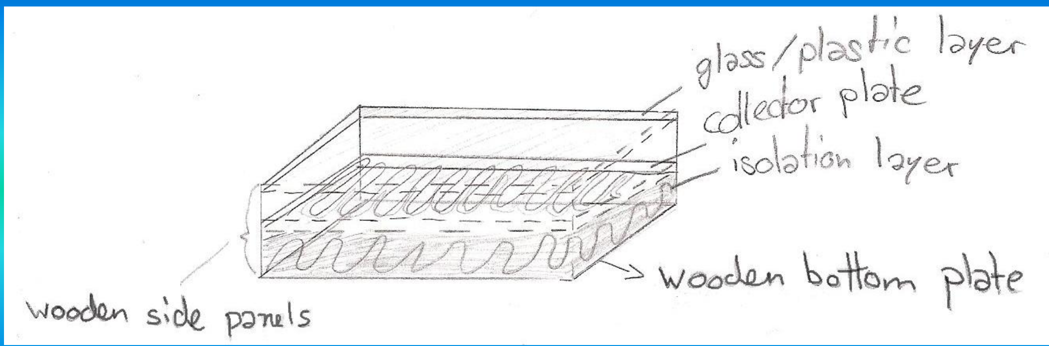
Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

Möglichkeiten für Kollektoren:

2. „semi handmade plate“



Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

Möglichkeiten für Kollektoren:

3. Fertige, gekaufte Kollektoren

Heisses Wasser für Namwala

Das eigentliche Projekt

Überlegungen:

Möglichkeiten für Kollektoren:

Vergleich:

System	Price	Water heating ability	Quality	Logistics
“Heating tray”	Cheap (only materialcosts)	Low (50 °C)	Depending on students	Complicated (gathering all the material)
“Semi plate”	?	? (high?)	Good	Easy
“Bought panel”	Expensive	High	Good	Easy

Heisses Wasser für Namwala

Das eigentliche Projekt

Offene Fragen:

1. Professionelle Meinung: 2. oder 3. Option?
2. Wie viele Kollektoren?
3. Wasserpumpe?
4. Problem des morgentlichen Wassers?
5. Löcher in der Tabelle füllen:

System	Price	Water heating ability	Quality	Logistics
“Heating tray”	Cheap (only materialcosts)	Low (50 °C)	Depending on students	Complicated (gathering all the material)
“Semi plate”	?	? (high?)	Good	Easy
“Bought panel”	Expensive	High	Good	Easy

Heisses Wasser für Namwala

System	**Price**	**Water heating ability**	**Quality**	**Logistics**
“Heating tray”	Cheap (only materialcosts)	Low (50 °C)	Depending on students	Complicated (gathering all the material)
“Semi plate”	?	? (high?)	Good	Easy
“Bought panel”	Expensive	High	Good	Easy

- ***Schläpfer, Bruno,*** **PDF-Document Vorprojekt** *(23.03.2011)*