McGill University

Solar Drying Shed for Cassava in Malawi

Design 2: BREE 490

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Executive Summary

The successful operation of post-harvest technologies is essential to food availability and security world-wide. More specifically, post-harvest drying operations can serve to important function of extending the availability of affordable food in countries such as Malawi where over a third of the population is estimated to be undernourished. The goal of this design project is to develop an improved cassava solar drying structure design that could potentially replace an existing drying shed that is currently in operation as part of a cassava microprocessing facility in Chisemphere, Malawi. The focus of this design will be to improve consistency and quality in the dried product, among other improvements. The challenges and limitations of this undertaking are outlined in this document. The details of the context of the design as well as our future design process, and descriptions of the philosophies that will influence that process, are also included. A work schedule and method for cost analysis are also proposed.

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3 Introduction

When originally considering potential topics for our senior design project, we decided to work as a team because of our shared interest in working on a project related to agriculture. We explored a number of other potential projects, including working with a medium sized grain mill in New Brunswick, called Speerville Mills, before our colleague, Jenna Senecal-Smith suggested that we get in touch with an overseas volunteer named Graham Lettner. Mr. Lettner is working with the organizations Engineers Without Borders (EWB) and PLAN Malawi, in Malawi, on a project involving the post-harvest processing and drying of the root crop, cassava. After contacting Mr. Lettner and obtaining some preliminary information about the project, we decided to choose the design of a solar drying structure for cassava as the subject of our project. What follows is an outline of the task at hand and our planned method of design.

4 Problem Statement

This problem statement outlines only the technical aspects of the problems concerning the drying shed of a cassava micro-processing facility in Chisemphere, Malawi, which is currently being managed and run by Mr. Mafayo Lungu, a member of that community. Challenges faced by the processing operation include numerous non-technical aspects of the facility's operation and context but will not be the focus of this design project, as will be later discussed.

4.1 Current Structure

The existing cassava drying structure is composed primarily of polyethylene transparent sheeting fastened to timber. It has a simple foundation made of concrete around the periphery with a dirt floor in the centre. The polyethylene sheeting is sealed to the concrete at the base of the structure. There are small sections of vents, made of aluminum wire mesh, located where the structure's walls meet the roof. The cassava is spread over two-tiered tables inside the structure to dry. The tables are made of more plastic sheeting and timber, and are fastened to the structure.

Figure 1: The existing drying shed in Chisemphere, Malawi

Source: Graham Lettner

Figure 2: **Inside the existing drying shed**

Source: Graham Lettner

4.2 Problems with Current Structure

The paper trail concerning the motivations behind the design of the current drying structure is non-existent but upon primary examination the structure appears to have been constructed with the main purpose of isolating the drying cassava from the elements, not for optimizing the drying process.

The structure is essentially sealed from the outside with the exception of the vents near the top of the walls. This arrangement restricts airflow over the cassava within the structure and therefore limits drying by natural convection. Ideally, the cassava should be dried to a sufficiently low moisture content in less than 48 hours. This would result in a white coloured product, which is considered desirable by both local markets and by the food processing industry in Malawi. Instead, the current structure produces a product of variable quality, meaning the cassava is only occasionally fully dried in the desired 48 hour period and the product is often discoloured.

Furthermore, the current structure is not sized appropriately. Often the drying shed is filled to capacity but there is still cassava remaining that requires processing and drying. Under such circumstances, the processing of the remaining cassava is delayed, which may results in the physical deterioration or complete loss of the raw cassava stock material, which begins to decay within days of harvesting.

In addition to production challenges, termites have managed to enter the structure and have started eating the legs of the drying tables. Furthermore, the current facility has no design elements that address the runoff that results from the structure's surface area during precipitation events. This runoff could potentially cause erosion to the exposed soil surrounding the structure.

5 Objectives

The objective of this project is to design an intermediate scale solar drying structure to dry cassava chips and/or pulp that will address the problems identified above. The structure will be developed for use in the region of Chisemphere, Malawi, and will be designed to replace the existing drying shed at Mr. Lungu's micro-processing facility.

We hope that by documenting this design process, and evaluating the costs and benefits of multiple potential designs, we will produce a resource for those on the ground involved with the project that can be referred to and utilized, should resources become available in the future for the existing drying shed to be replaced.

6 Scope

Our project will focus on producing a drying system that will reliably dry cassava under the conditions present during the rainy season in Chisemphere, Malawi. While drying would likely be more effective during Malawi's dry season, the harvest schedule of cassava farmers, who harvest primarily during the relatively moist months of October and November, and the perishable nature of cassava necessitate that we focus our design on drying during sub-optimal weather conditions.

The addition of fans and heating units to convert natural convection drying systems to forced convection systems drastically increases the reliability of such systems and decreases the amount of time required for drying (Rozis and Guinebault 1995). However, our design will not include forced convection components due to the relative unavailability of electrical power at the site location and the restrictive costs of fuel to run such elements off of fuel powered generators. Instead, our design will be restricted to mechanically and electrically un-aided natural convection solar systems.

In addition to the meteorological and infrastructural context of the project, our liaison in Malawi, Graham Lettner, has provided us with a number of constraints for the project. As was mentioned above, the design produced should be capable of drying cassava within 48 hours, in order to prevent the cassava from deteriorating. The design should be easy to construct and the materials used should be readily available in Malawi. The structure will be designed to require minimal maintenance, should be simple to repair and should be resistant to damage by termites. The facility should be sized to process 2400kg of fresh cassava per week because this is the expected cassava input in the coming years.

Should some of these design constraints be mutually exclusive, suggestions of alterations in parameters will be provided to our clients and various designs will be proposed, exploring various possible solutions. Lastly, but perhaps most importantly, the design should meet the needs of and appear to be feasible to Mr. Lungu, the current cassava facility operator, and Mr. Lettner.

The cassava drying facility with whom we are collaborating is the only one of five facilities established by PLAN Malawi and IITA, with funding from USAID in 2003 that is still in operation. The reasons for these project failures are numerous and include a lack of cash flow for the processors, the absence of developed end markets, management and supply problems, and the poor quality of the end-product at these facilities. It is also important to mention that the lack of transportation infrastructures such as roads, and the inexistence of affordable trucks to transport the crops between the different stages of transformation is a continuing obstacle for these and many other small scale enterprises in the region. Mr. Lungu's operation faces all of the challenges mentioned above.

Our project will address only one of these obstacles and will not address the socio-political and economic factors that are perhaps the biggest threats to the success and sustainability of Mr. Lungu's operations. As such, the redesign of the drying shed will in no way guarantee the future success of the operation. However, the implementation of our redesign could potentially allow Mr. Lungu to produce a product of consistent quality and thereby broaden his marketing opportunities. For example, one food processor in Malawi, called Universal Industries, could be a potential investor/buyer for Mr. Lungu's product if consistent quality could be assured. This would provide much needed cash flow for the operation and would secure the employment of individuals who currently work at the facility.

Due to the time restriction of this project and our lack of experience in the field of dryer design, our design will rely largely on the design procedures outlined in the literature. We do intend to conduct experiments to determine certain material properties of cassava, but our conclusions from those experiments should be taken as approximations of conditions that will likely be encountered in Chisemphere. Despite out best efforts to replicate them, the cassava preparation procedures in Chisemphere will be different as will the cassava itself from our experiments in the lab, due to the diversity of cultivars grown, and the fact that our cassava will have travelled large distances and undergone preservation processes before arriving in our lab.

7 Method

7.1 Description of site and context

7.1.1 History of Project

As we enter an era of global changes, food security has become a largely publicised topic, because these changes can greatly impact the production and availability of food to the most vulnerable populations of the world. Therefore, coming up with a way to transform and distribute locally-produced crops is an ever-growing challenge for communities and agricultural engineers around the globe.

It is in this line of thought that the processing facility we are working with for our project was established in 2003, and has been in operation for the past 5 years. The project was initially financially supported by the United States Agency for International Development (USAID), in collaboration with the local non-governmental organization (NGO) PLAN Malawi, and the research development organization IITA. The main objective of the project was to implement a long-term, sustainable industry to promote food security in the region, by increasing cassava production and distributing it locally.

After funding the project for 3 years, until 2006, USAID left the project to be handled by the local population and NGOs in Chisemphere. As was mentioned above, the project is currently experiencing some problems but is receiving the support of volunteers such as Graham Lettner from Engineers Without Borders. As we contacted Graham Lettner through e-mail, he introduced to us the main players of the cassava processing project.

At first, the multiple processing plants were implemented to process cassava for eventual use as flour. The crop inputs come from several farmers, who bring their fresh product to be grated, dried, and shipped to the local mill or final processing plant. The final result is a simple flour to be consumed locally, or through added-value products such as biscuits, to be consumed in other parts of the country.

Unfortunately, the system failed to produce the expected results and, as was mentioned earlier, all but one processing plant closed their doors. This is when Graham Lettner was asked to come in, and work to help restore the project. The focus of his work has been to work on developing end markets for the dried cassava produced at Mr. Lungu's facility. Having a good market structure before implementing a cassava production and processing system, including the credit infrastructures, should have been a priority for the people involved in the initial project implementation, but these aspects appear to have been largely ignored and contributed to the closing of the four other micro-processing projects.

7.1.2 Geography

In order to be able to design an appropriate drying facility for cassava, it is important to know more about its current location. The drying efficiency of the sheds will be influenced by weather conditions, as well as energy inputs from the sun. Malawi is located in south-central Africa, and Chisemphere has geographical coordinates of 12° 37' 0" South, 33° 31' 0" East, according to Google Maps. This would be considered as the sub-tropical band by weather scientists (Jury and Mwafulirwa

2002). These coordinates will be very important later on to determine local climate, but also to assess the energy balance of our system, as they will be involved in calculating the energy from solar inputs.

More generally, Malawi is "[...] located within tropical southern Africa and covers an area of 118 × 103 km2 between the latitudes 9–17 °S and longitudes 32–36 °E. Lake Malawi, part of the Great African Rift valley, is a major source of water, and its shores draw considerable tourism income (Jury and Mwafulirwa 2002)".

7.1.3 Weather

Weather conditions have been an important issue in the efficiency of the drying shed. In fact, drying requires certain levels of solar inputs, as well as being influenced by the relative humidity of the air (Afriyie, Nazha et al. 2008). For most of the regions of southern Africa, the rainy season occurs between the months of November and March (Ward and Nkhokwe 2003). This renders the design of a solar drier more difficult, considering the harvest season happens in conjunction with the rainy season, as was mentioned above. In general, the efficiency of solar dryers decreases as the solar inputs decrease and the relative humidity increases.

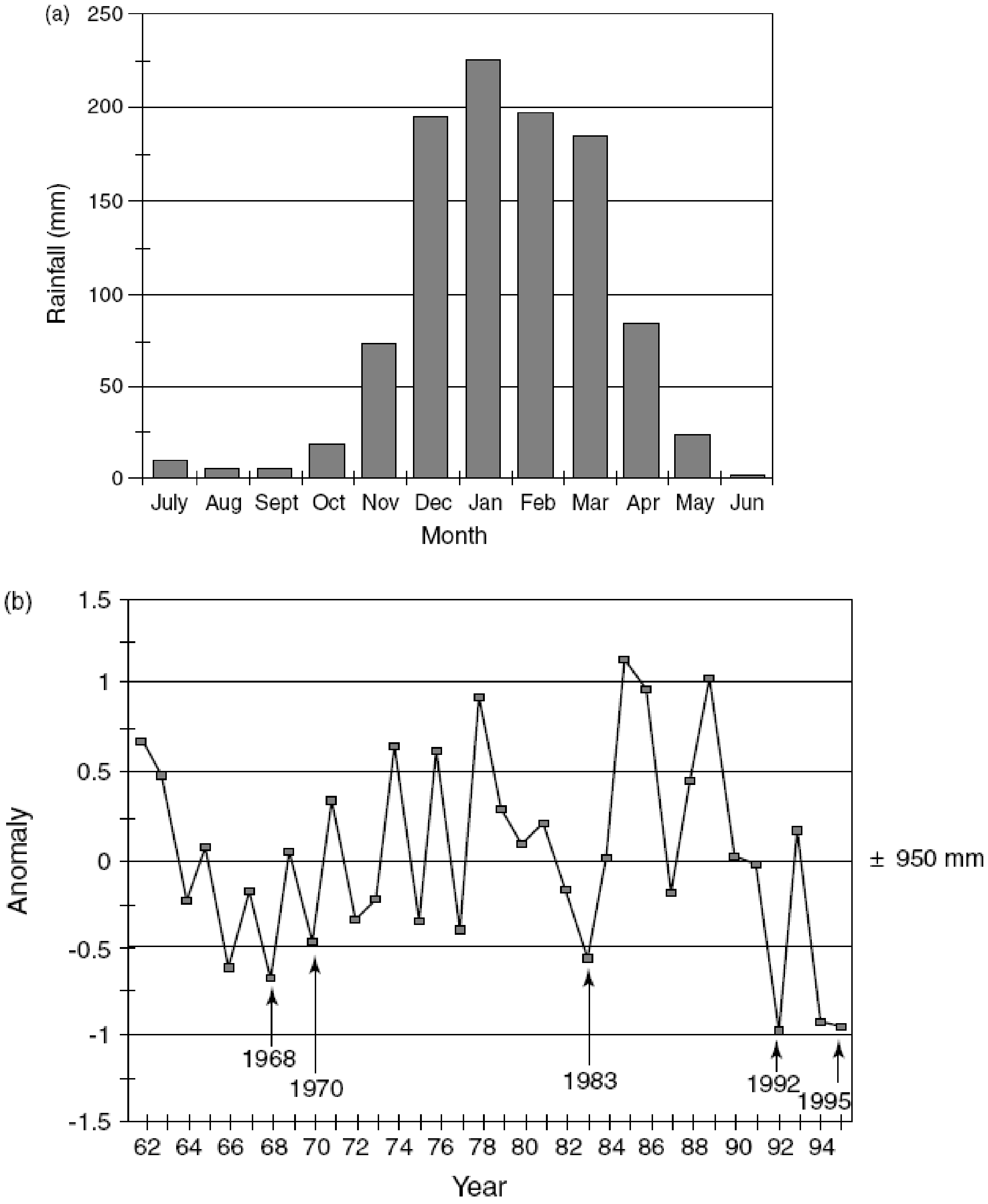
> Malawi experiences a mild tropical climate with an austral summer rainy season. The winter is very dry and nocturnal temperatures decline to near 5 °C from May to September. The climate of Malawi depends on the inter-tropical convergence zone (ITCZ), the sub-tropical high-pressure belt in the south, and the topography (Torrance, 1972). The ITCZ marks the convergence of the north-easterly monsoon and south-easterly trade winds, and during the rainy season it oscillates over the country, often connecting with troughs in the Mozambique Channel. The other main rain-bearing system for Malawi is the northwest monsoon, comprised of recurved tropical Atlantic air that reaches Malawi through the Congo basin. This system brings well distributed rainfall over the country, and floods may be experienced in conjunction with the ITCZ. There are times when the country is affected by tropical cyclones from the west Indian Ocean. Depending on their position, cyclones may result in either dry or wet spells over Malawi. Easterly waves originating near Madagascar often penetrate up the Zambezi Valley during summer. Extra-tropical westerly waves are thought to be most active at the beginning and end of the rainy season.(Jury and Mwafulirwa 2002)

Overall several factors have an influence over weather conditions in Malawi. Depending on the latitude and longitude, different climate scenarios can be observed. However, some severe climate variability can also occur due to the El Nino Southern Oscillation phenomenon (ENSO): "Spectral analysis of the rainfall index reveals cycles at 3.8 years, 2.4 years and 11.1 years, suggesting links with ENSO, the QBO and the solar cycle respectively" (Jury and Mwafulirwa 2002). In those years, climate scenarios are therefore very different from the usual. Normally, the weather conditions are described as follows:

> Rainfall increases rapidly to a plateau of 200 mm/month between December and March. November and April are drier transition months. The high summer rainfall indicates the presence of deep convection contributed by the ITCZ. Even in 'dry' years, the area-averaged rainfall is 700 mm.(Jury and Mwafulirwa 2002)

The information from Figure 3 a), which is normal values for monthly rainfall, shall be used in our design, considering they are the most accurate values available for Malawi. However, in order to be efficient during years of El Nino events, part b) of Figure 3 will be further analyzed and considered in the safety factors of the design, as it represents the anomalies observed in rainfall patterns over the years.

Figure 3: Rainfall time series: (a) long-term mean monthly rainfall illustrating the seasonal cycle; (b) standardized anomalies for the November to April period of each year(Jury and Mwafulirwa 2002)



Another aspect of climate which should be considered, especially for tropical areas found in Malawi, is relative humidity. The presence of moist air is highly correlated with the amount of rain that will be received on a certain region (Torrance 1979). This leads us to believe that the rainy season, which is also the season where the cassava will need to be dried, will have the highest relative humidity levels. From literature, we see that values used to test drying sheds in that part of the world oscillate between 43.2% and 86.4%, with a mean of 58.8% according to (Mumba 1995), and a mean between 76% and 81% according to (Olufayo and Ogunkunle 1996). The former worked in Malawi in the month of March 1992, while the later worked in Nigeria, at a time of year not mentioned, and used data from the IITA local weather station.

7.1.4 Importance of Weather Forecasting

Weather forecasting, in developed countries, is seen by the average citizen, as a practical tool to plan their daily activities. However, for developing countries such as Malawi, it is more than just a simple tool for daily planning. In fact, being able to predict the weather for a growing season can help influence decision-making relative to the management of the food stocks (Ward and Nkhokwe 2003). Rainfall events do not occur at even intervals during the year, being mostly during the summer season, and are not evenly distributed across the country (Klopper and Bartman 2003). This has a great influence on local food security, including the crop yields and drying capacities of solar sheds. Therefore, the amount of cassava being produced and transformed will vary considerably from one year to the next, as well as between the different regions of Malawi. Being able to predict when and how meteorological events will have an impact on agricultural production is therefore of primary importance, including in our crop drying facility design.

Various organizations, such as the Southern African Regional Climate Outlook Forum (SARCOF) and the Long-term Operational Group Information Center (LOGIC), work in order to produce and disseminate such climate information to end-users like farmers, in order to improve their decision-making process(Klopper and Bartman 2003). According to surveys conducted, commercial farmers would be the main beneficiaries of these services, accounting for as much as 75% of all users(Klopper and Bartman 2003). The farmers, when coming upon this information, generally modify their crop management practices. This may include delaying the planting of their crops, but also modify the type of crop they plant. Therefore, it will be difficult to evaluate, in such conditions, the true yearly inputs and time of inputs, which will be taken to the drying shed we will be designing.

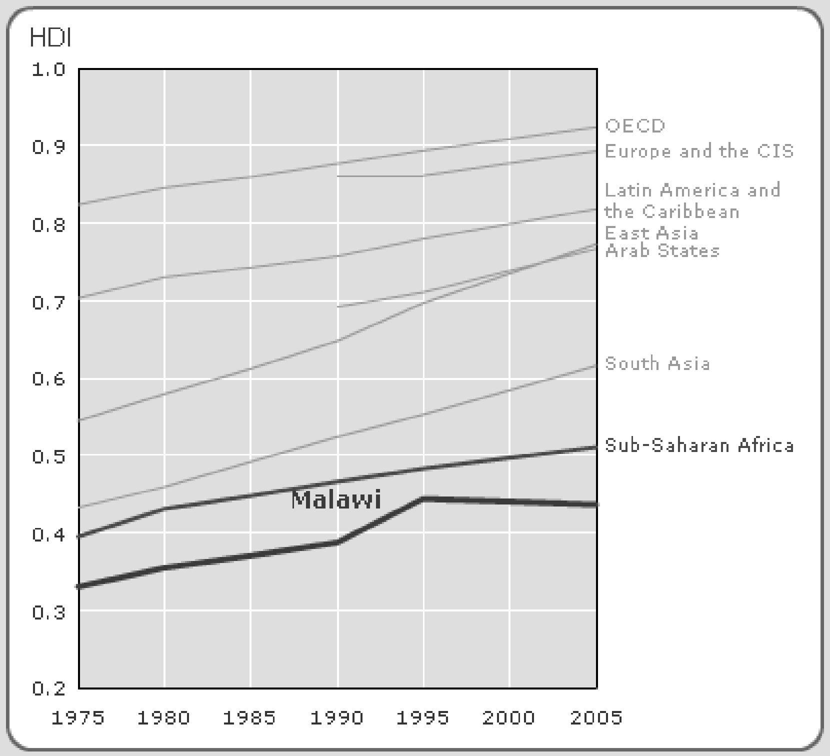
Apart from direct production considerations, it is important to look into the economical impacts of weather forecasting. During the whole production cycle, from the producer to the consumer, there are several components that might be affected by weather conditions, and these will have to be considered in a good decision-making process. Generally speaking, market conditions will vary with weather conditions(Klopper and Bartman 2003). In fact, for cassava, demand might be higher in years where the weather was very appropriate for that specific crop because of poor crop yields from other crop varieties, causing an increase in prices, and a better income for these farmers. Most importantly in our case, the amount of financing and rates of interest will be influenced by the weather conditions(Klopper and Bartman 2003), as capital availability will vary with the general agricultural production situation.

Despite all the advantages that we can find to climate forecasting, it still remains an uncertain science, and lots of research remains to be done in order to meet the specific needs of south African farmers(Ward and Nkhokwe 2003). In fact, although there are now some fairly accurate large-scale estimates that can be established for a season in Malawi, the availability and accuracy of small-scale forecasts still have to be improved(Ward and Nkhokwe 2003). Overall, there is a need for a wider variety of meteorological information in Malawi, including large-scale, small-scale, long-term, and short-term information. This would allow the farmers, but also ourselves as engineers and decision-makers in the agricultural industry to base our choices on reliable data, and therefore increase the chances of avoiding food insecurity for vulnerable populations.

7.1.5 Development in Malawi

According to the United Nations Statistics for 2007-2008, Malawi ranks 164 out of 177 countries for their Human Development Index (HDI), one of the lowest in the world. This index was created in order to assess the quality of life in different countries, beyond simple GDP statistics.

Figure 4: HDI trends(2007)



Source: Indicator Table 2 - HDR 2007/2008

It is clear from this figure that Malawi is a country in great need of international aid. Although their situation had overall been improving in the past, we can see stagnation in these improvements between 1995 and today.

Furthermore, when it comes to food security and the importance of making food available in such a country, the statistics (2007) are clear. In fact, for 2002-2004, 35% of the population was undernourished. For children under the age of 5, the situation is dramatic. Approximately 53% of this population group were under height for their age between 1996 and 2005, indicating a lack of nutrients to promote their normal growth. Considering that the individuals under 15 years of age represented 47.1% of the population in 2005, children will unfortunately be the ones most greatly affected by food insecurity.

Fortunately, several aid projects are currently going on in Malawi, corresponding to 575.3 million US dollars for 2005, or 44.70 US$ per capita (2007). However, this is clearly insufficient to remediate all of the challenges that are currently occurring in Malawi; economical, social, or environmental issues, especially considering global climate changes and the low resilience capacity of a country in such a poor human development situation.

7.2 Sources of Information

7.2.1 Graham Lettner

Graham Lettner is our main contact with the cassava production project in Malawi. He is an electrical engineer from the University of Alberta, presently working with IITA, as part of a long-term placement with Engineers Without Borders (EWB). We have been in contact with Graham since the beginning of the project, through email, as communication in such remote areas of the globe is otherwise quite arduous. Graham has been very helpful in providing us with information concerning the history of the project, local costs of materials, as well as pictures of the current drying shed facility. We have been able to obtain further information about the shed, including the materials that were used, the problems they are having with it relative to its functioning and efficiency, and more. We will continue to consult with him throughout the design process.

7.2.2 Literature Review

Several topics relative to the design of a drying shed have to be researched further, in order to be able to come up with a sustainable design. For this kind of information, we will have to look into different research papers. These should include as we have previously discussed weather forecasting, but also heat and mass transfer for drying kinetics, shed shape and type, as well as cyanide degradation and pest management.

Some of this information is available in a number of different books, user guides, and scientific publications. While there has been minimal literature thus far that explicitly described appropriate solar dryer process we have been able to find a small number of relevant articles on this topic that were recently published by researchers from Ghana (Forson, Nazha et al. 2007; Afriyie, Nazha et al. 2008). These describe in full detail some the different technical aspects involved in designing solar drying facilities in high relative humidity countries, which is perfectly adapted to our needs and they will be invaluable resources as we proceed through the design process.

7.2.3 Professors, Engineers and Lab Work

The Department of Bioresource Engineering at McGill University counts several Professors and staff members whom specialize in crop drying and also have experience with international development projects, similar to those described in this report. Therefore, these persons will be sources of valuable information and insight for our project. They will be able to criticize, comment, and complement our research and documentation. Also, we hope to be able to have access to research laboratories, in order to be able to establish the drying kinetics of cassava. These hands-on experiences will be of great importance for our understanding of the drying process and cassava properties. It would be of certain interest to assess in some controlled environment situations the effectiveness of our design. This will allow us to come up with the most accurate drying shed specifications, as well as being able to explain to our client what are the positive and negative aspects related to the different alternatives, all of this from experience. Lastly, we hope to consult with professional engineers working in the fields of international development and solar drying to gain further expertise and advice.

7.3 Input Data Required

The data required to effectively design a solar drying structure falls into three main categories: product characteristics, meteorological data and building material qualities.

7.3.1 Product Characteristics

Product characteristics of importance to the design of a solar dryer are defined by Rozis and Gunibault (1995), Forson *et al.* (2007) and Sharma, Sharma *et al.* (1986) and are described below.

The product characteristics of utmost importance for drying by any means are the initial and desired final moisture content of the cassava. These characteristics will determine the amount of water that must be removed from the product and, subsequently, the amount of solar energy and air flow that will be required to achieve the desired drying.

In order to ensure end product quality the maximum allowable temperature the cassava can endure must be established. It is also important to determine the drying kinetics of cassava and its solid specific heat capacity to establish an appropriate drying process and to accurately determine the energy requirements for the drying process. The drying characteristics will be determined according to the standard developed by the ASABE for thin-layer drying of Agricultural Crops(ASAE Grain and Feed Processing and Storage Committee 2001) in combination with a review of characteristics available in the literature concerning cassava produced in Malawi and surrounding regions. Also of relevance to product quality is the allowing amount of time without processing before cassava begins to deteriorate.

Other characteristics that are of importance when sizing a drying structure include the timing of harvest and delivery of the cassava to the drying facility. Because the cassava will be grated (or chipped) and pressed before drying, it is also important to determine the dimensions, shape, porosity, bulk density and loading bed void fraction of this processed cassava in order to size the structure and drying trays to accommodate the desired rate of dried cassava. Our clients have indicated that the design should be able to accommodate grated or chipped cassava and so the properties of both should be determined and utilized in the design. The effect of drying layer thickness on the rate of drying should also be optimized both in terms of drying speed and labour required.

Lastly, Mr. Lettner is currently attending a training session concerning industry standards for cassava products and will pass along the desired product characteristics outlined by local food processors in Malawi to us in the coming weeks.

7.3.2 Meteorological / Geographical Data

The temperature and relative humidity of the air that will be entering and leaving the drying structure during the monsoon season in Malawi will have extensive impacts on the design of this drying structure and will be determined using world weather databases.

Solar irradiation data can be used to help determine the ideal tilt of solar collectors and the surfaces of a drying structure's receptive panes. This process requires the input of the latitude of the site of interest.

Lastly, our design will require the input of the average solar radiation reaching ground level in Malawi during the rainy season. This data is readily available from an internet database developed by NASA and the Atmospheric Science Data Centre (Stackhouse and Whitlock 2008).

7.3.3 Building Material Qualities

We will also need to determine the durability of the materials being used in the design, in particular the expected lifespan of the material used as a transparent cover for the structure. According to Bassey (1982)certain plastics will be affected by solar radiation over time and this may reduce their transparence, resulting in less solar radiation reaching the product than initially anticipated.

Absorption is another important attribute of the transparent materials that will need to be determined. Absorption is the amount of solar radiation that is absorbed by a given material when radiation passes through it (Duffie and Beckman 2006). The calculations and input data required for determining absorption can be found in Appendix 4. The absorption of a material will affect the amount of surface area of the structure will be required to collect sufficient energy for natural convection solar drying.

The resistance to air flow caused by various materials should also be determined in order to be able to optimize air flow throughout the drying structure by natural convection.

The cost in Malawi of potential materials to be used in the design is another important input for the design of our drying structure. See Appendix 3 for the costs of some of the materials used to construct the existing drying shed. These figures give a sense of the acceptable price range of materials but more information will need to be gathered concerning the availability and cost of different materials in order to broaden the possibility of alternative design solutions.

7.4 Design Approach

Although our design focuses on one relatively simple structure, it will be dramatically influenced by the socio-politic, geography and economic context of the facility. It will also be part of a larger system that extends from the farmers' fields where the cassava is being grown and the agricultural practices there, to the end consumer's plate. As a result of these dynamic interactions and constraints, as well as the project requirements outlined earlier, we will use a systems design approach for this project combined with the architecture of the six steps of design in order to achieve the main goal of generating a drying shed design that will yield a cassava product, with the desired qualities, while staying within the cost and material constraints of this project. Furthermore, we will strive to incorporate principles of appropriate technology design and sustainable developments into our design process.

7.4.1 Systems approach

The systems approach to engineering problems stemmed out of the discovery that the overall efficiency of systems, in terms of energy and resources, are often better optimized when considering the system being examined as a whole instead of optimizing it component by component (Stasinopoulos, Smith et al. 2003). This approach involves looking at systems as a whole and examining all components and their inter-relationships. Hitchins (2003) outlined four principles that should be followed when taking a systems approach to design. They are as follows:

1. Approach an engineering problem with the highest level of abstraction for as long as practicable.
2. Apply 'disciplined anarchy', that is, explore all options and question all assumptions.
3. Analyze the whole problem breadth-wise before exploring parts of the solution in detail.
4. Understand the primary system level before exploring the sub-system.

5. Understand the functionality of the whole system before developing a physical prototype.

In applying such principles, multiple designs are typically generated to explore as many potential solutions to the design problem as possible before deciding on the final design to be pursued. We will attempt to incorporate this approach to design in the development of our cassava drying system.

7.5 Appropriate Technology and Development

The concept of appropriate technologies emerged in the 1970s as a result of growing concerns about human impact on the environment, the emerging interest in the localisation and democratisation of technological solutions and economies, as well as the need to address the energy and resource crises of that time period (Darrow and Saxenian n.d.). In reviewing these motivations we can see that such a design philosophy is all the more relevant today. But what is 'appropriate technology'? Village Earth, a non-profit, non-governmental organisation based in the United States, defines the concept well when they say that:

> "It is a way of thinking about technological change; recognizing that tools and techniques can evolve along different paths toward different ends. It includes the belief that human communities can have a hand in deciding what their future will be like, and that the choice of tools and techniques is an important part of this. It also includes the recognition that technologies can embody cultural biases and sometimes have political and distributional effects that go far beyond a strictly economic evaluation. [Appropriate technology] therefore involves a search for technologies that have, for example, beneficial effects on income distribution, human development, environmental quality, and the distribution of political power—as well as productivity—in the context of particular communities and nations."(Darrow and Saxenian n.d.)

Our primary correspondent in Malawi, Graham Lettner, is a volunteer with another NGO, Engineers Without Borders, which advocates for the implementation of appropriate development strategies and the goals stated in their charter will important for us to keep in mind as we proceed through this project. The main tenets outlined in the EWB charter include that people should be at the center of the design process, not an obstacle to change. This way, the probability of success of the project will be enhanced by the support of the community. Also, the solutions developed in collaboration with a community should be sustainable, addressing the causes of the root problems rather than symptoms. Partnerships and good organizational structures are also fundamental to the fruitful operation of a technological system. Further information concerning the EWB charter can be obtained from their Orange Book executive publication for 2007-2008.

Lastly, while we aim to embrace these technology and development philosophies in our design process, there are a number of restrictions that will prevent us from doing so completely, as will be discussed in the expected outputs.

7.5.1 Six Steps of Design

7.5.1.1 Problem Identification

This step of the design process has already largely been completed and its results are presented in Section 1 of this report. However, as we continue to communicate with our liaison in Malawi, information could come to light that would alter our original problem statement. Should this occur, the appropriate adjustments to our design process will be made at that time.

7.5.1.2 Preliminary Ideas/Problem Refinement

The generation of preliminary solutions to the design problem at hand and the refinement of problem details are traditionally considered the second and third steps of the design process, respectively, but due to the nature of our design project these steps will be largely integrated and will consist of a series of sub-steps, as follows.

7.5.1.2.1 Literature review

The first step in our development of preliminary design ideas will be to conduct a thorough literature review of the current literature pertaining to the design of passive solar drying of agricultural products and will also detail the physical phenomena driving the drying process, including heat and mass transfer theory.

7.5.1.2.2 Basic Design Calculations

Upon completion of the literature review we will amalgamate the design procedures and rules of thumb that have been suggested by Forson *et al.* (2007) and Rozis and Guinebault (1995)and any others we may come across during our literature review, to determine the basic parameters of required by our solar dryer. Please see Appendix 1 and 2 for an outline of the approaches used by Rozis and Guinebault (1995) and Forson *et al.* (2007), respectively, including listing of the parameters that will be established using these procedures and some of the equations that will be used. We will modify these design strategies to suit the drying needs of cassava and other design restrictions supplied by our client and will attempt to incorporate the other design suggestions that come to light in our literature review. Figure 5 illustrates the design process utilized by Santos, Queiroz *et al.* (2005), which is similar to those that we will be basing our work on. It displays a number of the dryer characteristics that we will be calculating and their inter-relationships.

Figure 5: Solar Dryer Design Parameters

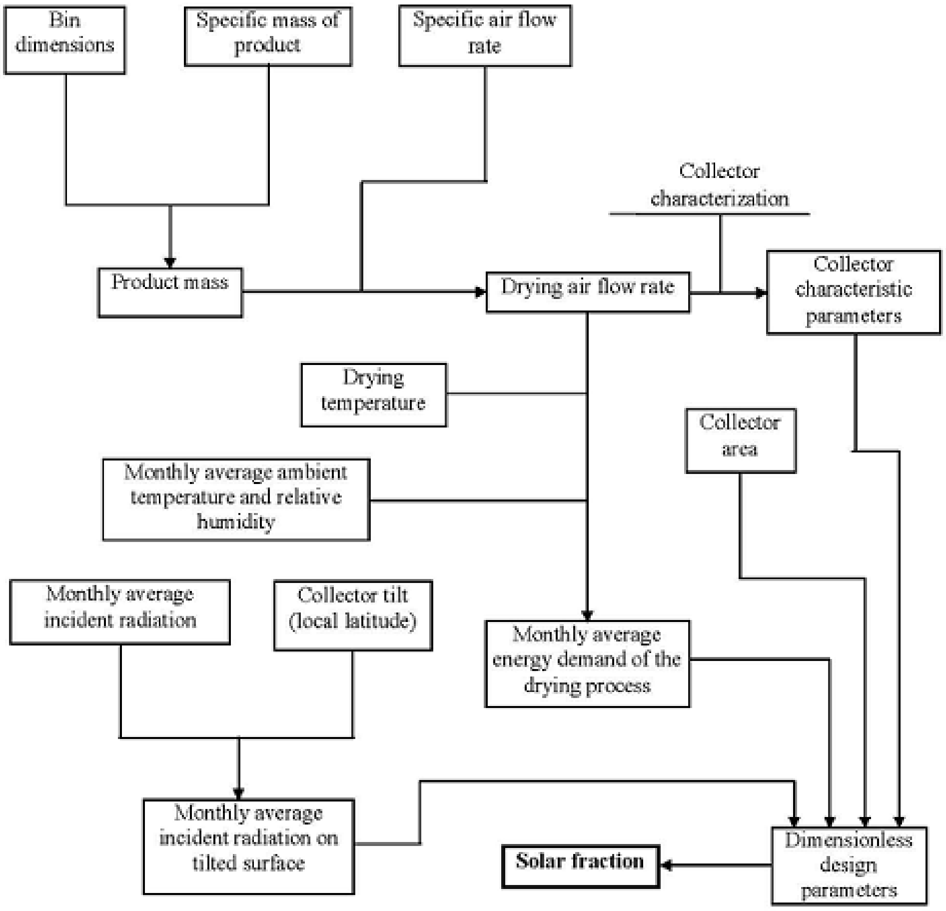


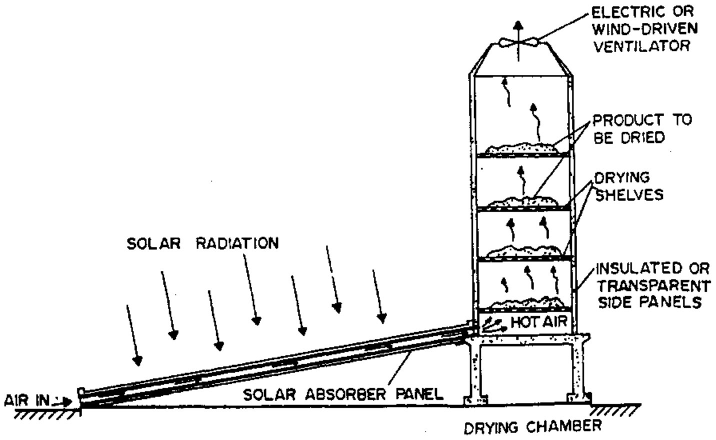
Figure 4: Parameters involved in the design of solar crop-drying systems.

Source: Santos, Queiroz *et al.* (2005)

7.5.1.2.3 Evaluation of Design Shapes and Internal Arrangements

Next, we will identify various possible solar dryer structural shapes that could meet the design parameters outlined in the previous step and identify the costs and benefits each. Two possible dryer shapes include the traditional elevated box type dryers and a dryer tunnel type dryer. Images of both types can be seen Figure 6 and Figure 7.

Figure 6: Elevated Direct Solar Radiation Box Dryer



Source: http://www.fao.org/docrep/V5030E/V5030E0J.GIF

Figure 7: Direct Solar Tunnel Dryer

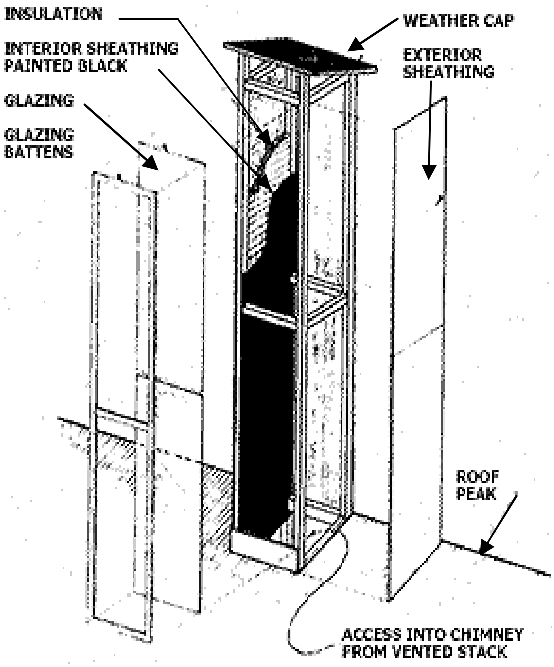
Source : http://www.icar.org.in/ciae/tunnel%20dryer.htm

One of the criteria used to evaluate the dryer shape will be the degree to which it facilitates the natural convection and the passive flow of air. To truly evaluate this aspect, complicated computer simulations would need to be developed to determine the effect of each shape on air velocity (Rozis 1997; Duffie and Beckman 2006). Such models are fairly expensive and time consuming to construct and so instead we will review the literature to see which shapes have had the best drying results.

7.5.1.2.4 Evaluation of Potential Structural Additions

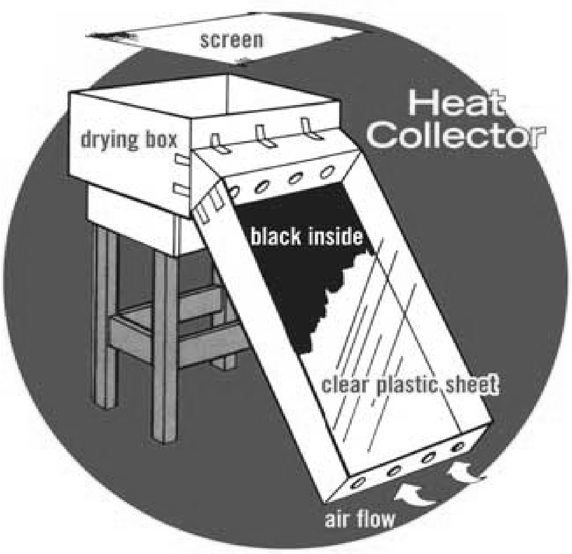
In addition to determining the ideal solar dryer shape for our set of design constraints, we will evaluate the effects of various structural additions to the basic design shape while also looking at how those additions will alter the cost and difficulty of construction and drying effectiveness. Afriyie *et al.* (2008) have suggested that solar chimneys, which are transparent chimneys at the peak of a drying structure that contain a heat absorbing material, can improve performance of cassava drying structures. An example of a solar chimney can be seen in Figure 8. Others have suggested that heat storage units, which store heat accumulated during the day and release it into the drying structure at night to maintain near constant temperature and air flow in the drying structure, and intake air heaters could be incorporated into the design of solar drying structures to speed up the drying the drying process (Khattab and Badawy 1996). Lastly, solar collectors to preheat incoming air will also be evaluated and an illustration of a simple solar collector can be seen in Figure 9. Each of these structural additions will be assessed in turn and in combination using design suggestions provided by Rozis and Guinebault (1995)and suggestions gathered in the literature review.

Figure 8: Illustration of a Solar Chimney



Source: http://attra.ncat.org/images/solar-gh/chimney.gif

Figure 9: Illustration of a Solar Collector



Source: http://www.motherearthnews.com/Green-Homes/1981-01-01/A-Solar-Food-Dryer-From-Cardboard-Boxes.aspx

7.5.1.2.5 Examination of Possibility of Multiple Moistures

Our client has also requested that our design allow for the presence of material at various stages of drying in the structure simultaneously. This possibility will be analyzed in terms of how the presence of multiple moisture contents affects the physical phenomena that motivate drying and the speed of product drying.

7.5.1.2.6 Design of Run-off System

We will review the literature and communicate with experienced professors in the Bioresource Engineering Department to develop and design a simple system to deal with run off that could be compatible with the dryer design.

7.5.1.2.7 Identification of Appropriate Materials

Three basic criteria will be used to identify and evaluate materials to be used in this design; cost, availability and performance over time. Furthermore, we will attempt to create a design that is as resistant to termite damage as possible.

7.5.1.3 Analysis

The physical processes involved in drying take place at a non-linear rate making it difficult to scale down dryers for the purpose of performance evaluation(Mujumdar and Devahastin 2000). As a result, the advantages and disadvantages of the potential designs outlined in the previous design step will be compared as a form of analysis. The basis of comparison of the designs will include monetary costs, difficulty of construction, drying performance, maintenance requirements and environmental impact, among other criteria. We will attempt to perform a life-cycle analysis of the potential designs, which involves the total analysis of the environmental impact of each design(Mulder 2006). This is a sizable undertaking and time-restraints may limit the extent to which we complete this aspect of the analysis.

Due to the interconnectedness of the various aspects of the design, the overall design process is largely iterative. The results of the analysis and comparison of the preliminary designs generated will likely result in the development of another set of potential designs that will improve upon the drawbacks of the first set. This feedback will continue until a set of potential designs are developed that are deemed to be satisfactory both to us as designers and to our clients. Communication will be of utmost importance at this step to ensure that the criteria being used to evaluate the designs are appropriate.

7.5.1.4 Decision

This set of the design process will be conducted, for the most part, by those on the ground in Malawi, perhaps in consultation with local industry. The designs analyzed utilizing the criteria outlined above and details of each of their advantages and disadvantages will be presented to our collaborators in Malawi.

7.5.1.5 Implementation

The implementation of our design will consist of developing virtual representations of the final design selected in the form of AutoCAD drawings to facilitate transmission and future evaluation of the design’s merits by those on the ground in Malawi, should future funding become available for the implementation of the design. We will also develop a set of operations and maintenance guidelines that would allow for the design to be operated at its maximum potential if it were to be implemented.

7.6 Expected Results

While all attempts will be made to create a suitable design that will address our clients' needs, we do not expect our design to necessarily be implemented on the ground in Malawi in the coming years, for multiple reasons. Firstly, we are not engineers and do not have the appropriate experience to say that the design we produce will function as expected or is the optimal design for our clients, though we will try our best in the coming months to collaborate with our professors and other engineers to try to make as realistic of a design as possible.

Secondly, we do not have the resources to build a full scale prototype of whatever design we develop, meaning our ability to test and predict the structures' performance will be severely limited.

Thirdly, even if our developed design is ideal and practical, the current cassava facility is facing challenges that extend far beyond the realm of technological solutions, as was mentioned earlier. The current cassava facility is struggling to generate the consistent cash flows required to sustain itself because of the lack of developed markets within the region. Furthermore, there is currently barely enough funding available to keep the current drying shed in production and in good repair, let alone to build a new structure. This is one of the major challenges faced by many development projects. When it comes to funding for construction projects in remote areas, local inputs are rare. According to Giné *et al.*, "[...] in developing countries, insurance and credit markets are typically incomplete or altogether absent. In this environment, the separation of consumption and production decisions may not obtain, and thus, the relative importance of credit constraints and risk aversion may be confounded (Gine and Yang 2008)". The initial capital investment for many, if not most, engineering works implemented in developing countries is provided by external agencies such as USAID, as was the case of the cassava project we are working with. However, after that initial investment, locals are often left to fend for themselves to maintain and run the facilities and as was the case when USAID left the cassava production facilities project in 2006.

Lastly, despite our best efforts throughout the design process, having never set foot in Malawi, let alone anywhere near the drying facility in Chisemphere, we have violated one of the most crucial rules of appropriate technology development: we have never met the people who will be affected by our design, nor heard their concerns, nor will we be able to work in collaboration with them throughout the design process.

Even with this skepticism concerning the relevance and usefulness of the end product of this design process, the goal for our final report remains to act as a resource, not a perfected solution, for those working on the ground in Malawi. In developing and evaluating multiple designs we will shed light on the costs and benefits of various design aspects.

8 Time Frame

8.1 Work schedule

Figure 10: Overview of Steps of the Design Process

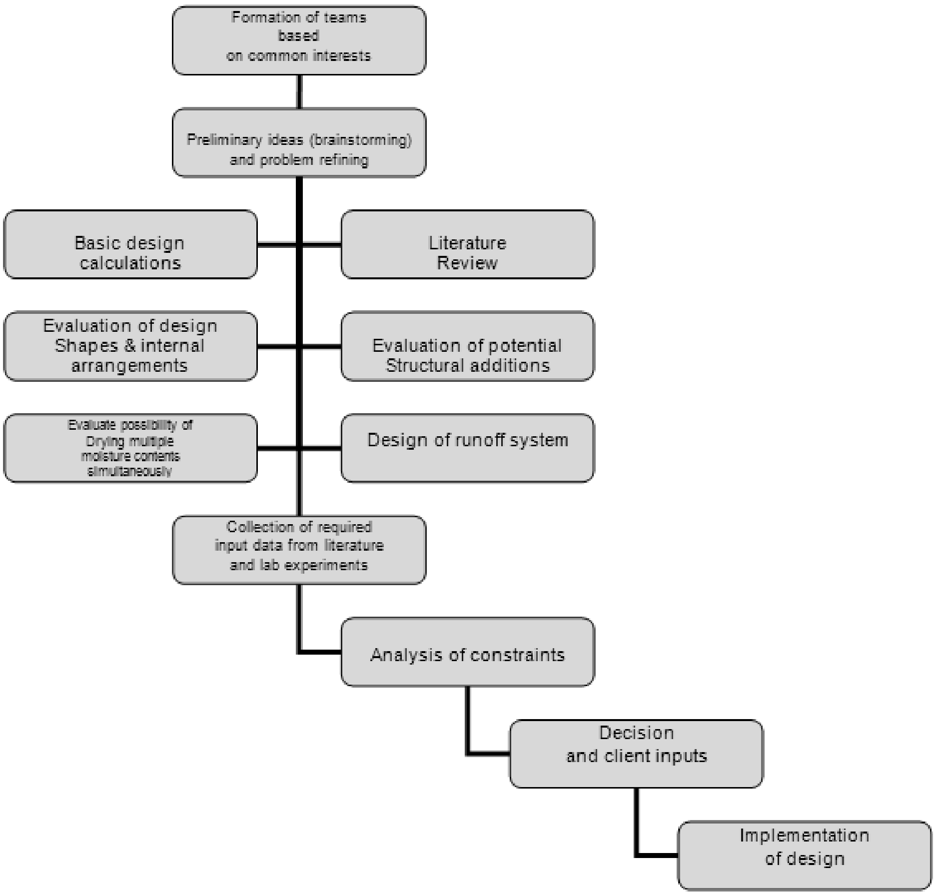


Table 1: Estimated work time for each step of the design process

Date	*Description of task*	*Time*
January 2008	Drying tests in the lab	25h
	Analysis of results	20h
	Literature review for lab work	20h
February 2008	Continued literature review based on results	15h
	Selection of materials based on costs/availability/needs	10h
	First design drafts	25h
March 2008	Design testing/ qualitative analysis	10h
	First proposal to client	10h
	Incorporation of client input in final design	25h
April 2008	Final design report writing	10h
	Final design presentation preparation	10h
TOTAL TIME		180h

8.2. Cost analysis of project

Any design project should involve an in depth cost analysis. In our case, this is difficult to do at this point. However, we will discuss the elements that should normally be considered in order to improve the decision-making process.

First of all, we have to consider the current market. The cost of production will vary depending on the crop, the quality of the product, the natural resources such as soil and water quality, as well as many other factors. The price that the producer will obtain for his crop will also depend on its quality, but also on the market conditions such as offer and demand. In our case, we are interested in knowing if the mill which buys the product would be ready to pay more for the dried cassava, if its output quality was increased. If so, it might trigger the possibility for a larger investment in the new technology, as the income over the years would be increased.

After considering this first step, there might be a need for further, more in depth evaluations. At this point of our project, we cannot evaluate all of these parameters. It should however be done later on, when we have defined all of our design needs and made decisions relative to them. The economical analysis should include several or all of the following components from the reference guide "Sécher des produits alimentaires" (Rozis and Guinebault 1995):

- Energy needs per kg of dried material
- Initial cost
- Maintenance fees per kg of dried material
- Time of payments
- Price of fresh product
- Efficiency of the process (i.e. losses)
- Price of dried product
- Transportation costs
- Salaries
- Other equipment costs
- Taxes
- Commercialisation costs
- General management fees

The initial costs will be mainly those of the drying shed in our case, therefore an estimate of the costs of building materials for the current shed is included in Appendix 3. An estimate of engineering research and development costs that would be incurred if Professional Engineers were working on this project are found in Table 1.

Table 2: Engineering Costs

Task / Service	Time (hrs)	Cost/hr (in dollars)	Total Cost
Consulting and design by professional engineer	200	80	16 000$
Technician on site	100	20	2000$
Communications with Malawi	20	10	200$
Legal advising	10	50	500$
TOTAL			18 700$

Finally, it is important to understand that the conclusion of the actual cost analysis will influence all the steps of design. In fact, considering there is a need for a very economical solution, some steps of design process might have to be redone several times in order to find the most cost-effective option. This includes considering constraints where we cannot input high technology, or designs with materials not available locally.

9 Conclusion

In conclusion, there is much work to be done in the coming months in order to lay the groundwork for and successfully complete our exploration of the design process for a feasible cassava drying shed for Chisemphere, Malawi during the 2008 winter semester. The end result of our project will be a report that will outline the details of our final design, as well as visual representations of the design in the form of graphic drawings. We hope that our final work will act as a resource for those working on the ground in Malawi should funding become available in the future for the construction of a new drying structure at Mr. Lungu's cassava microprocessing facility and/or other sites in the region. We look forward to the months of work and learning that lie ahead.

Appendix 1

What follows is an outline of the questions that (Rozis and Guinebault 1995)have suggested should be answered during the preliminary steps of the design process.

1. What type of product will be dried and what are the desired product characteristics?
2. What is the average quantity of product to be dried each day?
3. How long will the product to be dried last without drying before deterioration?
4. How much water must be extracted from the product (as per the below equation)?

$$M_e = \frac{(m_i - m_f)M_i}{100 - m_f}$$

Where

m_i= initial water content of product [%]

m_f= desired final water content of product [%]

M_e= mass of water to be extracted from the product [kg]

M_i= mass of product to be dried (after preparation) [kg]

5. How long will the drying period be?

6. How quickly will water be removed from the product (as per the below equation)?

$$V_{em} = \frac{M_e}{T_s}$$

Where

V_{em}= speed at which water must be removed from the product [kg/hr]

M_e= masse of water to be extracted from the product [kg]

T_s= ideal duration of drying (hr)

7. How hot must the incoming air be when it reaches the product?
8. What are the evaporative capabilities of that air?
9. How much water will be removed from the product per cubic meter of air flow?
10. What air flow is required inside the dryer (as per the below equation)?

$$Q_s = 1000 * V_{em} / (\rho_{air} * (x_m - x_a) * \eta_s)$$

Where

Q_s= desired air flow [m^3/hr]

V_{em}= speed at which water must be removed from the product [kg/hr]

ρ_{air}=bulk density of dry air ≈1.2 kg/m^3

x_m=average moisture content of air exiting the dryer [g/kg dry air]

x_a=moisture content of air entering the dryer [g/kg dry air]

η_s=drying efficiency

11. Can this flow be achieved without structural additions (such as fans or solar chimneys)?
12. Is the addition of a solar chimney appropriate?
13. How can frictional resistance to air movement be minimized?
14. How much energy is required to evaporate the water to be removed (as per the below equation)?

$$P_n = \rho_{air} * \frac{(h_s - h_a)}{3600} * Q_s$$

Where

Q_s= desired air flow [m^3/hr]

ρ_{air}=bulk density of dry air ≈1.2 kg/m^3

h_s and h_a: the energy contained in the air entering and exiting the dryer, respectively [kJ/kg]

P_n= Power required for the drying [kW]

3600: a conversion from hours to seconds

The power required can also be approximated by the following equation:

$$P_n' = \rho_{air} * Cp_{air} * \frac{(T_2 - T_1)}{3600} * Q_s$$

Where

P_n= Approximation of the power required for the drying [kW]

Cp_{air}= specific heat of air [J/kg/^oC]

T_1 and T_2: Temperature the air entering and exiting, respectively, the solar collector, which preheats the air coming into the dryer [^oC]

15. How much energy must be supplied to the air?

$$E_n = P_n * t_s$$

Where

E_n= Theoretical energy required [kWh]

t_s= Duration of drying [h]

P_n'= Approximation of power required for drying [kW]

Heat losses from the system and efficiencies of heat transfer should also be considered.

$$E_{actual} = \frac{E_n}{\eta_{thermal}}$$

Where

E_n= Theoretical energy required [kWh]

E_{actual}= Actual energy required [kWh]

$\eta_{thermal}$= Thermal efficiency of solar collector

Note: the thermal efficiency is typically determined through experiments.

16. What surface area is needed for the solar collector to supply the required heat (as per the below equation)?

$$A = \frac{P_n}{\eta_c * G_n}$$

Where

A= the surface area of the solar collector [m^2]

P_n= Power required for drying

G_n= Strength of available solar radiation [kW/m^2]

η_c= efficiency of solar capture (typically ranges from 0.4 to 0.6)

Appendix 2

Forson *et al.* (2007) laid out the following guidelines for designing a natural convection solar crop dryer with a solar air collector for drying cassava.

First they compiled cassava's crop characteristics from a variety of sources and defined them as follows:

- Crop porosity: 0.44
- Bulk density: 552 kg/m^3
- Initial moisture content: 62-67% (wet basis)
- Desired final moisture content: 17% w.b.
- Loading bed void fraction: 0.70
- Solid specific heat capacity: 840 J/kg K
- Maximum permissible drying temperature: 70^{o}C
- Ambient Relative humidity of test location: 77.8%

Secondly, them outlined a number of design constraints to consider that were also derived form the literature.

1. Dryers incorporating both direct solar radiation on the product to be dried and predrying of incoming air, using a solar collector, are the most effective dryer designs.
2. In order to achieve sufficient airflow through the dryer by natural convection, the average velocity, v_c, of air exiting a solar collecter unit should be between 0.20 and 0.40 m/s.
3. The tilt of the collector should be determined using the latitude of the site and considering the ability of water to run-off.
4. The drying bed thickness, h_L, should not exceed 200mm.
5. The maximum height of the hot air column, which extends from ground level to the air outlet of the structure, should be between 2 and 6m is order for a total pressure ranging between 0.8 and 2.5 Pa to be produced within the dryer.
6. A ratio of drying chamber area to solar collector intake area of 1.0 is recommended.
7. A general guideline for product loading is that if the average solar radiation ranges from 300 to 500 W/m^2 and can dry the product within 3 to 5 days, the product can be loaded at an acceptable rate between 5 and 18 kg/m^2.

8. For designs involving solar air heaters, single pass double duct designs have been found to be superior to other designs in terms of heating capabilities. Such solar collectors should have a length to width ratio from 1 to 2 and, for collectors with tilt angles for up to 60^o, the length to height ratio of the solar collector should be grater than 20 and less than 200 to accommodate varying flow conditions.

9. The ratio between the height of the upper duct and lower duct of a solar collector should be between 1.1 and 3.5. The total height of the two ducts combined should be greater than 90mm.

10. Two-layered drying beds are recommended for solar drying using natural convection.

11. Air mass flow through natural convection solar dryers is typically between 0.02 and 0.9 kg/s.

12. If humans will be entering the structure to load and manipulate the product to be dried, the drying surface of the dryer is approximately 60 to 80% of the drying chamber floor area under most circumstances.

Using these characteristics and guidelines they proceeded to perform design calculations for the following characteristics:

- Air flow requirement
- Area of drying bed
- Total area of the system for collecting incident energy
- Sizing the solar air-heater (ie. primary solar collector)
- Drying bed arrangement
- Other dimensions of the dryer
- Pressure drop through the drying bed
- Height of the hot air column

Lastly they built their design and compared its performance and characteristics to their calculated values, with fairly comparable values being generated by the physical prototype and the calculations.

Appendix 3

Table 2: A Summary of the Quantities and Cost of Various Materials Used in the construction of the Existing Drying Structure

ITEM	QUANTITY	UNIT PRICE (Malawian Kwacha)	TOTAL PRICE (Malawian Kwacha)
Bricks (9”x4.5”x 2.5”)	1000No	2.5	2 500
Cement (OPC)	5 pockets	2 500	12 500
Sand (river)	2 tonne	700	1 400
Timber (3” x2”)	60No.	450	27 000
Timber (2” x2”)	25No	250	6 250
Wire nails (2”)	4 Kg	300	1 200
Wire nails (4”)	5 kg	300	1 500
Wire nails (1”)	2 kg	300	600
Greenhouse sheeting (250 micron)	2 rolls	26 500	53 000
Aluminum wire mesh (45 micron)	2 roll	13 000	26 000
T and G (4”)	45 No.	600	27 000
Nylon ropes (0.25”)	30 m	250	7 500
Chlordane (gulf)	1 litre	2 500	2 500
Timber strips(40mm x20mm)	60No	450	27 000
Quarry stone	1 tonne	1 500	1 500
Labour			
Grand total			**237 450**

Conversion: 140 Malawian Kwacha = 1 Canadian Dollar

Appendix 4

The calculations for determining the material characteristics of absorptance and transmittance, according to Duffie and Beckman (2006) are described below.

Absorptance can be approximated by the following equation:

$\propto \cong 1 - \tau_a$

Where

α is the absorptance

τ_a is the transmittance, the proportion of solar radiation that passes through a material

Transmittance is defined by the following equation:

$$\tau_a = \frac{I_{transmitted}}{I_{incident}} = exp\left(-\frac{KL}{\cos\theta_2}\right)$$

Where

K is a proportionality constant that can be determined from the literature

L is the thickness of the material

Θ_2 is the refraction angle of radiation passing through the material

The fraction in the above equation shows that the transmittance is the proportion of incident solar radiation that passes through the material.

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