Bachelor Degree Project

UNIVERSITY OF SKÖVDE

WINDMILL DRIVEN WATER PUMP FOR SMALL-SCALE IRRIGATION AND DOMESTIC USE

-In Lake Victoria basin

Bachelor Degree Project in Mechanical Engineering
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Abstract

This project is a combination of mechanical engineering and sustainable development in developing countries. The goal has been to build a windmill driven water pump and to design a small-scale irrigation system for SCC-Vi Agroforestry's demonstration farm in Musoma, Mara region, Tanzania. The purpose was to enable SCC-Vi Agroforestry to demonstrate and spread knowledge about these techniques to farmers in the region.

In 2007, two students from Halmstad University conducted a field study in the Mara region and found that many farmers lack clean and running water. Back in Sweden they constructed a prototype of a windmill that employs wind energy to pump water using a semi-rotary pump. The intention is that local farmers should be able to build their own windmill, and thus have running water in their household. However, the windmill has never been built in Tanzania.

The windmill construction in this report is based on the prototype, but the original drawings were changed to fit the specific situation in Tanzania better. Important throughout the project has been to minimise cost and to only use material that local farmers can get hold of. Building and assembling of the windmill were then performed by the authors in co-operation with local workers. The windmill drives a pump that pumps water from a well to a tank for further use in irrigation.

Calculations have been made on the energy available in the wind and an energy analysis was then performed to see what wind speed is required for the system to work. If wind speed is low, the windmill can be adjusted by placing the connecting rod closer to the rotation centre where it requires less work to function. As a result of that, the volume of water per stroke will decrease and it will take longer time to fill the tank. This project was carried out during the rainy season when there is less wind; therefore the windmill has not been tested during optimal wind speed conditions. The tests that have been performed during the circumstances at the time showed that the performance of the windmill is consistent with the theoretical calculations.

A proposed design for a simple drip irrigation system has been developed based on the conditions at the project area. It is constructed of plastic pipes with holes that emit water. Covers are in place to prevent soil from clogging the holes. Building the irrigation system was not part of this project.

Sammanfattning

Detta projekt är en kombination av maskinteknik och hållbar utveckling i utvecklingsländer. Målet har varit att bygga en vindhjulsdriven vattenpump och att designa ett enkelt bevattningssystem för SCC-Vi Agroforestrys (Vi-skogen) demonstrationsfarm i Musoma, Mara-regionen, Tanzania. Syftet var att möjliggöra för SCC-Vi Agroforestry att demonstrera och sprida kunskap om dessa tekniker till lokala bönder.

Två studenter från Högskolan i Halmstad utförde 2007 en fältstudie i Mara-regionen. De fann att många bönder saknar tillgång till rent och rinnande vatten. Tillbaka i Sverige konstruerade de en prototyp av ett vindhjul som använder energin i vinden till att driva en vattenpump. Tanken är att lokala bönder ska kunna bygga sitt eget vindhjul och då få tillgång till vatten på sina gårdar. Detta vindhjul har dock aldrig blivit byggt i Tanzania.

Vindhjulet i denna rapport är baserat på prototypen, men originalritningarna ändrades för att passa den specifika situationen i Tanzania bättre. Något som har varit viktigt genom hela projektet är att hålla kostnaderna nere och bara använda material som de lokala bönderna kan få tag på. Byggandet och monteringen av vindhjulet utfördes sedan av författarna tillsammans med lokal arbetskraft. Vindhjulet driver en pump som pumpar upp vatten till en tank och som därefter kan användas till bevattning.

Beräkningar på tillgänglig energi i vinden har utförts och energiberäkningar har gjort på systemet för att se vilka vindhastigheter som krävs för att det ska fungera. Vid låga vindhastigheter kan vindhjulet justeras genom att flytta vevstaken närmare rotationscentrum. Då krävs det mindre energi för att pumpa, men slagvolymen blir också lägre och det tar längre tid att fylla tanken. Detta projekt pågick under regnperioden då det är mindre blåsigt och därför har inga tester under optimala vindförhållanden kunnat utföras. Resultaten från de tester som gjordes under rådande förhållanden överrensstämmer dock bra med de teoretiska beräkningarna.

En design på ett enkelt droppbevattningssystem har föreslagits baserad på områdets förutsättningar. Det består av plaströr med hål vid varje planta där vattnet kan sippra ut. Hålen är täckta med ett skydd för att förhindra jord att täppa igen dem. Att bygga bevattningssystemet var dock inte en del av detta projekt.

Acknowledgment

We would like to thank Björn Horváth, manager at the Mara project, SCC-Vi Agroforestry Programme, who has been our mentor in Tanzania. We would also like to thank all staff at the Mara project for making it possible for us to carry out this project. Special thanks go to Damian Sillas, Nicholous Kababmbo, Aloyce Mawazo and Felix Assey for their help and advice. Furthermore, thanks to the drivers who took us out to the ATC in Bweri no matter what weather conditions!

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LIST OF ABBREVIATIONS

ATC – Agroforestry Training Centre
GNP – Gross National Product
LVFO – Lake Victoria Fisheries Organization
NGO – Non-governmental organisation
RPM – Rotation per minute
SCC – Swedish Cooperative Centre
SCC-ViAFP – SCC-Vi Agroforestry Programme
SIDA – Swedish International Development Cooperation Agency

1 Introduction

1.1 Background

Tanzania (figure 1) is one of the poorest countries in the world, with 89.9 % of the population living on less than 2 US dollar per person and day [1]. The economy is largely based on agriculture, which in 2004 accounted for more than 43 % of the Gross National Product, GNP [2].

Many Tanzanians live in the rural areas of the country, making their livelihood as small-scale farmers. The crops they grow are mostly for their own family's use, but if there is any surplus, it can be sold on local markets for profit.

Figure 1. Map over Tanzania [3][4].

Rural Tanzania is in many ways underdeveloped. The infrastructure is poor; roads are in bad shape, there is no electricity or running water, and waste management is inadequate. The lack of water is a problem many farmers wrestle with. Even those who live close to a water source, such as a lake or a river, are lacking running water in their homes. It is usually the women and children of the household who have to walk long ways to bring home water. The time they spend on fetching water could be better spent doing something else. Children could go to school, and women could work more in the home or perhaps take a part-time-job to increase the family's income.

Another consequence of lack of water is that it is difficult for farmers to provide the crops with enough water during the dry season (January to March and June to October). This means that farmers can only grow crops that will withstand water shortage for a period of time, or perhaps even last through drought. Only a few kinds of crops can survive in these conditions. Growing the same crops every season can deplete the soil of its nutrients [5], which may lead to an unbalanced diet with not enough vital nutrients and vitamins.

Because of the hard living conditions in rural Tanzania, a common attitude to work and life is to live day by day and earn money just to survive the day. There is almost no long-term planning for the future.

Quick facts about Tanzania

Capital city	Dodoma(Political), Dar es Salaam (Admin. and Commercial)
Languages	Swahili (official language), English and about 200 tribe languages
Area	945,087 sq.km
Population	38.3 million (2006)
Currency	Tanzania Shilling (TZS)
GNP	11.7 billion USD (2006)
Government	Republic

Table 1. Quick facts about Tanzania [6].

1.2 SCC-Vi Agroforestry

Vi Agroforestry Programme (ViAFP), or Vi-skogen as the organization is known in Sweden, is working with educating farmers in the Lake Victoria basin in East Africa. The work started in Kenya in 1983, with plantation of trees aiming to prevent soil erosion and halt desertification. In 2006 Vi Agroforestry and Swedish Cooperative Centre formed a regional organization in East Africa called SCC-Vi Eastern Africa [7], which in this report will be referred to as SCC-ViAFP. It is a non-governmental organization (NGO) financed by SIDA and the Swedish Cooperative movement, as well as through private contributions and individual donors [8].

SCC-ViAFP works with different projects aimed at small-scale farmers in the Lake Victoria basin. The main focus has since the beginning been on agroforestry and environment but today work also include enterprise development, organizational development, lobbying and advocacy and micro financing as well as cross-cutting issues like how to prevent and reduce malaria and HIV/AIDS, and gender and youth questions among farmers. A lot of work is being done in the field with introducing new cultivation and agroforestry methods, water harvesting techniques and other farming technologies to farmers.

There are currently six projects running in Kenya, Tanzania, Uganda and Rwanda. This report will focus on the Mara project in north-western Tanzania, which has been active since 1994, and its Agroforestry Training Centre (ATC). The purpose of an ATC is to demonstrate agroforestry practices to farmers, such as how to plant trees and crops together to improve soil conditions, but also to show the general public the potential of agroforestry [8].

SCC-ViAFP's vision is "A sustainable environment offering good living conditions for farmer families" and their mission is "To make agroforestry and enterprise development engines of economic growth and poverty reduction" [7].

1.3 Earlier feasibility study

In 2007, Anna Håkansson and Petra Nilsson, two students from Halmstad University, visited SCC-ViAFP in Musoma, Tanzania. They conducted a field study [9] that identified several problems that many farmers in the region have; one of them being lack of clean and running water. Håkansson and Nilsson's goal were to develop a product that could solve this problem.

Back in Sweden they constructed a windmill prototype (figure 2) that employs wind energy to pump water using a semi-rotary pump. The intention is that local farmers should be able to build their own windmill [10] and pipe system, and thus have running water in their household.

However, the windmill has never been built in Tanzania, but SCC-ViAFP wish to implement this solution at their ATC.

Figure 2. Windmill prototype in Halmstad [9].

1.4 Purpose/Objectives

The project presented in this report will be a combination of mechanical engineering and sustainable development in developing countries. It is based on the earlier feasibility study made by Håkansson and Nilsson [9], but modifications will be made to their proposed construction [10].

The goal of this project is to build a windmill driven water pump that can pump water from a nearby source to a tank. The purpose is to enable SCC-ViAFP to demonstrate and spread knowledge about wind-powered water pump technique to farmers in the Mara region. As previously mentioned, SCC-ViAFP is interested in building the proposed windmill construction. A windmill at the ATC would provide good means for showing visitors how wind energy can be used for water harvesting. That is the main reason for building the windmill. The secondary reason is to use it to pump water to a tank for further use in irrigation or livestock farming at the ATC.

SCC-ViAFP is also interested in a solution for an irrigation system connected to the tank. The irrigation system shall be designed for usage at the ATC, but it shall also be used to demonstrate small-scale irrigation methods to farmers.

The keywords for this project are *simple* and *cost-effective*, so that it will be possible for local farmers to use the techniques on their own farms.

1.5 Delimitations

This project has been limited to the following:

- No major changes will be done to the original construction. The report will not include strength of materials calculations on the windmill construction.
- The type and size of the irrigation system will depend on actual field conditions at the project area, but the system will not be designed for fields larger than 4 000 m^2.
- No full-scale irrigation system will be built on site.
- Only water from Lake Victoria will be considered. The possibility of drilling for ground water will not be taken into consideration.

2 Method

As a start, a project plan (appendix 1) was outlined that considered the delimitation and time frame. A Gantt chart (appendix 2) was used to visualize the deadlines for the project. An important part of the project was the field study to Musoma, Tanzania, to realize the windmill construction for SCC-ViAFP and gather data for designing an irrigation system.

Information was gathered in different ways. Internet searches and literature studies were conducted during the whole project to find the information needed. Knowledge about Tanzania, the project area, culture and other conditions was mostly acquired by talking to local people and working with them. When possible, the information was verified by other sources, such as different books, websites or people, to avoid misinterpretations and prevent misunderstandings due to language difficulties.

Several field studies were done to get a fair view on the living conditions for small-scale farmers in Tanzania. Photographs and videos were taken for documentation and used as inspiration during informal brainstorming sessions.

An evaluation matrix (appendix 3) was used in order to decide where to build the windmill. Wishes and demands were formulated as criteria and sorted by importance, then measured against each other to find the most suitable location.

3 Theory

3.1 Lake Victoria basin & Mara region

Lake Victoria is the second largest freshwater lake in the world. The shallow lake is only 82 metres deep but has an area of almost 70,000 m^2. It is situated in central Africa, 1,134 metres above sea level [11], with shorelines in Tanzania, Uganda and Kenya [12]. The Lake Victoria basin (figure 3) is one of Africa's most densely populated regions, with about 30 million inhabitants [13].

Figure 3. Lake Victoria basin [16].

The fish industry is a vital source of income for many of these residents. Lake Victoria Fisheries Organization (LVFO) estimates that about 2 million residents in the area are supported directly through fishery [14]. Other livelihoods include farming, bee-keeping, trading activities, quarrying and mining.

Agriculture is an important sector for all three countries, but unfortunately not much of the basin's land area has good conditions for farming. The gradually increasing reduction of vegetation cover causes the soil to erode, leaving behind soils of low fertility and bed texture [13].

One of Lake Victoria's influents, Mara River, has given name to the region in north-western Tanzania. The Mara region (figure 4) borders the Republic of Kenya in the north, Lake Victoria in the west and has a large part of the national park Serengeti in the southeast. The population in Mara was 1,363,397 [15] in 2002 and the region's capital is Musoma, situated on the lake shore.

Figure 4. Mara region [20].

There are two rainy seasons in the Lake Victoria basin, which normally occur from March to May and from October to December. The annual rain fall around the lake is 750–2,250 mm [17], with an average of 750-1,000 mm in the Mara region [18]. Water harvesting is often needed in order to grow crops all year round and provide food and income for the family. Some common crops for farmers to grow are sorghum, cassava, maize and vegetables.

In the experience of local people, it is much windier during the dry seasons than during the wet. Some farmers utilize wind energy through windmill technology to pump water, cut wood or grind grains [19], but it is not frequently seen.

3.2 Wind

Wind primarily occurs because of temperature differences in the air caused by sun radiation. When air is heated it becomes less dense and therefore rises. The pressure at ground level decreases, and because air always flows from high pressure to low pressure, thermal circulation is then developed.

One example of this thermal circulation is the sea breeze; a local wind found in coastal areas or at large lakes. It occurs on relatively clear days when the sun heats the land more than the sea, causing the air above the land to rise and flow out over the water. The air cools off, sinks, and flows back in over land. The sea breeze can occur all year round in the tropics, and can reach a speed of 5-10 m/s at ground level [21]. It is most extensive during the afternoons when the sun has heated the ground to a high temperature [22].

The opposite of sea breeze is land breeze. It happens during the night when the land cools off faster than the water, and the process described above is reversed. It is a lot weaker with speed at only about 1 m/s [21].

The wind speed increases with altitude and can be estimated using the Beaufort scale, which is based on observations of the surroundings [23], see appendix 4.

3.2.1 Wind power

The kinetic energy in the wind can be converted into different useful energy forms, such as mechanical energy or electricity. This is called wind power. It is a renewable energy resource that is under steady development worldwide. It is also said to be an absolutely clean source of energy, since there are no emissions or direct influences on the environment, except for the aesthetical [24]. It can also produce disturbing noise while running.

Wind power technology has come forward since the 12th century when the first windmills were built in Europe for grinding grains into flour. In 19th century America, windmills were used for pumping water at farms. Today's wind power stations are very advanced and use complex technology, but the old-fashioned type of windmill is still being built and used. It is common all over the world, especially in developing countries, but also among famers in America and Australia [24].

One disadvantage with wind power is that it is unreliable, as the wind cannot be controlled. Hills and trees can reduce wind speed and cause the wind to change direction [19]. With a suitable location and with good wind conditions, wind power is a good energy source.

3.3 Pumps

3.3.1 Piston pump

A piston pump (figure 5) is a simple construction. It consists of a cylinder pipe with a piston inside and two non-return valves placed opposite each other. When mechanical work is exerted on the connecting rod the piston moves up and down, sucking water in to the pipe and then pumping it out. As the piston is pulled upwards, water enters the pipe through one of the valves because of the low pressure that has arisen in the pipe. When the piston is then pushed down, the water is forced out through the second valve because the first valve is closed. By repeating this movement water is transported [26].

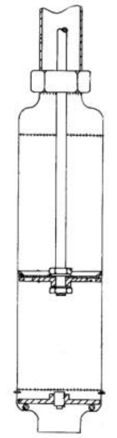

Figure 5. Piston pump [25].

The torque required to start a piston pump is relatively high, because it needs to overcome both the weight of the pump rod and that of the water being lifted. Once the rotor is turning, wind speed can drop to about 2/3 compared to the start speed [27].

The capacity of a piston pump is relatively low and the water flow will not be constant, but it is cheap to manufacture and easy to use. A piston pump can produce large head even with low rotation speed [28].

3.3.2 Semi-rotary pump

A semi-rotary pump (figure 6) works like a piston pump, but instead of a straight connecting rod it has a lever. The lever is rotated back and forth in a semi-circular path. The leverage means that the semi-rotary pump does not need as much force as a piston pump to perform the work of pumping liquids.

It is suitable for liquids with low viscosity, such as water or diesel, and it is generally used as a hand pump. Since it is sensitive to dirt that may come in the system it is not optimal to use this type of pump for irrigation [29].

Figure 6. Semi-rotary pump [30].

3.4 Plain bearings

A plain bearing (figure 7) is in its simplest form only a shaft rotating in a hole, which can be lubricated for improved performance [31]. If mixed conditions apply and the surfaces are not fully separated by oil or grease, the friction factor is about 0.02 - 0.1 [32]. That is high compared to roller or ball bearings. Risk for wear and tear, especially in start and stop periods, suggest that plain bearings are most suitable for small loads and low speeds [33]. Regular maintenance and greasing are required.

Figure 7. Plain bearings [34].

3.5 Agroforestry

Agroforestry is the practice of integrating woody perennials with crops and animals on the same field, either simultaneously or in subsequent growing seasons [35]. It can be advantageous in many ways.

For example, a common agricultural problem in East Africa is lack of nitrogen and organic matter in the soil. By growing nitrogen fixing trees in or next to the fields, soil fertility is improved and harvests can often be doubled. Different tree species can be used for different reason: fast growing trees can be used for fuel-wood or animal fodder; fruit trees will add nutrient to the family’s diet; and trees that grow slowly can be sold as timber in the future [36].

3.6 Crop rotation

Crop rotation is the practice of alternating crops grown on a certain field in order to reduce the risk for pests and diseases [37]. Growing crops from the same family in subsequent seasons will deplete the soil of its nutrients [5], whereas crop rotation can improve soil conditions.

Some crops are especially suitable to grow in a rotating scheme. For example, cabbage requires a lot of nitrate, thus it should be grown after nitrate-fixing crops such as legumes. Cabbage, in turn, prepares the soil for root vegetables and onions [38].

3.7 Irrigation methods

There are several types of irrigation methods, where the most common is some kind of surface irrigation, sprinkle irrigation or drip irrigation.

Surface irrigation (figure 8) is when the field is covered with water, either for a short period or during a longer. The water moves over the surface of the field by gravity flow. There are different types of surface irrigation; furrow irrigation where water flows along through channels in the field; and basin irrigation where the whole field is flooded [39]. Surface irrigation requires that the farmer has access to a lot of water.

Figure 8. Surface irrigation [40].

Sprinkle irrigation (figure 9) is when water is pumped through a pipe system and by rotating sprinkle heads is spread onto the field [39]. In a field with sprinkle irrigation there are several sprinkle heads placed with distance between each other. Disadvantages with sprinkle irrigations are that if it is windy the water is not distributed in the desired places, and if it is very hot the water evaporates quickly.

With drip irrigation (figure 10), the water is conveyed under pressure through a pipe system with small diameter and then slowly emitted into the soil. The emitters are placed nearby the plants so water can reach the crop roots directly, which lowers the evaporation. Because of this, a smaller amount of water is needed than when using surface or sprinkle irrigation. The water is emitted at a low rate, only about 2-20 litres per hour and emitter, and the emitters can be placed on the surface or underground. Each crop is provided with one or more emitters depending on water requirements for the specific plant. Drip irrigation is suitable for trees, soft fruit, vegetables or other row crops [39].

Figure 9. Sprinkle irrigation [41].

Figure 10. Drip irrigation [42].

4 Present situation analysis

4.1 Water supply in Mara region today

The largest water source in the Mara region is Lake Victoria and its influents Mara River and Grumeti River. Because of the lack of water supply pipes, many farmers have to fetch water outside their homes, such as at a communal well or at a neighbouring farm. This is a heavy, time-consuming work, most often carried out by women and children. The water is then being used for cooking, hygiene and farming. Irrigation systems are not common; most farmers irrigate by hand.

Mr. Moris is one of few farmers in the region who has a windmill (figure 11). His windmill is placed at the shoreline of Lake Victoria and drives a piston pump which pumps water to his farm 600 metres away. The inlet is 30 metres out in the lake. The total head is about 6 metres. Mr. Moris has had his windmill for 6 years. He uses a plain bearing made of wood for the axis and it works very well. His family is supplied with all water needed for domestic use.

Figure 11. Mr. Moris's windmill.

4.2 Original windmill construction

Håkansson and Nilsson's original windmill construction (figure 12) consists of a wooden frame, a steel axis with six steel bar wings stabilised by strings, two bicycle wheels used as bearings, and a bar and connecting rod (conrod) used for power transference. The sails should be made of a fabric that does not let too much wind through, or absorb too much water. The sails are then tied to the wings with strings. There are different ways to anchor the frame in the ground. It can be dug down in the sand and hold in place with heavy stones, or tied to nearby trees or stumps [10].

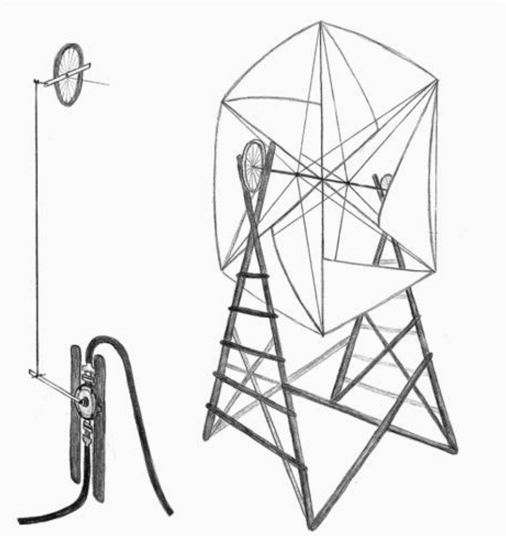

Figure 12. Sketch of original construction [10].

The bar is fastened on one of the bicycle wheels, so when the wheel rotates, the conrod is driven up and down in a pumping motion (figure 13). A pump can be attached to lower end of the conrod, and thus the pump will be driven by the windmill when the wind blows. It will pump one stroke per rotation of the windmill.

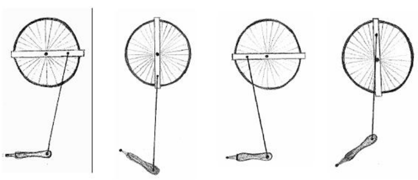

Figure 13. Schematic picture over semi-rotary pump function [10].

Tests with the prototype windmill were performed only with a semi-rotary pump. According to the manual, it is also possible to use a piston pump. The sails for the prototype were made of real sail fabric, sponsored by a sail manufacturer.

The prototype resembles a Cretan windmill, with cloth instead of metal blades covering a large part of the swept area [29].

4.3 The project area: Agroforestry Training Centre, Bweri

SCC-ViAFP's demonstration farm, or Agroforestry Training Centre (ATC), in the Mara region is located in Bweri, about 6 km east of Musoma Town. The area is about 13.3 hectare and divided in two parts; farm 1 is 5.5 hectare and farm 2 is 7.8 hectare (figure 14) [43]. It is situated near Lake Victoria but does not have a shoreline.

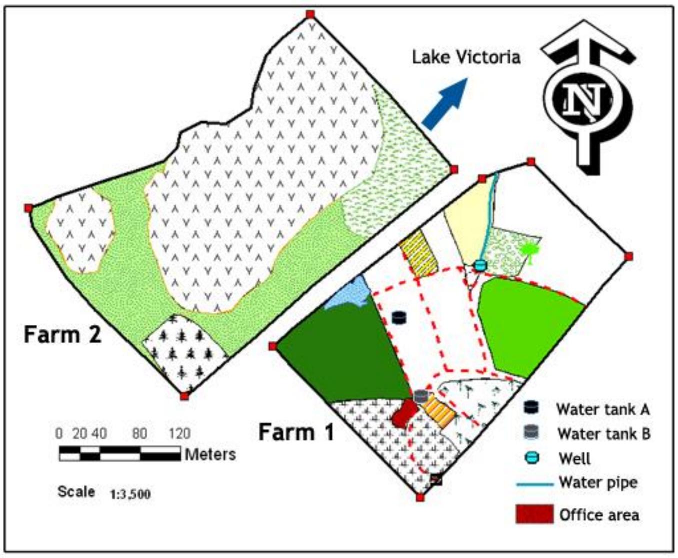

Figure 14. Map over ATC [43].

Most of the cultivation is on farm 1, which also houses office buildings, a plant nursery, a chicken farm and bee hives, a well and two water tanks. Farm 2 consists of a big hill, trees and shrubberies. There is no electricity at the ATC, but tests with solar energy are currently going on.

The ATC employs four permanent staff and casual labour is hired if needed.

4.3.1 Crops & soil

Crop rotation is practiced to allow use of the fields all year round without depleting the soil. Some of the vegetables that are grown here are cabbage, cauliflower, tomato and cucumber. There are several fruit trees such as passion fruit, guava, banana and water melon. Maize, sunflower and nitrogen fixing trees like sesbania are also common.

A field suitable for an irrigation system is situated right next to water tank A on farm 1 (figure 14). It is 30 x 20 metres and has a gentle slope. The top soil texture is sandy clay to clay loam, with a hardpan between 40 and 100 cm depth. A hardpan is a hard layer of soil which causes water to drain poorly [43]. This kind of soil is suitable for growing vegetables, such as cabbage, beans and onions [44]. Certain species with strong roots can be grown to crack the hard pan.

4.3.2 Water sources

The water used at the ATC is either harvested rainwater or water coming from Lake Victoria, and water shortage is rarely a problem. The ground water in the area is too salt to be used for irrigation, according to Håkansson and Nilsson [9].

Rain water harvesting is being done at the office building area where water is collected in a large cement tank and mainly used for cooking and hygiene.


Figure 15. Water tank A at ATC.

The well at the ATC is connected with Lake Victoria through a pipe and it is filled with water due to natural pressure. Water from this well is then pumped a distance of 92 metres to water tank A (figure 15), which is placed on a 2 metre high concrete platform and holds 5,000 litres.

To take water directly from the lake, an annual fee has to be paid to the government. This is not needed in order to use water from the well.

4.3.3 Existing pumping system

There is a diesel pump (figure 16) which is used to pump water from the well to the tank when it is necessary. The capacity of the pump is 600 l/min and it has a total head of 300 metres. The pump is placed in a wheelbarrow and transported from the storage shed to the well each time it is being used.

Figure 16. Diesel pump at ATC.

A pipe going from the well to the tank is always in place, and the pump can be connected to this at the well. The part of the pipe that is submerged in water has a filter made from a plastic bottle with holes in, in order to prevent particles from entering the pipe system. There is no better filter in use today.

Since the pipe system is of a larger dimension than the inlets at the tank, the inlets are not being used. Instead the end of the pipe is put over the top edge of the tank, which is possible because the tank lid is not always in place. It takes about 30-40 minutes to fill the tank with water.

4.3.4 Irrigation

Today the fields are irrigated by hand using hoses and pipes. The irrigation water comes from tank A, to which pipes are connected where the water can flow because of natural pressure. Fertilizers are being used at the fields, but are not mixed with the irrigation water [45].

Irrigating large fields by hand is time-consuming for the staff. For example, a field of 1,000 cabbage plants is irrigated with 3,000 litres of water per week, distributed on two or three occasions [46].

The conditions at the ATC, with access to water but with no effective transportation of it to the fields, apply to many of the farmers who live near the shoreline.

4.3.5 Weather and wind conditions

As mentioned earlier, wind conditions in the Lake Victoria basin is favourable for extracting wind energy. This is also true for the ATC area as it is situated nearby the shore. Factors that might reduce the wind speed are the hill at farm 2 and the many trees growing on both farms. According to the staff's experience and consistent with meteorological facts, there is significant more wind during the dry season.

Figure 17. Flood at ATC.

When there is heavy rain falls large parts of the fields get flooded (figure 17), due to a drainage problem that has yet to be solved.

5 Realization

5.1 Choosing location for the windmill

SCC-ViAFP had not decided on the location for the windmill, but wished for it to be easy to demonstrate for visitors. Several visits were made to the ATC and discussions were held with the staff to learn about weather conditions, wind speed and direction, water usage, suitable locations (figure 18) and other necessary information needed in order to choose where to build the windmill.

Five different combinations of windmill location and water source were then considered;

- A: Windmill placed at the hill and water pumped from the lake.
- B: Windmill placed at the shore and water pumped from the lake.
- C: Windmill placed at the shore and water pumped from the well.
- D: Windmill placed close to the well and water pumped from the well.
- E: Windmill placed close to the well and water pumped from the lake.

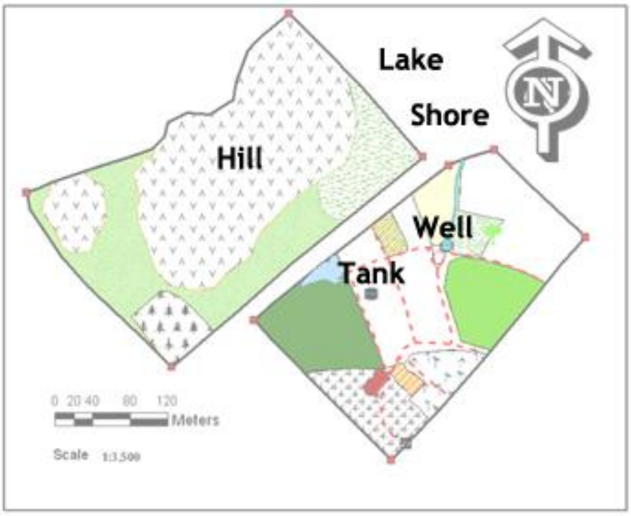

Figure 18. ATC area [43].

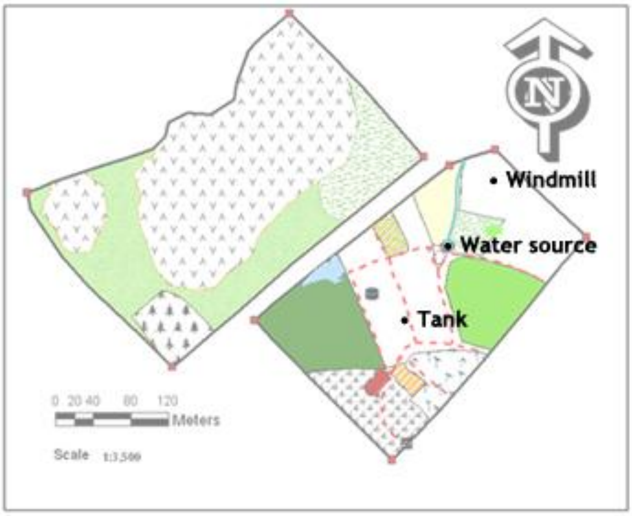

Figure 19. Chosen location for windmill [43].

To choose the most suitable location, an evaluation matrix (appendix 3) was used. After discussing with the people involved with the project, a list of demands and wishes could be put together. These were changed into criteria and given different weights depending on how important they were deemed to be. Some of the most important criteria were wind conditions and demonstration ability.

The comparison showed that alternative D was the best option. The exact location of the windmill was chosen to be at farm 1 (figure 19), where there are relatively few trees. If needed, some can be taken down to enhance wind conditions. The location is also close enough to the well, so there is no water fee.

5.2 Changing windmill construction

After analyzing the drawings of the original model, the impression was that it would probably not withstand storms due to a rather weak construction. Several modifications were made to strengthen the construction. In this work, Mr. Moris's windmill was used as a source of inspiration. Discussions with an experienced mechanic also gave some important insights about bearings.

Hand-written drawings (appendix 5) of the new construction were made to be able to explain the windmill for everyone involved with the project. A list of materials needed to build the windmill was put together to serve as a purchase order (appendix 6).

For this particular location, there was also need for a concrete foundation, which was planned in collaboration with an experienced carpenter.

5.2.1 Pump

There was already a piston pump at the ATC, so to save money and material the old pump was restored. Another benefit from changing to the piston pump is that it is easier for rural farmers to make their own or order one from a local pump maker.

5.2.2 Frame

The basic construction of the wooden frame is kept. Due to some inconsistency in the original drawings, calculations were made on the measurements of wood logs and number of horizontal placed logs needed, and new drawings were developed accordingly (figure 20).

The lowest horizontal step is now placed at the very bottom of the triangular frame to make it easy to fasten in the concrete foundation.

Figure 20. CAD-model of frame.

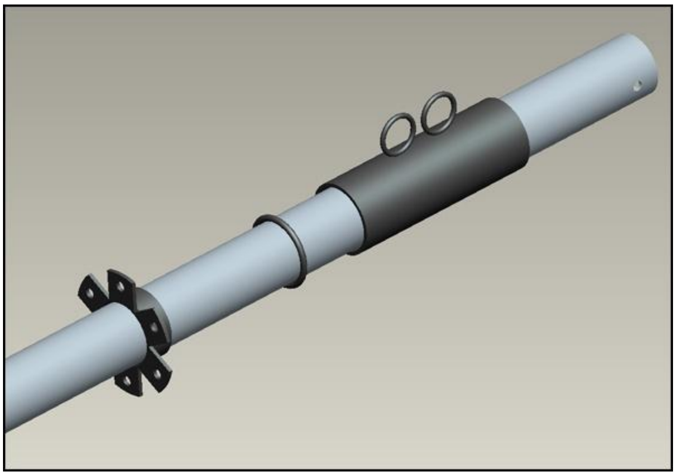

Figure 21. CAD-model of axis, wire holder, stop ring and bearing.

5.2.3 Axis and bearings

A problem is that the original construction calls for two functional front wheels. Because bikes are valuable and used for transportation until complete breakdown and spare parts are expensive, the bicycle wheels are replaced by simple plain bearings. Fastening the bicycle wheels to the frame only by rope could also be unstable.

The plain bearings are made from a metal pipe with larger diameter than the axis, and placed directly in the crotch for increased stability. Two rings are welded to the pipe and used for fastening it to the frame, either by ropes or nails. Compared to bicycle wheels, plain bearings require more grease but are easy to maintain. Advantages with the new bearings are that they are cheaper and easier for farmers to obtain than bicycle wheels.

In order to save money and be eco-friendly, a galvanized steel pipe that was already at the project is used as an axis (figure 21). It is important for the axis to be horizontal so that it will turn smoothly in the bearing.

Stop rings are put on the axis approximately 1.15 m from the centre to stop it from going all the way through. The loops are replaced with a wire holder on each side of the centre.

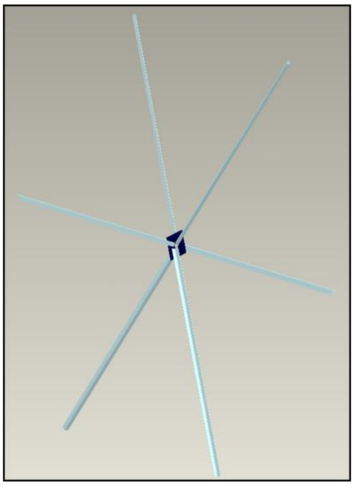

Figure 22. CAD-model of wings.

5.2.4 Wings

L-profile steel bars were chosen for the wings. They are lighter than square pipes, which reduce the self-weight of the wheel, and they are easier to drill holes in compared to round pipes. Welding the wings together at the axis centre is also easy with L-profiles. In this construction the wings are welded to a metal plate which is in turn welded to the middle of axis (figure 22).

The strings connecting the wings with each other and with the axis were replaced with metal wires to increase lifespan and stability. Instead of putting loops on the wings to fasten the wires, holes were drilled and nuts and bolts can be used.

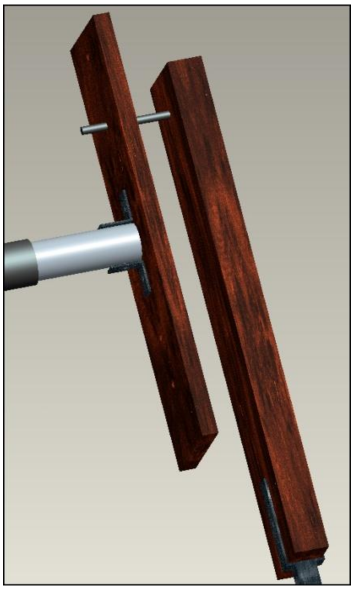

Figure 23. CAD-model of power transference.

5.2.5 Power transference

A homemade piston pump has no lever, which means that the power exerted on the pump needs to be larger than if a semi-rotary pump is utilized. The basic concept of the power transference is kept, but the steel bar is replaced by a wooden plate fixed to the axis with two angle irons and bolts. The conrod is attached to the plate with a thick screw (figure 23).

Four holes are drilled in the plate to make the construction adjustable depending on the wind conditions. During periods with low wind speeds the conrod can be placed closer to the rotation centre where it requires less power to work. As a result of that, the volume per stroke will decrease and it will take longer time to fill the tank.

5.2.6 Sails & emergency stop

Instead of sail fabric, regular cotton fabric is used to make the sails. It is cheaper and can be found almost anywhere in the country, but it is not as windproof as sail fabric.

The emergency stop was omitted in this construction. The windmill needs to be under supervision, which it will be during the working days. If there is a storm coming, the sails have to be taken down to prevent the windmill from getting destroyed.

5.2.7 Foundation

Because of the risk of the field getting flooded during the rainy season there was a need for a concrete foundation here. Otherwise the wooden frame might rotten and fall apart. Putting the frame on a foundation also protects it from termites and other vermin. In addition, it gives height to the construction which increases the potential energy extraction. U-bolts are anchored in the concrete. The frame is put in the U-bolts and locked with a metal plate and bolts. It is then possible to change the wood if needed (figure 24).

A concrete foundation will be an expensive investment for farmers, but how to anchor the windmill has to be considered in each individual case.

Figure 24. U-bolt.

5.3 Calculations on available and required energy for the system

Pumping water from the well requires energy, which there is plenty of in the wind. The higher the wind speed is the more energy is available. The produced energy in the windmill has to be greater than the energy needed to drive the pump; otherwise the system will not work. These calculations shows how much energy is needed to pump the water at different lengths of lever and different wind speeds.

Measuring wind speed without good instruments is very difficult, but it is possible to measure the tip speed by observation and timekeeping. Therefore, the following calculations are based on tip speed. The theoretical results can then be compared to observations made during test runs.

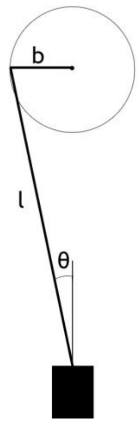

Figure 25. Angle between lever and pump.

5.3.1 Force and moment required to pump water

Because the potential energy, $E_p = mgh$, is the same at the starting position as when the conrod has rotated one full rotation, the mass of the conrod is omitted from these calculations. The extra weight from the conrod on the way up is compensated by help from gravitational force on the way down.

The force F required to lift the water in the pump is:

$$F = \frac{\rho\ g\ \ A(h+h_L)}{\cos\theta}\ [\mathrm{N}] \quad (1)$$

where ρ is the density of water in kg/m^3; g is the gravitational acceleration in m/s^2; A is the area of the pump in m^2; h is the head from water surface to tank in metre; h_L is the head losses in metre; and θ is the angle (figure 25). It depends on b, the length of the lever; and l, the length of the conrod. It is computed with:

$$\sin\theta = \frac{b}{l} \quad (2)$$

The maximum moment required occurs when the lever is in a 90° angle in relation to the pump, and is computed with:

$$M_{pump} = F\ b\ [\mathrm{Nm}] \quad (3)$$

where F is the force required to lift the water in newton; and b is the length of the corresponding lever in metre.

Using the following data, force and moment is computed for different lengths of lever and the results are presented in table 2.

- $\rho = 998$ kg/m^3
- $g = 9.78$ m/s^2
- $h = 4$ m
- $h_L = 0.0177$ m

Lever [m]	Θ [degrees]	F [N]	M [Nm]
0.12	0.06	76.98	9.24
0.15	0.07	77.04	11.56
0.18	0.08	77.12	13.88
0.24	0.11	77.33	18.56

Table 2. Force and moment required for lifting water.

In order for the windmill to keep rotating, the wind has to be powerful enough to produce a moment larger than the value for any given length of lever in table 2.

5.3.2 Work required for pumping water

The work needed to pump water is calculated as:

$$W = F\, s \text{ [J]} \tag{4}$$

where F is the maximum force needed for any given length of lever in newton; and s is the distance the water will move in the pump, or twice the length of the given lever, in metre.

The results of the calculations performed for each lever length are presented in table 3. The conclusion is that more work is needed if the lever length is increased. The minimum work is 18.47 J for a lever of 12 cm, meaning that the windmill needs to produce at least that amount of energy in order for the system to function.

Friction in the pump has been neglected.

Lever [cm]	Work [J]
12	18.47
15	23.11
18	27.76
24	37.12

Table 3. Maximum work needed to pump water with different lengths of lever.

5.3.3 Available kinetic energy in the system

The following equations describe how much energy that is theoretically available in the windmill when the pump is disconnected. Losses due to friction or heat are built-in in these calculations and will therefore not appear in comparisons later on. The wheel with wings, sails, wire and rope is treated as a disc where the mass is equally divided. This means that the result is an approximation of the real value.

The kinetic energy in the system can be computed as:

$$E_k = 0.5\, I\, \omega^2 \text{ [J]} \tag{5}$$

The *moment of inertia*, I, for the wheel and axis is calculated as:

$$I = 0.5\, m_{wheel} r_{wheel}{}^2 + m_{axis} r_{axis}{}^2 \text{ [kgm}^2\text{]} \tag{6}$$

where m_{wheel} is the mass of the material included in the swept area (wings, sails, wire and ropes) in kg; r_{wheel} is the radius of the wheel in metre; m_{axis} is the mass of the axis in kg; and r_{axis} is the radius of the axis in metre.

Where:

- $m_{wheel} = 24.59$ kg
- $r_{wheel} = 2$ m
- $m_{axis} = 11.45$ kg
- $r_{axis} = 0.025$ m

This gives: I = 49.187 kgm^2

The *angular speed*, ω, is calculated as:

$$\omega = \frac{v_{tip}}{r_{wheel}} \text{ [rad/s]} \quad (7)$$

where v_{tip} is the velocity in the rotor's circular orbit in m/s; and r_{wheel} is the wheel's radius in metre.

Though not essential for computing the kinetic energy, the time for 1 rotation is calculated as:

$$t = \frac{2\pi}{\omega} \text{ [s]} \quad (8)$$

The results are presented in table 4.

The windmill will work at a tip speed of 3 m/s for all the distances, since the available energy 55.35 J is more than the most required energy (37.12 J at 24 cm lever).

The friction factor for the pump is unknown, and friction is for that reason not taken into consideration here. It is realistic to assume that more energy than given in table 3 will be needed to perform the work.

v_{tip} [m/s]	ω [rad/s]	E_k [J]	t for 1 rotation [s]
1	0.5	6.15	12.57
2	1	24.60	6.28
3	1.5	55.35	4.19
4	2	98.41	3.14
5	2.5	153.76	2.51
6	3	221.41	2.09
7	3.5	301.37	1.80
8	4	393.62	1.57

Table 4. Energy available from windmill.

5.3.4 Wind speed in relation to tip speed

It is relevant to know what wind speed is necessary to reach the required tip speed in order to evaluate the system. The speed at the outer most tips of the wings is related to wind speed as:

$$\lambda = \frac{v_{tip}}{v_{wind}} \quad (9)$$

where λ is the tip speed ratio; v_{tip} is the tip speed in m/s; and v_{wind} is the wind speed in m/s.

For an optimal Cretan windmill the tip speed ratio is 1.5 (appendix 7) [29], but in this case, the windmill is most likely not optimal. Therefore, three different values for λ are used and the wind speed computed accordingly. The results are presented in table 5.

If λ is set to 1, it is now possible to compute what wind speeds are needed for the system to produce enough energy for running the pump system (table 6).

	λ=0,5	*λ=1*	*λ=1,5*
v_{tip} [m/s]	v_{wind} [m/s]	v_{wind} [m/s]	v_{wind} [m/s]
1	2.00	1.00	0.67
2	4.00	2.00	1.33
3	6.00	3.00	2.00
4	8.00	4.00	2.67
5	10.00	5.00	3.33
6	12.00	6.00	4.00
7	14.00	7.00	4.67
8	16.00	8.00	5.33

Table 5. Wind speeds for different λ values required to attain a certain tip speed.

v_{wind} [m/s]	v_{tip} [m/s]	E_k [J]
1	1	6.15
2	2	24.60
3	3	55.35
4	4	98.41
5	5	153.76
6	6	221.41
7	7	301.37
8	8	393.62

Table 6. Energy available at a certain wind speed when λ is set to 1.

5.4 Building & installing

5.4.1 Foundation

A carpenter was hired to make the concrete foundation. Casual labour was also involved. It took four days for the work to be completed. It was expensive, even though the use of gravel and sand that already were at the project reduced the total cost.

The foundation is made up of two concrete blocks with reinforcement bars, cast 2.5 metres apart. Each block was 3 metres long, 0.7 metres wide and 2 metres high, where 1 metre is below ground. Three U-bolts were anchored in each block.

5.4.2 Windmill

Round wood logs, as in the original drawings [10], turned out to be difficult to buy in Musoma. Regular wood boards were much easier to find, and therefore used to make the wooden frame. There were already wood boards of different dimensions at the project that could be used, so only one board were bought. The wooden frame was built at the ATC with help from two students from Baggiums Praktiska Gymnasium in Norrköping, Sweden.

Steel bars and plates could only be bought in whole, large pieces, which meant high costs and a lot of redundant material. Two whole L-profiles could be cut into 6 pieces of 2 metres each. The small parts, such as angle irons, centre plate, bearings, stop rings and wire holders, could be made of waste material from Musoma Metal Workshop.

Wings, centre plate, stop rings and wire holders were welded to the axis at a welding shop in Bweri and carried to the ATC. The wheel and frame were then painted white for protection and good appearance. The wires were connected to the wire holders on the axis.

The windmill was then assembled on the concrete foundation with help from workers at the ATC and the carpenter (figure 26). Adjustments to the bearings were done to keep the axis horizontal and finally, the sails were set. The triangular sails have synthetic ropes attached at each corner for binding them to the wings.

Figure 26. Putting the windmill together.

5.4.3 Pump

The pump from the old windmill was still in store at the ATC. It is a simple piston pump made of a plastic pipe, a t-link, leather cups, pumping rod and a stop plate. It also has two check valves attached to it.

Figure 27. Pump before and after restoring.

As shown in figure 27 it was bent, and the leather cup had dried out. A local pump maker was hired to restore the old pump. The leather cup, pumping rod and stop plate were replaced, and the pipe was straightened out. Some function improvements were made; it is now possible to change stop plate and leather cups without taking the whole pump apart.

Pump specification	
Length	24″
Diameter	2″
Piston displacement	0.76 litres

Table 7. Pump specification.

Before installing the pump, it was tested independently to confirm that it worked. The pump was then connected to the pipe system. The pipes were filled with water before pumping by hand to ensure water was indeed pumped all the way through the system.

5.4.4 Pipes

A total of 300 metres of plastic pipes are needed to connect the system. At the project there were approximately 240 metres of 1″ pipes and six couplings. Some pipes were broken and needed to be spliced; therefore more couplings were bought along with the remaining 60 metres of pipes. The quality of the pipes differs; some are thicker and more rigid than others.

The pipe should be dug down where it passes trails, but will for the most part be left above ground. It is important to know where pipes are located in order to not destroy them during field work. Otherwise it will be better to have them under ground to avoid the UV-radiation from the sun to damage them. To make it easier for maintenance or troubleshooting, pipes going from the well to the pump are marked with blue tape, and pipes from the pump to the tank are marked with yellow tape.

A filter made of cotton fabric is put on the pipe that is immersed in water. The filter stops particles and debris from entering the system.

5.4.5 Test of windmill connected to pump and pipe system

Tests were performed with the lever at 15 cm and 24 cm, respectively. During these tests the wind felt like a light breeze. According to the Beaufort scale (appendix 4), the velocity of a light breeze wind is between 1.6 and 3.3 m/s. Thus the wind speed is estimated to be in that interval.

Tests were also performed with the sails slackened and tightened to see what is most effective.

5.5 Irrigation system

After researching the current conditions and possibilities, a field appropriate for an irrigation system was chosen (figure 28). The selected field is situated close to water tank A (figure 14), which was desirable in order to reduce the amount of pipes needed to connect the system. The crops grown here will be vegetables like cabbage, beans and onions.

Figure 28. Field chosen for irrigation system.

The field is 30 metres long and 20 metres wide. The rows are 1 metre apart and crops are planted with 1 foot (0.3 metre) in between, making it a total of 2,000 crops. The irrigation system is dimensioned based on the assumption that each crop needs 3 litres of water per week [46].

5.5.1 Choice of irrigation method

Drip irrigation is the most suitable method for irrigating this field for several reasons; it is suitable for row crops such as vegetables; water is saved because it is delivered directly to the crop and evaporation is minimised; and the system can operate under pressures of 0.5-25 metres head. The pressure from tank A is 2 metres head. A simple drip irrigation system can be built to a moderately low cost and is for that reason suitable for small-scale farmers.

Because of the tight time schedule, no full-scale irrigation system was built on-site. This report will present a proposed design for a simple drip irrigation system, based on literature studies and on information gathered at the ATC.

6 Results

6.1 Windmill

Figure 29. The windmill.

The windmill (figure 29) is now in place and connected to the pump and pipe system. It stands on a concrete foundation and is composed of one wooden frame that holds up the wheel and axis. The pump is attached to the axis through a conrod. When the wind is captured by the six triangular sails, the wind energy is converted into kinetic energy that makes the axis rotate. The conrod is then moved up and down in a pumping motion, making the water flow through the pipes from the well to the tank.

The windmill and pump is situated 100 metres from the well and the distance to the tank is 200 metres. The elevation is 3 metres from water surface to pump, and 5 metres from pump to tank.

6.1.1 Materials

All material used to build this windmill, pump and pipe system could be bought in Musoma. See appendix 6 for description of each item.

6.1.2 Test of system

Tests have been done on the pump and pipe system before the two systems was put together. That test showed that it is possible to pump water from the well to the tank while pumping by hand. Before connecting it with the pump, the windmill was tested to see that the wheel rotated smoothly. Even though wind speed was low, it started rotating on its own.

When the pump was connected and the lever was 24 cm the windmill did not rotate a full rotation. If the tip speed is 2 m/s, it only generates 24.60 J, as shown in table 4. That is not enough, since the energy needed to produce the maximum work is 37 J. Consequently, it is not possible for the windmill to rotate with such moment that the conrod is lifted above the critical point at 90°, which was proven during this test.

During the test with 15 cm lever and the pump connected, the windmill began rotating by itself. An average rotation took 7 seconds to complete. This gives an average tip speed of 1.8 m/s, according to equation 10.

$$v_{tip} = \frac{2\pi \, \mathrm{r}}{t} \, [\mathrm{m/s}] \qquad (10)$$

where r is the radius of the wheel in metres; and *t* is the rotation time in seconds.

Because the tip speed of the wings were around 2 m/s during this test, and the wind speed between 1.6 and 3.3 m/s, the λ-value of the windmill is estimated to be between 1 and 1.5 (table 5). A λ-value of 0.5 can be excluded since the wind speed would then need to be 4 m/s. As the windmill is most likely not optimal, it is further assumed that the λ-value is closer to 1 than 1.5.

Unfortunately, because of the rainy season, the wind speed was only high enough in short intervals, which made it difficult to see if the water actually reached the tank.

The sails should neither be too tight or too slack for the windmill to rotate properly. With time, the windmill operator will learn the sails behaviour and know how to set them correctly.

6.1.3 Maintenance

In order for the windmill to work properly, some regular maintenance is needed:

- The bearings need to be greased regularly; approximately every three to four weeks depending on the weather conditions.
- If the windmill is not in use for a longer period of time, the sails should be taken in to storage to prevent damage.
- The filter needs to be checked regularly, and if needed cleaned or changed.
- If water is not coming through the pipes; check valves and couplings for leakage.

6.1.4 Costs & time schedule for building windmill

Table 8 shows the approximated total cost for this windmill and pump system. Some material that was used was already at the project, and these costs are not included in the compilation. The foundation cost is very high because of the labour charge and the amount of cement required for this location. For detailed cost specifications, see appendix 8.

Table 9 shows the required time to construct the windmill, with careful planning and no unexpected problems.

Part	Cost (TZS)	Cost ($)[2]	Cost (SEK)[3]
Windmill	294,850	205	1,714
Pump[1]	60,000	42	351
Pipes & couplings	80,000	56	468
Foundation	1,805,300	1,252	10,466
TOTAL	**2,240,150**	**1,555**	**12,999**

Table 8. Approximate cost for windmill.

[1]Charge for repairing the old pump

[2]1,000 TZS = $0.7 (2010-06-08)

[3]$1 = 8.36 SEK (2010-06-08)

Activity	Time
Buy material	1 day
Welding	½ day
Build frame	½ day
Make foundation	4 days
Assemble windmill	½ day
Place pipes	1 day
Make sails	½ day
TOTAL	**7 days**

Table 9. Optimised time schedule.

6.2 Irrigation system

6.2.1 Proposed irrigation system design & construction

A drip irrigation system suitable for this field can be made of plastic pipes with small holes in it. This is a simple construction that can be reproduced by local farmers. The amount of pipes depends on the size of the field but can be quite a large amount, thus making this a costly investment. However, investing in an irrigation system reduces the need to water by hand and gives an opportunity to grow crops all year around.

A main line that is connected to the tank is laid out along the top of the field (figure 30). Pipes of a smaller dimension (laterals) should be placed along each row, and then connected to the main line with couplings. The last lateral should be connected with an elbow. Holes spaced 30 cm apart are punched in the smaller pipes. To prevent dirt from clogging the emitter holes, the holes can each be covered with a piece of hose (figure 31) [44]. The hose should be roughly the same size as the laterals. It is cut into 2,000 pieces, each 5 cm long. It is slit alongside and placed around the laterals to cover the holes. The main line is connected to the tank through a tap, which is used to regulate the water flow. All material is listed in table 10.

The pipes and emitters need to be checked regularly to see that they are not clogged or broken.

Material	Usage	Amount
Plastic pipe	Main line	20 m
	Connect to tank	Distance between tank & field
Smaller plastic pipe	Laterals	600 m (30 m x 20 rows)
Couplings	Connect laterals to main line & main line to tank	20 pcs
Elbow	Connect last lateral to main line	1 pc
End caps	At end of laterals	20 pcs
Hose	Cover emitters	100 m
Tap	Between tank and main line	1 pc

Table 10. Material needed to construct a drip irrigation system at ATC.

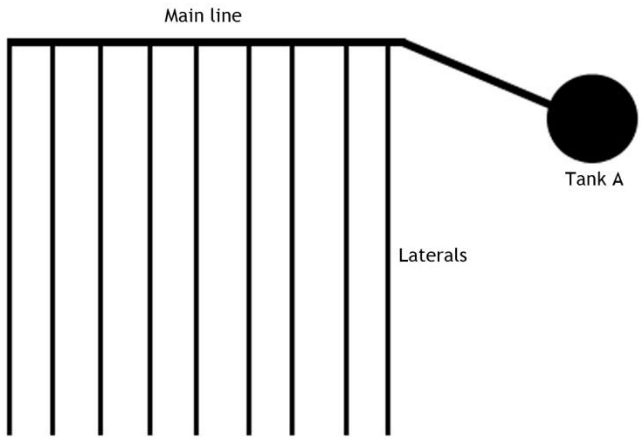

Figure 30. Sketch of irrigation system, not to scale.

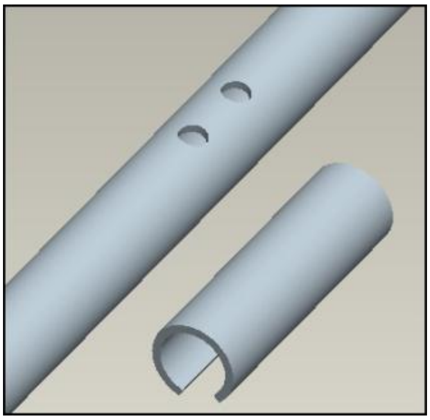

Figure 31. Emitter with cover hose.

7 Discussion

7.1 Windmill

A windmill driven water pump at the ATC reduces the need for a diesel driven pump. A diesel pump fills the water tank quickly, but a windmill will instead produce a continuous flow of water, as long as it is windy, and does not need fuel. It is therefore a more eco-friendly solution.

Under the construction and assembly of the windmill, some problems and set backs were encountered.

The foundation, which is the most expensive part of this project, was not planned for initially. Local farmers will probably not make a concrete foundation due to the high cost. In this case, it was needed because of the wind and ground conditions. The windmill at the ATC needed a foundation to be able to stand during heavy rains when the field can be flooded. If the windmill should fall apart, the whole concept with demonstration and education of farmers would be lost. It might have been possible to make the foundation lower to save money on material cost.

Pipes and metal plates had to be bought in big quantities, i.e. pipes of 6 metres length only, or plates of 2x2 metres. SCC-ViAFP was not interested in the redundant material, and it is unnecessary to spend money on material that will not be used. This problem was solved because Musoma Metal Workshop that were hired to do all metal work, such as cutting, drilling and welding, could also make the small parts for the construction from waste material.

Originally, once changed from the bicycle wheels, the bearings were supposed to be welded to small metal plates and then screwed into the crotch of the wooden frame. This turned out to be very difficult to achieve, because of measuring problems and communication difficulties. It is hard to measure it right on the pipes, even when the angle of the frame is known. After receiving incorrect pieces twice, a new and simpler solution for fastening the bearings was developed. Benefits from the new bearing construction are that it is now possible to take down, grease or replace the bearings with almost no work.

Regular cotton fabric is used for sails in this construction. Real sail fabric lets less air through and thus requires less wind speed, so by changing to sails made of sail fabric more energy can be extracted. Sail fabric is available in Musoma, but it was twice as expensive as regular fabric. Because of the higher cost, it is not likely that local farmers would buy it. They are probably more prone to use whatever fabric they have, such as worn-out sheets or similar.

A larger pump would mean a larger volume displacement and a quicker filling of the tank, but it also requires the wind speed to be higher. Since there already was a pump at the project and money should be saved wherever possible, that one was used. That meant that it was not possible to change the maximum output flow. To be able to use the windmill even during low wind speed, the length of lever is adjustable. If the wind speed is not high enough to produce the moment needed to start the windmill, it is possible to start it by giving the wheel a push.

Further studies could be made on this windmill construction. The plain bearing solution can be improved; perhaps a bushing can be used to reduce the bearing clearance. A solution for an emergency stop could be a bicycle break with rubber plates that when it is clamped slows down the axis. The best way to run the system though, is to be observant on the weather and take in the sails if there is a storm approaching.

7.2 Irrigation

The irrigation part of this project is not very extensive, but there is a lot of literature available on small-scale drip irrigation that can be referred to. Therefore, this report only presents one simple solution on how to irrigate a certain area at the ATC.

Due to lack of time, calculations on pressure and volume flow have not been performed for the irrigation system. The pressure should be enough, since many small-scale systems function with only 1 metre head.

For small-scale farmers, having an irrigation system can increase crop yield and bring more food and money to the household. This improves the quality of life for the whole family.

7.3 Reflections

More research should have been done while in Sweden; especially the manual for the original windmill construction should have been retrieved before departure. Reading that would have given a better insight to how much work this project really required.

Due to the conditions in rural Tanzania, with lack of modern technology and electricity, most of the work was done by hand. It is therefore necessary to think different than when working in a western country. After arrival in Tanzania, some major changes in the original project plan were made due to the new information that was received. Focus was then put on the windmill instead of the irrigation system, once it became clear that there was not enough time to do both.

There were some communication problems due to fact that most people in Musoma speak only Swahili. English is not widely used and therefore an interpreter was needed, especially in the beginning of the project. One example of when language difficulties caused a problem was when a new pump needed to be made. The old pump was supposedly broken, but after a couple of weeks, it came up that it was in fact possible to restore the old pump. Had this been communicated from the beginning maybe time and some money could have been saved. Having all the necessary material ready when the building process started so that hired labour was not kept idle could also have saved time and money.

A project like this is probably better carried out during the dry season. The weather conditions were not optimal for working outside with the actual construction, or for testing the system. Fair results were not obtained because of the lack of strong winds.

7.4 Recommendations

- Wind conditions are important to consider when planning for a windmill.
- When the pipes are in position, they should be dug down to prevent them from being damaged or stolen.
- The demonstration purpose of the ATC means that the pipes should be kept visible for visitors to see, at least for some parts.
- Some kind of cover for the bearings can be constructed in order to protect the grease from rain and dust.
- A plastic bottle with holes in should be put over the inlet of the pipes to prevent the small filter from clogging too fast.
- Last but not least, if there is water left in the tank after irrigation, it can be used for livestock farming.

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Appendices

Project plan – Irrigation system driven by wind energy at Lake Victoria in Tanzania

Background

The organisation SCC-Vi Agroforestry has an Agroforestry Training Centre in Musoma, Tanzania, where local farmers are educated in agroforestry - the practice of growing trees and crops together. The trees improve soil fertility which increases crop yields, and also contribute to prevent soil erosion.

An earlier feasibility study conducted by students from Halmstad University treats how it is possible to use wind force to pump water to a tank for further use domestically or in farming. Their work resulted in a construction of a windmill, intended to be build by the farmers themselves.

The windmill has never been built in Tanzania, but now SCC-Vi Agroforestry wishes to implement this solution at their Agroforestry Training Centre. The organisation is also interested in a solution for a small-scale irrigation system.

Purpose

To give local farmers better access to water and technology for irrigation on their farms.

Goal

Build a windmill with a pump that pumps up water and transports it to storage. The water shall then be distributed over a field not larger than 4,000 m^2 in an irrigation system. All this should be done keeping the cost minimised.

Problem description

- Find a suitable location to build the windmill at. Consider wind conditions and water sources as well as security aspects. The water shall preferably come from Lake Victoria, since earlier studies[1] shows that the ground water is too salt to be suitable for irrigation.
- Start with original drawings[2] and adjust them if necessary to make the windmill suitable for transport of water from the chosen water source to a tank.
- Build the windmill according to the adapted drawings. The performance of the windmill shall form the basis for dimensioning of the irrigation system.
- Planning of a simple and inexpensive irrigation system. Possibly build a model of the system.
- Most material shall be produced or available locally to make maintenance and reparations easier and to support the local economy.

Delimitations

- The area intended for irrigation shall not be larger than 4,000 m^2.
- Only water from Lake Victoria will be considered.
- No full-scale irrigation system will be built.

Time schedule

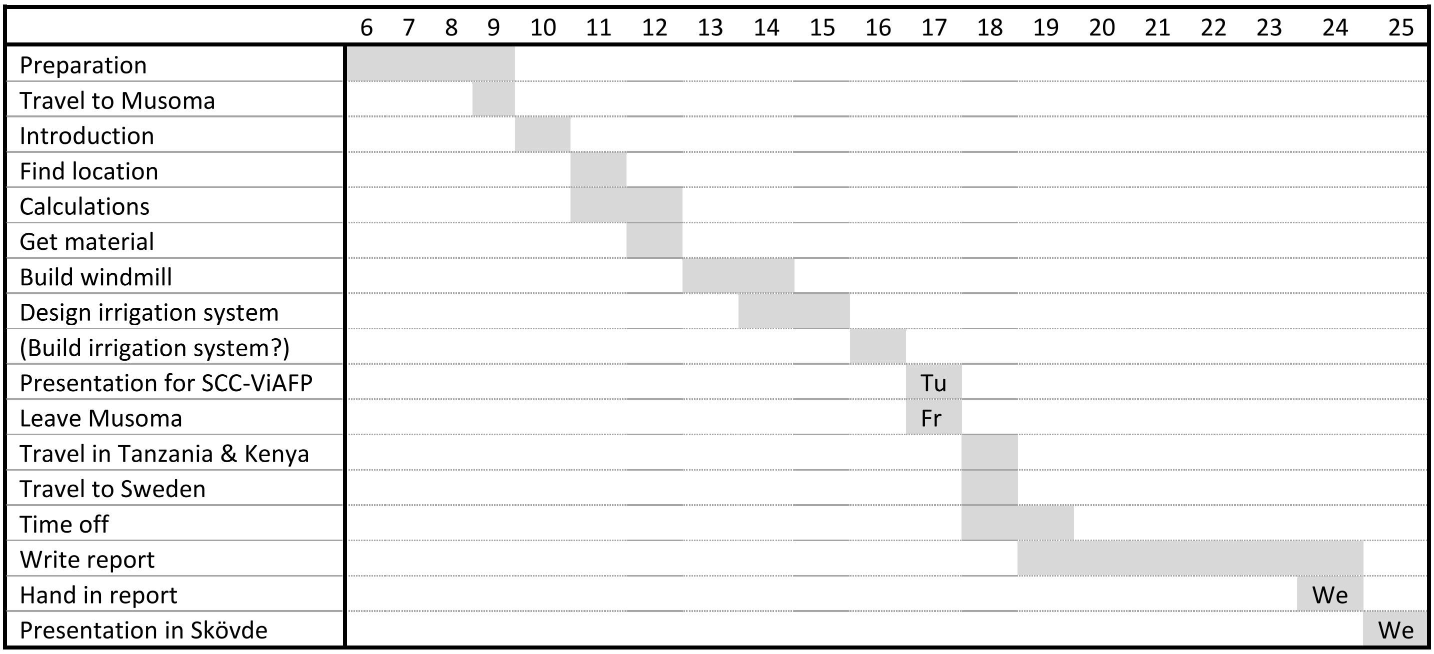
The thesis work starts in February 2010 and shall be finished before September 2010. A field study is conducted in Musoma between 2010-03-04 and 2010-05-07.

References

1. Report from students at Halmstad University

2. Drawings from students at Halmstad University

Appendix 2
Gantt chart



Appendix 3
Evaluation matrix for windmill location & water source, with criteria

Criteria	Importance	**Location of windmill & water source** A: hill, lake	B: shore, lake	C: shore, well	D: well, well	E: well, lake
Good wind condition	5	1	0	0	-1	-1
Water free from particles	3	0	0	1	1	0
Pump close to water source, distance	2	1	1	0	1	0
Pump close to water source, elevation	5	-1	1	0	0	0
Pump close to tank, distance	2	-1	0	0	1	1
Pump close to tank, elevation	3	1	0	0	0	0
Easy access to windmill for operating purposes	4	-1	0	0	1	1
Few metres of pipes needed	3	-1	0	-1	1	-1
Land owned by SCC-ViAFP	5	1	-1	-1	1	1
Easy access for demonstration purposes	4	-1	0	0	1	1
No need to pay for water	1	-1	-1	1	1	-1
Result		**-4**	**1**	**-4**	**19**	**6**

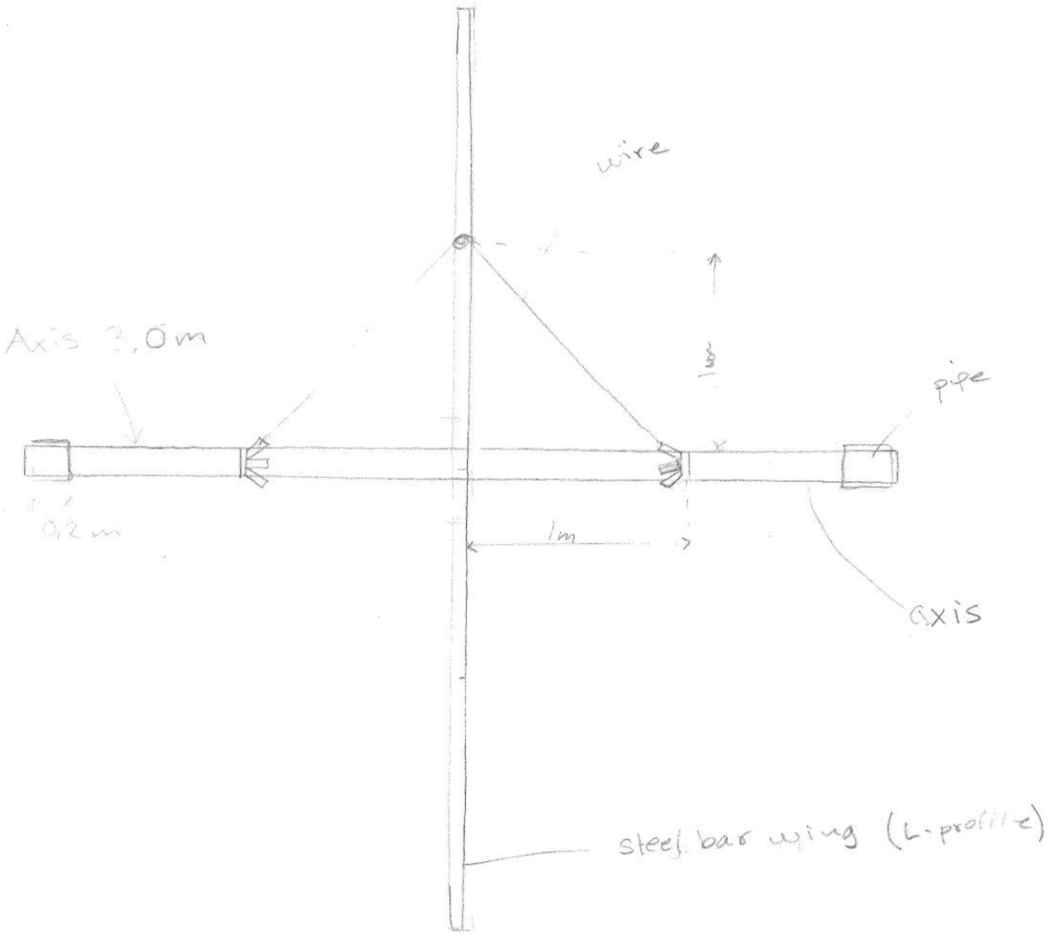
Criteria	**Definition**	**Importance**
Good wind condition	The wind speed needs to be strong enough for the windmill to work.	5
Water free from particles	Rubbish from the lake or nearby surroundings should be kept to a minimum in the water to prevent the system from breaking down.	3
Pump close to water source, distance	More metres of pipes mean higher costs and have an effect on pressure losses.	2
Pump close to water source, elevation	A piston pump can pump approximately 8 metres high at most. The elevation to the water source must not exceed 8 metres.	5
Pump close to tank, distance	More metres of pipes mean higher costs and have an effect on pressure losses.	2
Pump close to tank, elevation	A piston pump can pump approximately 8 metres high at most. The tank will not be more than 5 metres above the pump level.	3
Easy access to windmill for operating purposes	The windmill should be reached easily for maintenance work, or to stop it quickly in case of very strong winds.	4
Few metres of pipes needed	If the parts of the system are close together, less metres of pipe will be needed. This is a cost-saving factor.	3
Land owned by SCC-ViAFP	If SCC-ViAFP owns the land where the windmill is placed, no permission is needed for building or running it.	5
Easy access for demonstration purposes	The purpose with the ATC is to demonstrate different technologies for farmers. It should therefore be placed at location that is easy to reach.	4
No need to pay for water	There is a fee to be paid to pump water from the Victoria lake. There is no fee to use the water from the well.	1

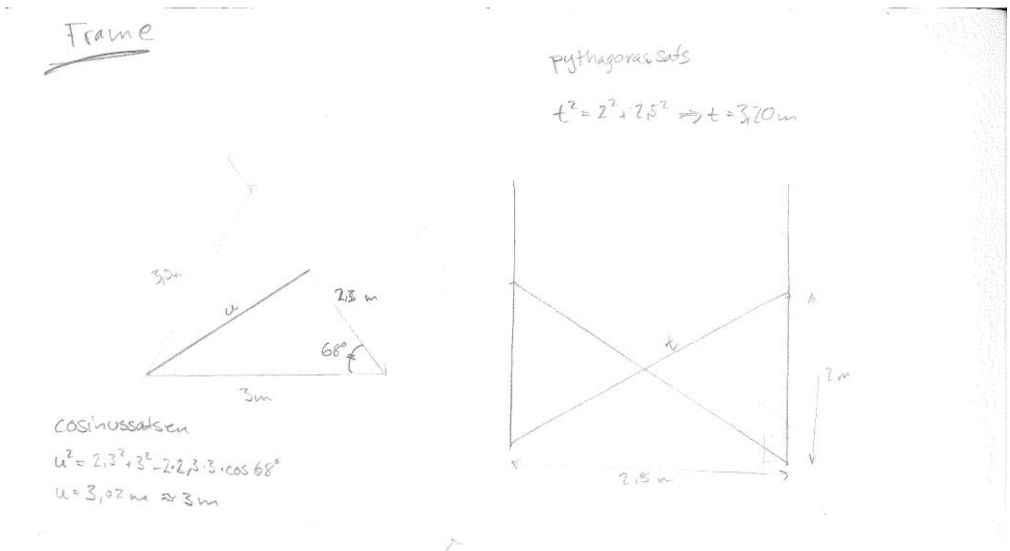
Beaufort scale

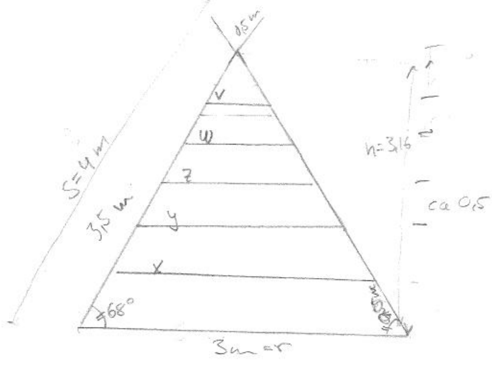
Force	Wind (m/s)	WMO Classification	Appearance of Wind Effects	
			On the water	On land
0	0-0.2	Calm	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1	0.3-1.5	Light Air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
2	1.6-3.3	Light Breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
3	3.4-5.4	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
4	5.5-7.9	Moderate Breeze	Small waves 1-4 ft. becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	8.0-10.7	Fresh Breeze	Moderate waves 4-8 ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	10.8-13.8	Strong Breeze	Larger waves 8-13 ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
7	13.9-17.1	Near Gale	Sea heaps up, waves 13-20 ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
8	17.2-20.7	Gale	Moderately high (13-20 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Whole trees in motion, resistance felt walking against wind
9	20.8-24.4	Strong Gale	High waves (20 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs
10	24.5-28.4	Storm	Very high waves (20-30 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	28.5-32.6	Violent Storm	Exceptionally high (30-45 ft) waves, foam patches cover sea, visibility more reduced	
12	32.7+	Hurricane	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced	

Adapted from The Online Tornado FAQ *(http://www.spc.noaa.gov/faq/tornado/beaufort.html) [2010-06-15] and* prognosen.se *(http://www.prognosen.se/vaderskola.php) [2010-06-15]*

Appendix 5
Hand-made drawings of new windmill construction





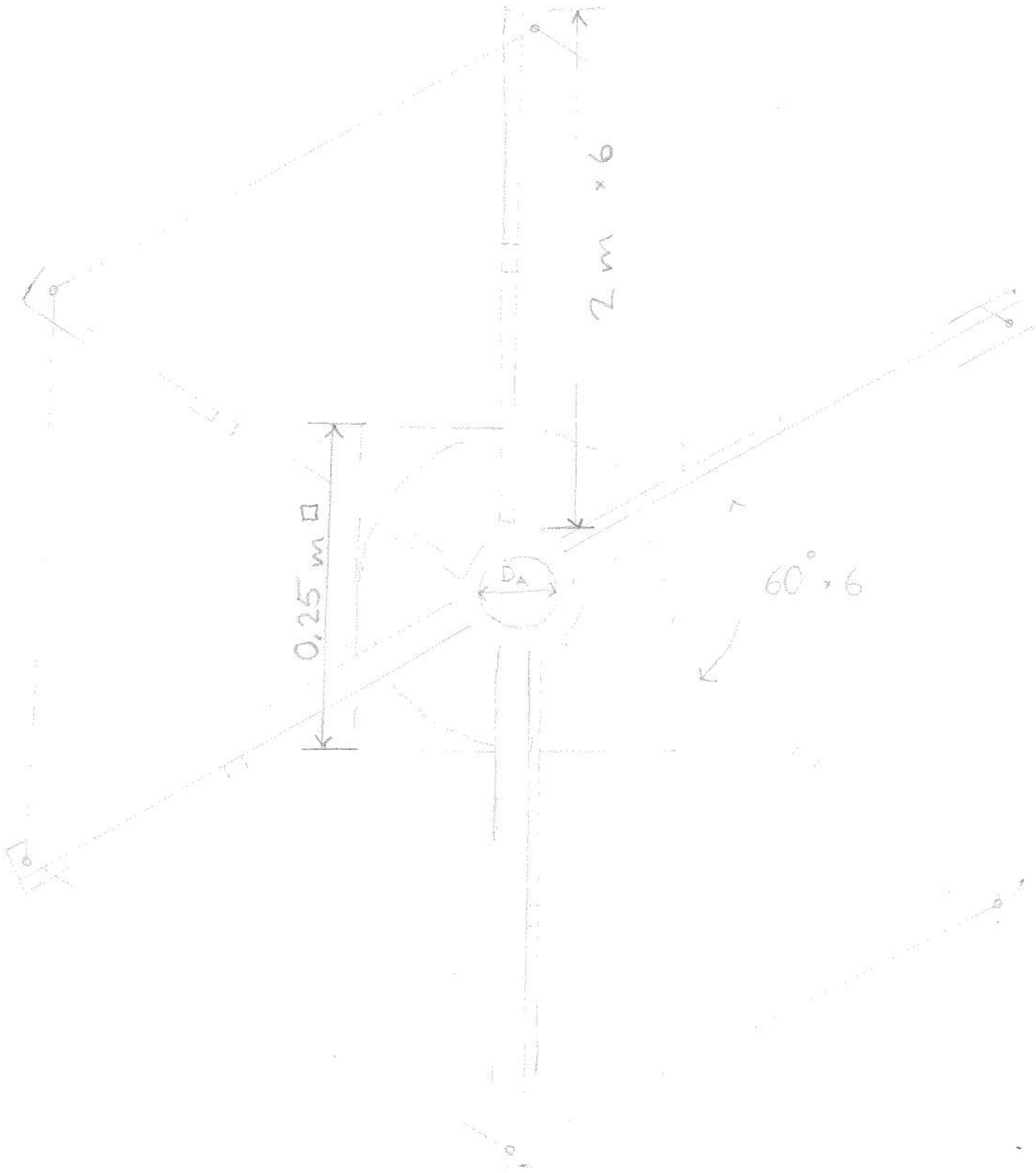


Appendix 5
Hand-made drawings of new windmill construction

D_A = diameter of axis

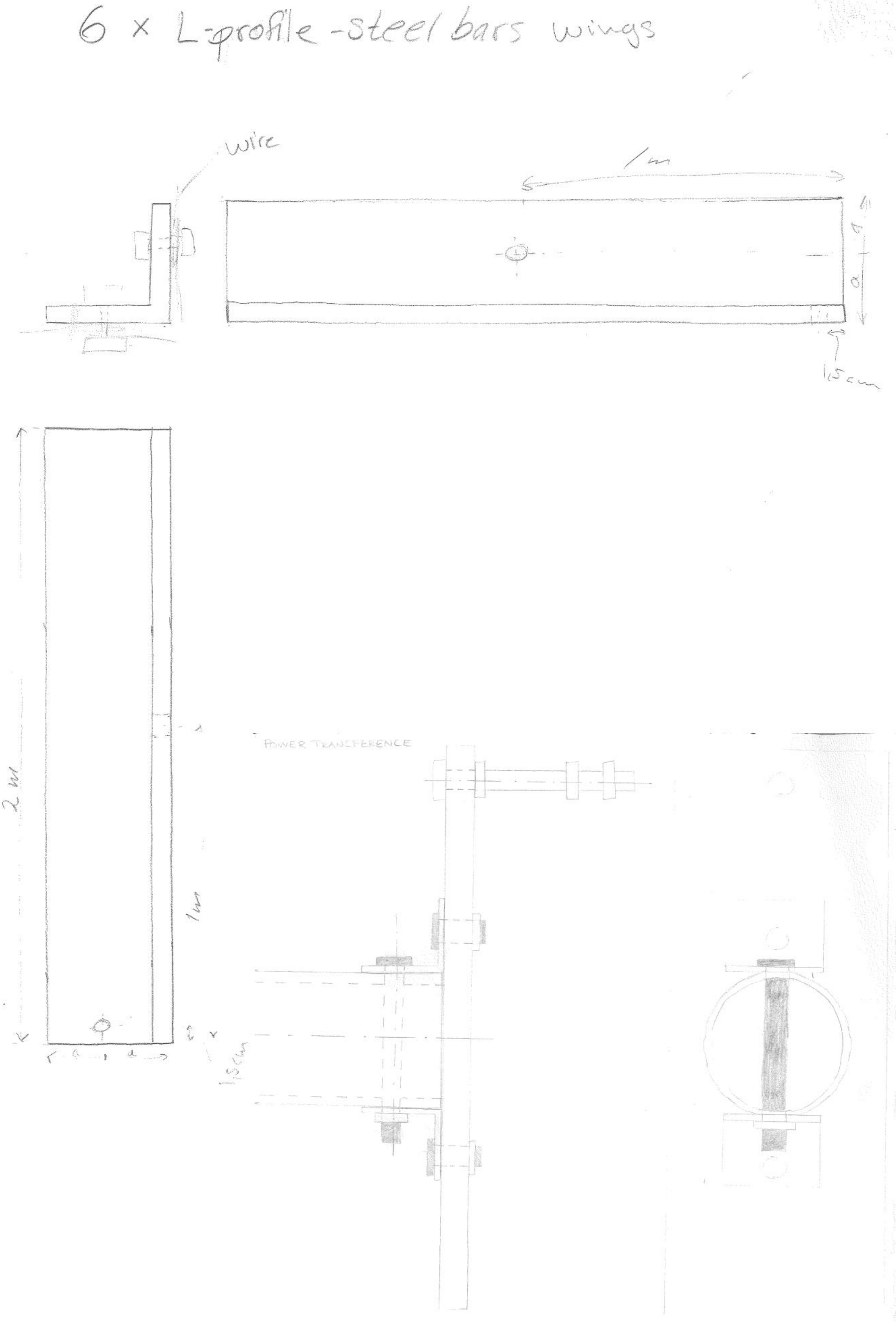
6 steel bar (wing), L-profile, 2 m

Steel plate, 0,25 × 0,25 m



Appendix 5

Hand-made drawings of new windmill construction

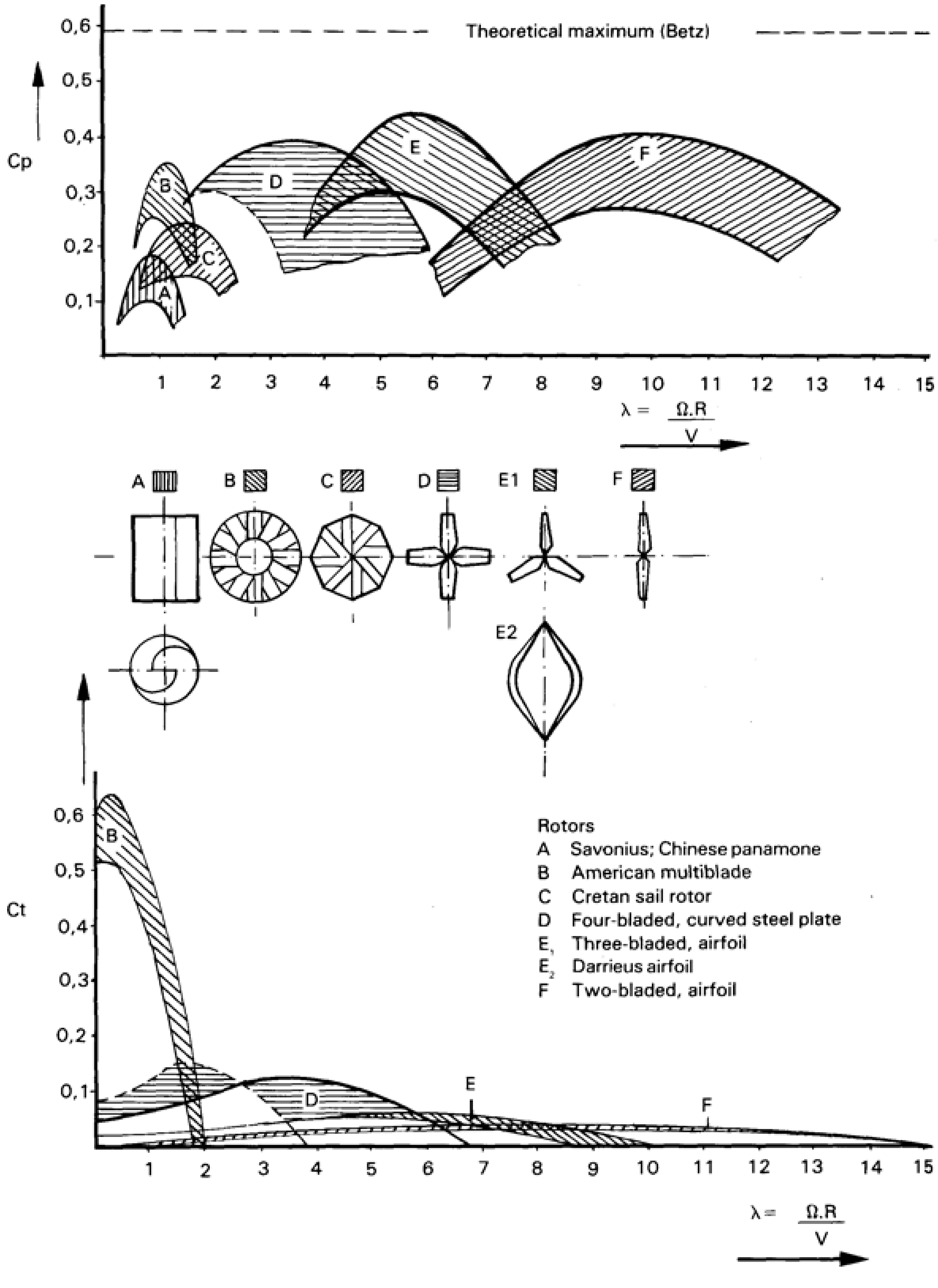


Appendix 6
Windmill – List of material & tools

	Component	Measurement	Comment
Sail			
	3 x fabric	1 x 2 m	For 6 sails
	Rope	23 m	For fastening sails on wings
Frame			
	4 x wood logs	L: 4 m, Ø 8-10 cm	Legs
	4 x wood logs	L: 3 m, Ø 8-10 cm	Side cross
	4 x wood logs	L: 2 m, Ø 5-7 cm	Cross
	10 x wood logs	L: 3 m, Ø 5-7 cm	Steps
	Nails		
Wheel			
	1 x metal plate	200 x 200 x 6 mm	Central wheel plate
	6 x steel bar wings	L: 2 m, 40x40x4 mm	L-profile
	Wire	31 metres, Ø 3 mm	For stabilizing wings
	12 x screws & nuts	About 3 cm long	For fastening wires
Axis			
	1 x steel pipe	L: 3 m, Ø 5 cm	Axis
	2 x metal band	8 x 25 cm, 3 mm thick	Wire holders on axis
	2 x steel pipe	L: 0.23 – 0.25 m, Ø >5 cm	Axis should fit in here
	4 x metal plate	17 x 4 cm, 2-4 mm thick	For fastening pipes to frame
	8 x screws	L: 3-4 cm (for wood)	Fasten metal plate in logs
	2 x rings	Or metal band?	Stop rings for axis
Power T.			
	1 x wooden plate	60 x 8 x 3 cm	For power transference
	2 x angle iron	3 x 3 cm, 3 mm thick	Fasten axis to wooden plate
	1 x long screw & nut	7 cm long, depends on axis	Fasten angle irons to axis
	2 x screws & nuts	Larger than 3.5 cm	Fasten angle irons to plate
	1 x very long screw	L: 15 cm, Ø 3cm	For power transference
	3 x nuts		For very long screw
Other side			
	1 x wooden plate	15 x 8 x 3 cm	End stop for axis
	2 x angle iron	3 x 3 cm, 3 mm thick	Fasten axis to wooden plate
	1 x long screw & nut	7 cm long, depends on axis	Fasten angle irons to axis
	2 x screws & nuts	Larger than 3.5 cm	Fasten angle irons to plate

Tools needed for assembly:

- Measuring tape or similar
- Scissors
- Hammer
- Saw
- Cutting nippers (pliers)
- Screwdriver
- Metal drill, wood drill
- Welding set (gas)



"The power coefficients (Cp) (above) and the torque coefficients (Ct) of various types of wind turbine rotor plotted against tip-speed ratio (λ) (after Lysen/CWD [45])"
(http://www.fao.org/docrep/010/ah810e/AH810E10.htm#10.1) [2010-06-15]

Appendix 8
Windmill at ATC, Bweri – Costs (windmill)

	Component	Quantity	Comment	Total cost (TZS)
Sails				
	Fabric	5 m		9,000
	Rope, Manila	80 m		14,000
	Thread	1 reel		3,000
	Needles	2 pcs		1,000
				27,000
Wheel				
	Axis	Ø 5 cm	Already at project	-
	Black pipe, 2″	2 pcs	Bearing, stop ring, wire holders	20,000
	Metal plate,	1 pc		20,000
	L-profile steel bars	2 pcs		70,000
	Wire	1 kg		3,000
	Bolts & nuts			22,050
	Labour charge		Musoma Metal Workshop	28,000
	Welding at Bweri			50,000
				213,050
Frame				
	Wood to build frame		Already at project	-
	Wood plates (Conrod)	2 pc	Already at project	-
	1x9″ wood	6 m	Replacement wood	25,800
	Nails	2.5 kg		6,000
	Wood screws	1 box		2,000
	Oil paint	4 litres		14,000
	Paint brushes	2 pc		4,000
	Thinner	1 litre		3,000
	Conrod		Already at project	
				54,800
Pipes				
	Poly pipes, 1″	60 m		66,000
	Couplings	4 pc		14,000
				80,000
Pump				
	Labour charge			60,000
				60,000
TOTAL COST (TZS)				**434,850**

Appendix 8
Windmill at ATC, Bweri – Costs (foundation)

	Component	Quantity	Comment	Total cost (TZS)
Foundation				
	Gravel	1 trip	Some already at project	180,000
	Cement	30 bags		510,000
	Sand	-	Already at project	-
	Bars 16 mm	15 pc		315,000
	U bolt 16 mm	6 pc		84,000
	Binding wire	2 kg		6,000
	Spring plate	6 pc	Incl. cutting & drilling	100,800
	Wood, 1x8″	30 m		105,000
	Nails	5 kg		12,500
	Wood, 6x2″	12 m		60,000
	Round bars, 8mm	4 pcs		32,000
	Labour charge	4 days		400,000
TOTAL COST (TZS)				**1,805,300**