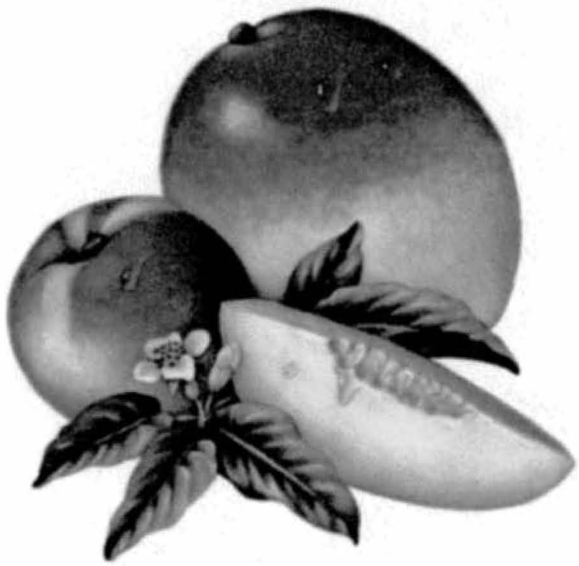
Design of a Solar Dryer
For Processing Mangoes



Presented to Dr. Raghavan

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Table of Contents

List of Figures

List of Tables

Problem Statement

In many countries in East Africa, there is a large potential for economic gain in the fruit market. This market is unfortunately not fully exploited since more than half of these fruits spoil before they can be sold to consumers. Thousands of tons of fresh fruits in Africa spoil every year due to lack of post-harvest techniques such as processing and preservation (Andrew Ngereza 2007). In these same countries, there is a large portion of the population who suffer from what is known as vitamin A deficiency. This disease is developed by a lack of ingesting vitamin A through the consumption of fruits and vegetables. Mangoes are a fruit with a high content of vitamin A and are locally grown in East Africa. Unfortunately major losses due to spoilage are experienced because the high moisture content in the fruit leads to a quick deterioration of the fruit tissue. It is therefore our goal to develop a solar dryer to address these issues in the hopes of utilizing this lost resource as well as aiding to decrease the population that develops this completely preventable disease. Emphasis of the design will be placed on conservation of vitamin A during the drying process and quality of the final product.

Figure 1: Dried Mango Slices

Scope

Since our design has a significant socio-economic component involved, an overview of vitamin A deficiency and its prevention is described. Vitamin A deficiency (or Xerophthalmia) is especially widespread in Africa among children younger than 5 years of age(Rankins, Sathe et al. 2008). Under steadily deteriorating vitamin A condition, the body undergoes a sequence of changes. This begins with night blindness, the reduction of sight under low levels of light (Sommer 2008). This is followed by more severe forms of vitamin A deficiency, namely xerosis of the cornea and corneal ulceration. Finally keratomalacia occurs, the melting of the cornea. The loss of the eye proceeds soon after (Sommer 2008). In developing countries, child mortality rate and vitamin A deficiency are closely linked. A clinical trial in Indonesia showed that the mortality rate of children one to five years of age was reduced by 34% when vitamin A was introduced to their diet (Sommer 2008). This number seems too high to ignore. Figure 2 of the Appendix shows the vitamin A content in food supply for various continents. According to the Institute of Medicine and using their conversion rate of beta-carotene, the food supply in Asia and Africa is deficient in vitamin A(Sommer 2008).

Proper preservation and processing of fruit in these countries are two great steps to be achieved in helping the population fight this disease, while at the same time increasing the wealth and livelihood of the entire region. The main reasons that are liable for the loss of tropical fruit to waste are short shelf life due to ethylene biosynthesis, mechanical damage due to mistreatment while in storage, and water loss due to evaporation and transpiration of the fruit(Rankins, Sathe et al. 2008). This causes shriveling of the fruit and therefore loses the aesthetic and juicy appeal. Since mangoes are actually a produce that the local communities enjoy, increasing the amount available will increase the amount consumed. There is no factor of persuasion that needs to be involved to show the community that eating this fruit is beneficial and healthy.

It will be important to further investigate the impacts on the local community of increasing the availability of dried mangoes rich in vitamin A. Certain questions will need to be addressed; such as whether the implementation the proposed dryer will have a measureable effect on vitamin A deficiency rates. Also, we will need to investigate whether the consumers would be willing to pay a slightly higher price for a more nutritious product.

Objective

Mangoes have a relatively high content of vitamin A as stated previously. This value is estimated at 0.053mg in fresh mango(Lenntech 2008). Direct solar radiation diminishes this amount significantly; therefore it is desired to develop a solar dryer in which the fruit themselves do not have direct contact with sunlight. The dryer must be built with materials that are readily available in the area, or materials that can easily be shipped to the area at a low cost. The materials used should be inexpensive and comprehensive to use. The solar dryer should be easy to maintain and require little use of power tools and such equipment to uphold it. In short, it is desired to design a simple dryer with local materials that can be bought by the farmer so he can build it himself. The design would essentially be a blueprint of the dryer.

A computer model of the dryer will be developed using CAD software. The model will comprehensively describe and demonstrate all components of the dryer.

If time permits, a scale model of a solar dryer will be built. It will include all components previously mentioned and will provide us with a tool to test the theory found in the literature review of this topic. With these results, conclusions will be drawn accordingly.

Method

Description of Site and Context

Climate

The chosen site for implementing the design is south-eastern Africa. Initially, the plan was to choose a specific community in the country of Malawi since there are Engineers Without Borders (EWB) volunteers stationed there with whom we could potentially communicate with. After some discussion, it was decided that the site for the design be expanded to south-eastern Africa. The decision was based on the idea that if the design were to be adaptable for a larger area of the continent, more people could potentially benefit from its use. The boundary to the area of interest is based on climate zone and similar harvest seasons. Since the design of the solar dryer will depend on climate and weather conditions, the design will be for a region with similar climate. The climate zone considered will be a tropical climate. A superficial study of the climate had been conducted so far, and more in-depth research will be done in the coming months. To have an idea of average temperature, daylight hours and timing of rainy seasons, Dodoma, the legislative capital of Tanzania and Lilongwe, the capital of Malawi were looked at. The two cities have a similar climate profiles. These cities were chosen are inland, which is where the focus will be placed. This is due to the fact that the coastal regions have a very different climate profile. The rainy season typically takes place from November to April inclusive.

According to this first look at the local climate, during the dry season, the average temperatures are 23-28°C during the day for both Dodoma and Lilongwe. See figure 4 of the Appendix. In contrast, nighttime temperatures can go as low as 7°C in Lilongwe and as low as 13°C in Dodoma. Another important parameter is the number of daylight hours during that time of year. The information was not available for Dodoma, yet the average sunlight hours for Lilongwe are 8 hours per day. Lastly, the relative humidity fluctuates from approximately 75-85% during the day and 40-55% at night. Ideally, the drying of the mangoes would take place during the dry season; however this is not always the case. Harvesting times vary with the breed of mango as well as climate. In general, they can be split into three categories: early, intermediate and late. An example of an early variety is the Baladi cultivar, intermediates include Alphonse and Zibdah and lates include Totapari Abusamaka. In some areas two harvest seasons occur, however, for the majority it is only one harvest. Harvesting times can vary from March to September depending on location and cultivar. One of the major obstacles in the design will be dealing with trying to dry the mangoes in the solar drying system when there are days of rain. This will be discussed further throughout this paper and in the following months. (El-Mardi and El-Awad 1989)

Economic Context

According to the United Nations, Tanzania, Rwanda, Uganda, Zambia, Malawi and Mozambique are all considered to be "Least Developed Countries" or LDCs. To be classified as an LCD the country must have a gross national income (GNI) of less than $745 per capita per year. Least Developed Countries represent the poorest portion of the global population. Weak economies and extreme poverty make it difficult to improve quality of life. Furthermore, many of the people living the in aforementioned countries are living on less than one dollar per day. The percentage of people living on less than a dollar per day varies by country, in Malawi it is 42%, in Mozambique it is 38%, in Tanzania it is 58% and in Zambia it is 76%. Also, the rates of undernourishment range from 30-50% of each country's population. Agriculture also represents a significant portion of the economy and a large percentage of the GDP; 35% in Malawi, 25% in Mozambique, 42% in Rwanda, 45% in Tanzania, 34% in Uganda, and 20% in Zambia. (The_United_Nations 2006)

For these reasons, our design must fit in with the economic situation of the area. The cost to build and maintain the solar dryer must be absolutely minimal.

International trade of mangoes is dominated by only a few of the varieties available worldwide. The local varieties of mango found in south eastern Africa generally have a stringy texture and are less desirable for consumers. In most of the design area, mango is produced at the subsistence level with very minimal crop management. Mango production consists of 99% local varieties. The other 1% is what is referred to as export varieties that would be suitable for foreign markets. Also, access to North American and European markets is shielded by strict standards and certification requirements (GLOBAL GAP, HACCP) and Ethical Trading Initiatives (ETI). These factors make exporting of mangoes from many African countries very difficult. The effort needed to change the economic framework in order to enable international trade of dried mango does not enter into the scope of our project. We will be focusing on providing a nutritious dried product for the local population and in hopes of decreasing the level of vitamin A deficiency. If a surplus of mango exists in one area, domestic trade is another possibility that could be investigated. The feasibility of domestic trade and trade with bordering countries depends on the infrastructure and transport systems available in the region of interest. Once again, this will not enter into the scope of our design. Our economic analysis will attempt to discern whether or not such a solar dryer would be an affordable asset for a small mango producer and what effect the implementation of such a technology would have on local market conditions(Tanzania Federation of Cooperatives 2003).

Source of Information

The three sources of information that will be used to determine all the design parameters needed are literature, experiment and calculations.

Much of the input date required will not be possible to determine ourselves by experiment means. We will thus take advantage of articles published in peer reviewed journals to determine essential information on climactic conditions, material properties and parameters of mango growing operations. Through research some design parameters have already been narrowed down to approximate values.

The average incident solar radiation for the region is 20MJ/m^2/day (El-Amin, Mohamed et al. 2005). The drying time will depend on daily sunshine hours. The range of daily sunshine hours during the harvest season is 8 to 10 hours per day. Please see Figure 4 in the Appendix. The number of days needed or the total drying time will be found based on the drying load and the amount of energy needed to remove the moisture up to the level of final moisture content. The inlet temperature of the collector is the average ambient temperature. The values for ambient temperature as well as relative humidity can be found in the climate section of this proposal. The average wind speed is approximately 2m/s(El-Amin, Mohamed et al. 2005).

There is more information needed from literature that has not been found so far. The drying load or capacity of the dryer is one example. This will depend on the capacity needed by the farmers. It is known that small farming operations are from three to five hectares in size(Tanzania Federation of Cooperatives 2003). However it is yet to be determined how much of that land would typically be used for mango production and how many trees would typically grow on that section. When this information becomes known the number of trees would be multiplied by 100-600 mangoes per tree to find the total capacity of the operation(El-Mardi and El-Awad 1989). Once this is known, the amount of fruit sold and consumed fresh needs to be taken into account before an idea of the amount to be dried to prevent spoilage can be formed. From literature we must also determine how long we have to dry the mangoes before they spoil. This is another factor that will influence the capacity needed for the dryer. In addition we need information about how long the dried product can be stored for. Furthermore, we will investigate the vitamin A losses during the drying process and find out how these can be minimized. Finally some material properties like the transmittance, absorbance and thermal conductivity of the chosen transparent material as well as all the thermal conductivity of the wood will be needed for calculations of efficiency and heat loss.

The second source of information is experimental. The experiment will focus on the properties of mangoes. The rough outline for the experiment follows.

Objective:

1) To ascertain the effect of different slices thicknesses, drying temperatures and drying times on final moisture content
2) To study the properties of different varieties of mango
3) To determine at which moisture content the water activity reaches 0.35
4) To obtain values for amount of mass and volume lost during drying process

Materials:

- 3-5 mangoes of different varieties
- Oven
- Drying trays
- Water activity meter
- Scale
- Ruler
- Slicer

Procedure:

Slice each mango into 3mm, 5mm, 7mm and 9mm slices using the slicer. Using a ruler cut 16 2cm by 2cm pieces of each thickness and variety. Weigh each slice on the scale and record the mass. Place the samples in the oven in pairs on labeled drying trays as the samples will be tested in duplicate. Dry the samples in the oven at two different temperatures and four different drying times. These times and temperatures will be decided upon based on calculations done and typical values from literature. Once drying is completed, re-weigh each sample and record the dry weight. Determine the water activity for each sample using the water activity meter. Also measure the approximate dimensions of each sample using a ruler. Once all measurements are taken, put all samples back in the oven for 24 h at 105°C and weigh again to obtain the dry weight.

Analysis:

Compare the quality attributes of the dried samples for the different varieties, thicknesses, drying times and drying temperatures. Compute the moisture content of each fresh and dried sample using the change in mass and the dry weight and compare for different treatments. Compare the water activities of all different categories and determine which samples have the required water activity to inhibit microbial degradation and biochemical activity over a long period. Determine which moisture content corresponds to the desired water activity of 0.35 (Adedeji 2008). Find the amount of shrinkage in mass and volume by comparing the initial and final masses and dimensions. Compare results to values from literature.

The results from the above experiment will be used to determine some of the design parameters like ideal slice thickness, initial moisture content and desired final moisture content of mango. We are aware that the drying kinetics for solar drying are not exactly the same as for oven drying. However, by using the same drying temperatures, drying times and slice thicknesses we get a very good idea of the desired properties of the final product.

The remaining parameters need to be calculated or found with the help of the psychometric chart in Figure 5 in the Appendix. These parameters are:

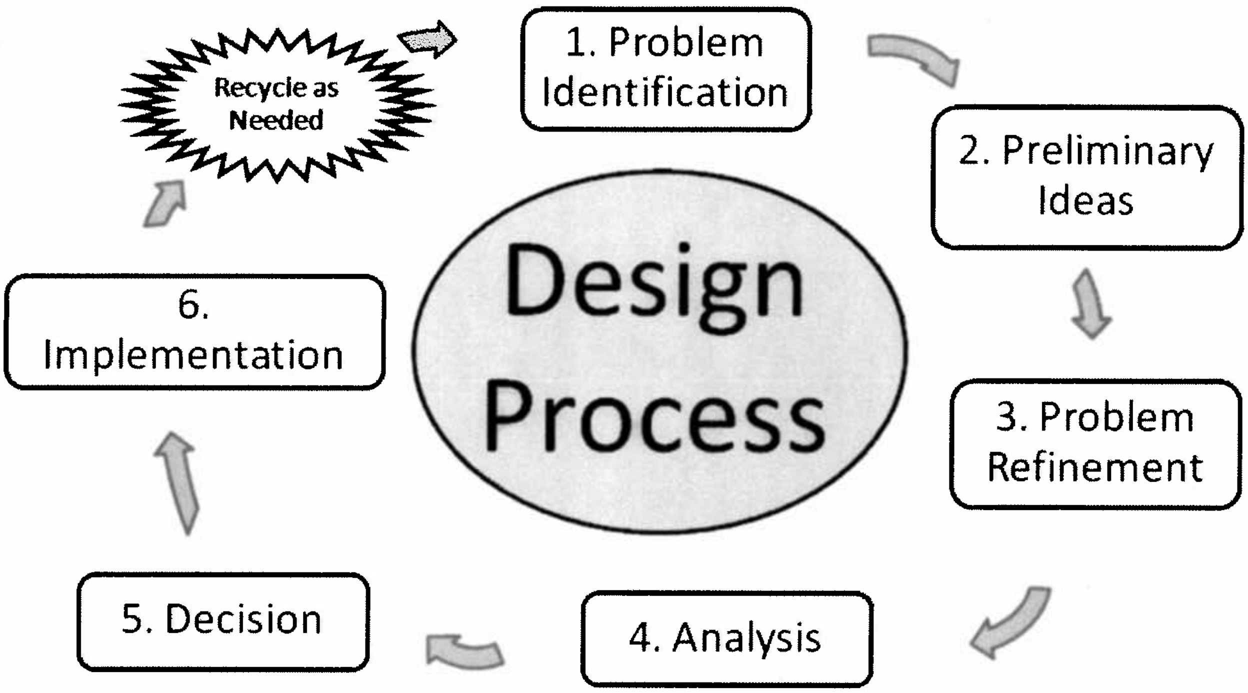
- Drying temperature
- Drying time
- Efficiency of collector
- Heat transfer rates
- Heat transfer coefficients
- Mass of water removed
- Energy needed to remove water
- Collector dimensions
- Drying Chamber dimensions
- Distance between trays
- Energy/heat losses
- Properties of air
  - Change in enthalpy
  - Change in density (air)
  - Change in pressure
  - Change in moisture ratio
  - Mass flow rate

The types of equations that will be used to calculate these parameters are heat transfer equations, dehydration equations and empirical correlations. Some fluid mechanics analysis will also be done to determine the flow characteristics. It is known that as flow changes from laminar to turbulent, the flow of exergy increases (Torres-Reyes, Navarrete-Gonzalez et al. 2002). Exergy is a property used to determine the useful work potential of a given amount of energy at some specified state(Google 2008).

Many of the unknown design parameters depend on each other so it may be necessary to make some initial assumptions and then verify at the end of the calculations whether the assumptions ~~were~~ are valid. Several iterations may be needed to make the assumed and calculated values equal each other. For example this kind of process could be used to find total drying time. As the design process progresses other design parameters may come into play and thus need to be considered at that time.

Design Approach

The design was approached using the 'seven steps of design' process. The seven steps can be represented as follows:



1. **Problem Identification**

The first step was to form a team. Working with others is an effective way to share the work load and also offer different insights to solving the problem. Once the team was complete, the first task was to brainstorm for possible topics for the project. The top three ideas under consideration were designing a water hammer pump, a constructed wetland, or a dryer for mangoes. The decision to design the dryer for mangoes in south eastern Africa was based on a number of factors. Firstly, the problem has a more defined socioeconomic context and the resources available to analyze the input data required, such as the food engineering lab on campus.

Once the topic was chosen, the background information was gathered and the literature review was started. It is crucial to collect as much information as possible on the problem before attempting to work on a solution. At this stage, the data was coming from journal articles and textbooks. The first statistics found were the rates of post harvest losses of fruits, including mangoes, in the region. For example one study claims that post-harvest fruit losses are as high as 30 to 40% in Uganda(Ndawula J. 2004). It was at this point that the high rates of vitamin A deficiency in the region also became significant. It was also at this time that we discovered that mangoes can be a good source of vitamin A. (Rankins, Sathe et al. 2008) This gave an added purpose for the dryer and another important parameter to consider in the design; the dryer would have to minimize the loss of vitamin A.

2. Preliminary Ideas

Once the problem was identified, it was time to come up with preliminary ideas for the design. It was at this point the decision was made that the dryer would run on solar energy. The decision to have a solar dryer was due to the fact that solar energy is free and renewable. Also, other forms of energy, such as electricity or fuel are not always available in the region of interest. Furthermore, according to the literature, solar dryers require as much lower capital investment as compared with dryers using a different energy source. (Akoy, Ismail et al. 2006) This was important bearing in mind the economic context of the project, since the dryer is to be used by low-income farmers. The different types of existing solar dryers were reviewed, such as tunnel dryers, tent dryers, cabinet dryers, etc. The types of dryers could be classified as direct or indirect and passive or active. In a direct solar dryer, the food product being dried receives direct solar radiation. In an indirect solar dryer, the solar energy is used to heat up the air for drying in a collector; however the food product is shielded from direct solar radiation by an opaque drying chamber. Both direct and indirect dryers can both be either passive or active. In a passive dryer the air circulates by natural convection. In an active dryer there is a fan included in the design to circulate air and giving rise to forced convection. (Ekechukwu and Norton 1999) Rough sketches of different possible dryers were made and there were brainstorms for new ideas or possible modifications to existing designs.

3. Problem Refinement

This is the current stage of the project; much information has been gathered and preliminary ideas have been listed. During the refinement stage, the first decision was to choose to design an indirect-passive dryer, see figure 6. This was based on the fact that vitamin A is light sensitive and therefore the mangoes should not receive direct sunlight. For the moment, it seems that a passive dryer will be more economically feasible. This will be part of the economic analysis to compare the added investment of a fan versus the gains in drying speed. Also, currently the cabinet type dryer is the proposed design; however other types are still possible such as a tunnel dryer. This will require further investigation and as the design process continues a final decision will be made on the style of dryer.

4. Analysis

As outlined above in the 'sources of information and input data required' the analysis will involve a number of aspects. There will be lab experiments with mangoes to determine properties and observe the drying kinetics. Data which is not possible to generate ourselves in the lab will have to be supplemented by what is found in literature. Once the data is gathered it will be time to perform the necessary calculations to complete the design. There may also be the possibility of generating computer models or simulations to aid in optimization of the design. The economic analysis will also be performed to ensure the costs of the project do not exceed the tight budget.

5. **Decision**

Once the analysis is complete, decisions must be made for the final design. The decisions will be based on the results from the analysis. Parameters, such as, the total size of the dryer, the exact dimensions, the maximum load input, the final moisture content desired, thickness of mango slices, the materials used, as well as others, will need to be decided upon.

6. **Implementation**

The implementation step will be where the whole design comes together. The final drawings are completed as well any models. Also, this is the stage when the final report is compiled and edited. The project is then presented to the department and the report is submitted. More details on the expected results are in the following section.

7. **Recycle**

There will surely be a need to repeat various steps of the design process. There maybe be a need to repeat the cycle for the different components of the design or as more information is made available. For instance, once the data for analysis becomes available, there may be a need to go back and re-evaluate the design.

Materials

The most basic materials that could be used for the construction of the dryer are local wood, black paint and a transparent material for the collector. Wood seems to be the best option for the drying chamber, the bottom of the collector and the frame of the structure because it is the most available, versatile and inexpensive building material. The black paint is needed for the inside of the collector to provide a high absorbance value of about 0.90 (Gbaha, Andoh et al. 2007). Glass or plexiglass would be the most durable transparent materials. If these are not available or are too expensive to make the dryer economically viable, then a transparent plastic film of polyethylene could also be used. Glass and polyethylene film both have similar average transmittance coefficients of γ=0.88 (Gbaha, Andoh et al. 2007). However, glass, being thicker would provide more insulation and thus keep heat in the collector better than polyethylene film. Other properties of these transparent materials will be considered and compared to find the most cost-efficient option. The material that will be used for the drying trays is still being reviewed. The trays could also be made of wood with slots to allow air to flow through. A second possibility is to make them out of plastic mesh in a wooden frame. The mesh would allow more air flow than the wood which is favorable to the drying process. The availability of plastic mesh might a limiting factor. A plastic or fabric gauze should be fitted to the collector inlet to prevent insects and other pests from entering the dryer. Another material that could be added is a removable steel screen to act as a heat absorber in the collector area in addition to the black paint(Madhlopa, Jones et al. 2002). Steel is quite expensive in the area of interest but could be added to the dryer after the farmer has already overcome the payback period for the dryer and started to make a profit. The final decision for all construction materials will be based on the availability of materials, the cost and the effectiveness in the design. We will try to find the ideal balance between these three important considerations.

While deciding on materials to be used, an emphasis will be put on safety and hygiene since the dryer will be in contact with food material. Therefore, any part of the dryer in direct contact with the food must be food safe and free of contaminants. If possible, it would be preferable to use recycled materials, which may also come at a lower price. Furthermore, since this is a project for the Bioresource Engineering Program, natural or biological materials will be considered when possible. For example, we will consider the possibility of using natural plant dyes rather than black paint for the collector.

Expected Results

The general expectation for the project is to design a solar dryer for mangoes to be used by small farmer in south-eastern Africa. More specifically, the dryer design must have a lower rate of vitamin A destruction as compared to sun drying. Also, it must be economically feasible for the region in which it would be implemented. The solar dryer must also be made from local materials and be simple to construct with locally available tools. The design needs to be an 'appropriate technology', (AT). This implies a "technology that is designed with special consideration to the environmental, ethical, cultural, social and economical aspects of the community it is intended for. With these goals in mind, AT typically requires fewer resources, is easier to maintain, has a lower overall cost and less of an impact on the environment compared to industrialized practices." (Village_Earth 2008)

The tangible output expected will include detailed drawings of solar dryer using CAD software. As well, blueprints and instructions for assembly of the unit would be desirable. Also, if possible a physical scale model would be useful, even if only for demonstration purposes.

Other factors to consider

Some issues, to be considered in the future, have come up during the preliminary design steps and literature review. For example, one thing to consider is the possible inclusion of a back-up system for days with insufficient sunlight, rain or over night when the sun is not shining. One option that has been studied is the inclusion of a biomass back-up heater. (Bena and Fuller 2002) It would need to be known if the burning of biomass would have an effect on the taste or quality of the final product. Also, the source of the biomass and availability will need to be considered. Perhaps most importantly, the capital cost of the biomass burning system will be the likely be determining factor on whether it is a practical technology for the design.

Another issue is what to do at night when the temperature lowers. The problem is that condensation can accumulate on the surface of the drying mangoes when the temperature falls below the dew point temperature. A possible solution would be to determine a way to store some of the energy during the day for use at night. In the literature it seems that dryers have been constructed that include a bed of rocks or gravel in the design to absorb heat during the day which can be used to keep the mangoes warm at night. At the same time, the vents need to be adjustable to slow the flow of air as to conserve the heat. There have also been dryers built with water as the energy storage. (Othman, Sopian et al. 2006)

Another option to be explored is the addition of a fan. This would change the dryer from a passive to an active drying system. The forced convection would increase the drying rate and lower the drying time. This would make it possible to process more mangoes in the same amount of time and possibly result in a higher quality final product. The difficulty is to determine the source of power for the fan. Perhaps the same biomass system could be used to power the fan and heat the air during the night. One method which had been done is to use a photovoltaic solar panel to power the fan. This option plausible since it is still only solar energy being used. However, the significant capital investment would make this option too expensive. Also, if the solar panel were damaged, it is likely that the user would not have the resources to repair it.

Lastly, although the dryer will be optimized for use with mangoes, it would be useful to review the possibility of using the system for other applications when the mangoes are not being harvested. For example, drying a different fruit or produce with similar drying characteristics as mango.

These and other future considerations reiterate the need for the solar dryer to be easily modified and upgraded by the user as more investment capital becomes available, rather than invest in a whole new dryer.

Cost of Project

Analysis

A cost benefit analysis is difficult to perform at this stage since not all costs are yet known. It is also difficult because not all of the benefits to be gained are in monetary form. Obvious costs are materials, travel, transport, and labour. What is known is that the dryer has stringent budget constraints since it is to be implemented in a low-income region of south-eastern Africa. The design will be limited by the cost; therefore some additions which could improve the function of the dryer may not be feasible. An example of this could be the addition of a back-up system for nighttime and bad weather, or a fan to circulate air. A comparison must be made of the added improvement versus the added capital investment of the extra components.

The key economic indicators for the economic analysis of the design include cost of maintenance, payback period and internal rate of return. (Othman, Sopian et al. 2006) Cost of maintenance should be minimal. Attention will be given during the design process to ensure the dryer is durable or easy to repair with what is available to the user should there be a need. On that note, the design will also include some flexibility so that if in the future the user would like to add to the design as more funds become available, it will be possible to do so. For example, the user may want to add a fan to increase the drying rate, therefore the design will have space for a fan even if it not part of the initial construction. Next, for the design to be economically feasible a short payback period is necessary. Payback period should also be compared with the expected design life of the dryer.

Benefits will be discussed in qualitative and quantitative terms. Qualitative Benefits refer to the quality of the finished product. When comparing with sun drying, the solar drying is a much cleaner, safer and more efficient process. It is cleaner because the goods are placed in a closed environment away from insects, birds and other animals. It is safer because insects carry diseases that can be transmitted through the ingestion of food that has been in contact with certain insects and bacteria. The process of solar drying is more efficient than sun drying because it takes less time to dry the produce, therefore a larger quantity can be dried in the same amount of time.

Special economic considerations need to be taken care of when a technological improvement is implemented in a developing country. The improvement increases the amount of produce in the market; therefore a shift in the supply curve will occur. When considering an elastic good such as mangoes, the supply curve will shift downward. An elastic good is a product for which slight changes in price create drastic changes in demand. This is the case with goods not considered necessities because people will not buy them unless the price is low enough. With an increase in produce, a decrease in price is expected. Both producers and consumers benefit as a result, since the producer has a higher quantity of goods for market, while the consumers will pay a lower price because of the boost in marketable goods(Caroline Dinwiddy 1996). An illustration is shown in Figure 7 in the Appendix.

To conclude the economic analysis of this proposal, it is believed the implementation of such a solar dryer is quite feasible if costs of materials are kept at a minimum. The benefits outweigh the costs by a large enough margin to allow the design of this project to proceed.

Travel

Travel will not be included in our costs because all experiments, research and calculations will be performed at Macdonald Campus. Since all three group members take courses at Macdonald Campus, this travel time will not be considered as part of the project.

Report

It would be ideal if the report were written as the project progresses, but usually this is not so and the final report will most probably be written at the end of next semester when all unknowns have been calculated and proper conclusions can be made. The report will be a comprehensive study and research document showing all literature reviews, assumptions, hypotheses, calculations, drawings and conclusions.

Consulting

Our consulting will most likely be with professors in the department. We expected approximate consulting hours to be 4. If we meet once per month for approximately one hour to ensure we are on schedule and on the right track.

Time Frame

Work Schedule

A timeline of our projected work schedule is described below:

Table 1: Time Schedule and Goals

January	➢ Complete literature review ➢ Finalize our proposed design, components and materials
February	➢ Have a preliminary CAD drawing completed ➢ specific details on materials used ➢ All costs of materials known
March	➢ Completion of a Cost Benefit Analysis in detail ➢ Commence the writing of the final report
April	➢ Complete Report and Present to the Department

Estimated Work Time per Step

It is easiest to split the hours worked into categories:

1. Research and Literature Review: 8 hours/week X 4 weeks = 32 hours
2. Work in the Food Lab: 3 hours/week X 2 weeks = 6 hours
3. Analyzing data and performing calculations: 6 hours/week X 6 weeks = 36 hours
4. CAD drawings: 6 hours/week X 3 weeks = 18 hours
5. Writing the Report: 6 hours/week X 2 weeks = 12 hours

A total of approximately **102 hours** will be spent on this research design project, excluding consultation hours.

Appendix

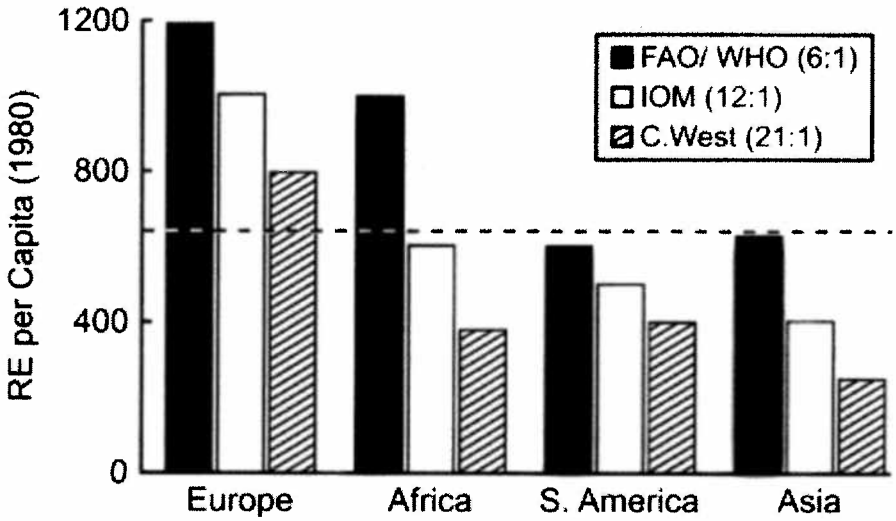


Figure 2: Vitamin A in Food Supply for Various Continents

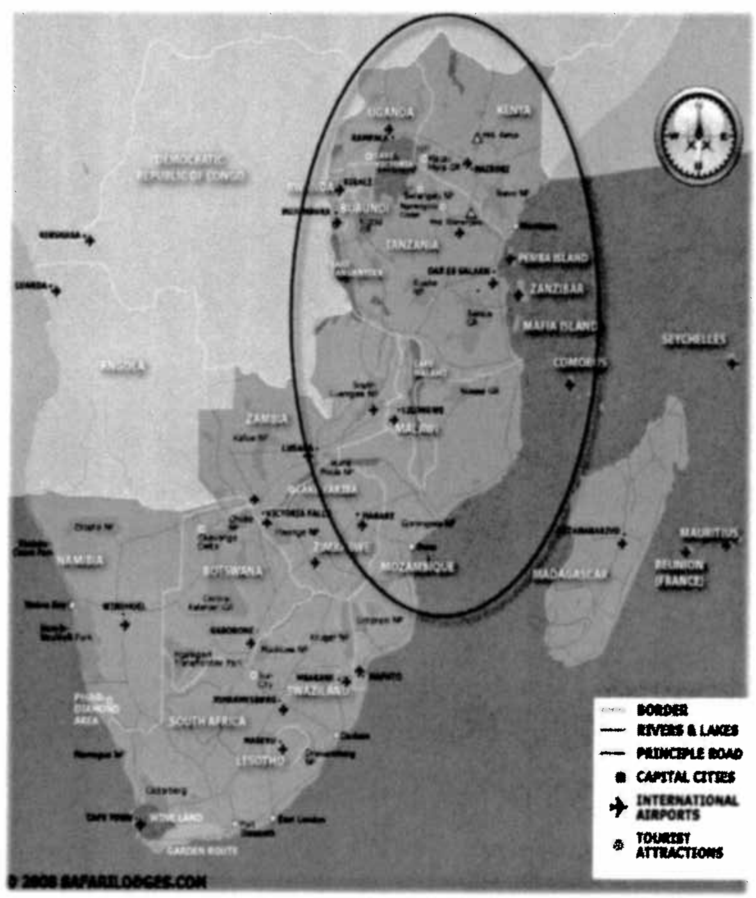


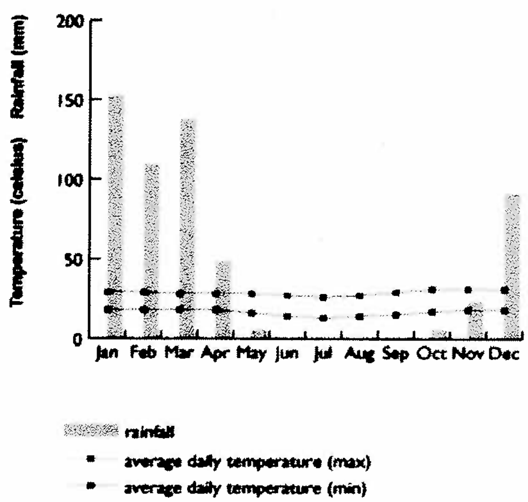
Figure 3: Map of South Eastern Africa

Average Conditions

Dodoma, Tanzania

Month	Average Sunlight (hours)	Temperature Average Min	Temperature Average Max	Temperature Record Min	Temperature Record Max	Discomfort from heat and humidity	Relative humidity am	Relative humidity pm	Average Precipitation (mm)	Wet Days (+0.25 mm)
Jan	-	18	29	16	35	Medium	80	52	152	12
Feb	-	18	29	13	36	Medium	83	53	109	9
March	-	18	28	15	34	Medium	84	56	137	11
April	-	18	28	15	33	Medium	82	54	48	7
May	-	16	28	11	33	Medium	76	49	5	2
June	-	14	27	9	32	Moderate	75	45	0	0.2
July	-	13	26	8	31	Moderate	74	43	0	0
Aug	-	14	27	9	34	Moderate	74	42	0	0
Sept	-	15	29	11	33	Medium	71	38	0	0
Oct	-	17	31	13	36	Medium	70	36	5	1
Nov	-	18	31	14	36	Medium	71	39	23	4
Dec	-	18	31	14	36	Medium	77	48	91	9

The following bar chart for **Dodoma, Tanzania** shows the years average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.

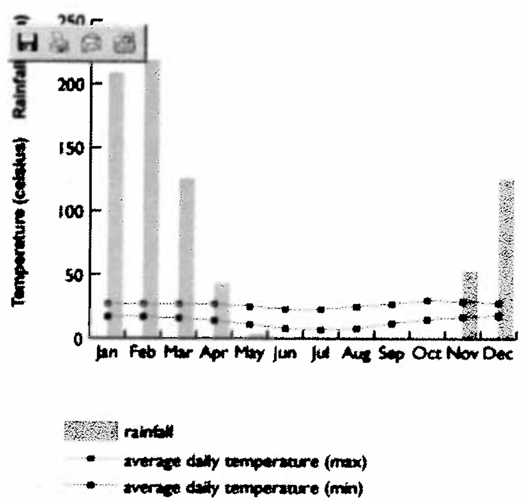


Average Conditions

Lilongwe, Malawi

Month	Average Sunlight (hours)	Temperature Average Min	Temperature Average Max	Temperature Record Min	Temperature Record Max	Discomfort from heat and humidity	Relative humidity am	Relative humidity pm	Average Precipitation (mm)	Wet Days (+0.25 mm)
Jan	5	17	27	13	32	Medium	85	64	208	19
Feb	5	17	27	12	31	Medium	89	66	218	18
March	6	16	27	11	32	Medium	86	60	125	13
April	8	14	27	10	30	Medium	84	50	43	5
May	8	11	25	4	30	Moderate	82	41	3	1
June	8	8	23	2	28	-	79	38	0	0.1
July	8	7	23	-1	28	-	77	33	0	0.1
Aug	8	8	25	-1	31	-	68	31	0	1
Sept	9	12	27	4	32	Moderate	55	30	0	0.6
Oct	10	15	30	9	34	Medium	50	28	0	1
Nov	7	17	29	12	34	Medium	60	42	53	7
Dec	5	18	28	13	33	Medium	76	58	125	15

The following bar chart for **Lilongwe, Malawi** shows the years average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.



http://www.bbc.co.uk/weather/world/city_guides/results.shtml?tt=TT000680

http://www.bbc.co.uk/weather/world/city_guides/results.shtml?tt=TT000360

Figure 4: Comparing Temperatures between the two Capital Cities in Malawi and Tanzania

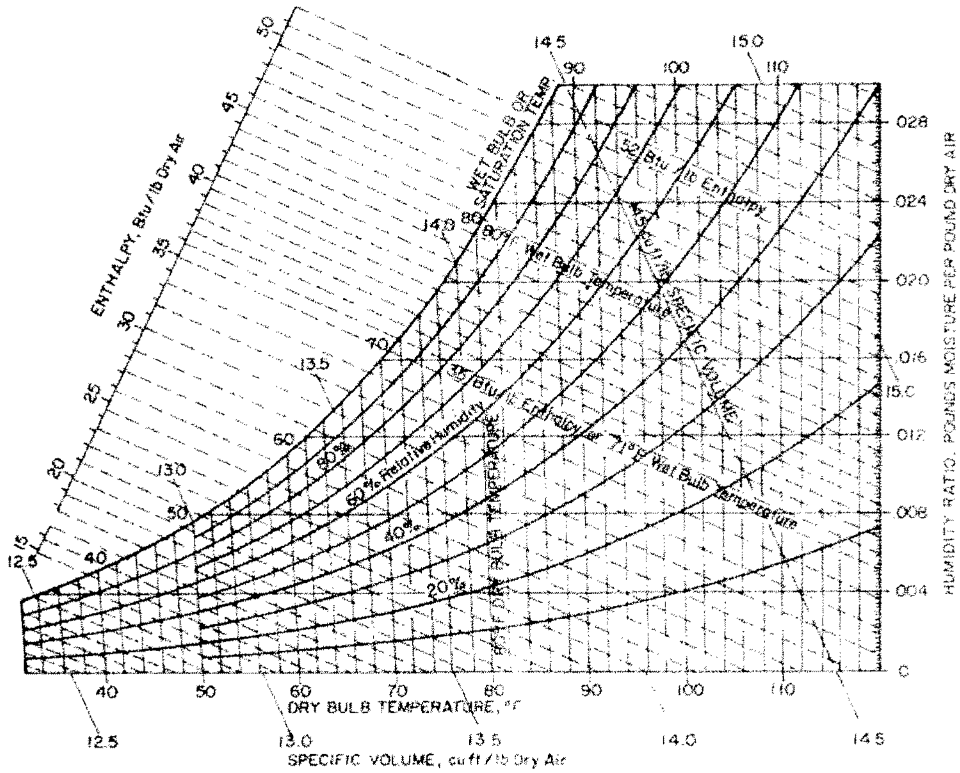


Figure 5: Psychometric Chart

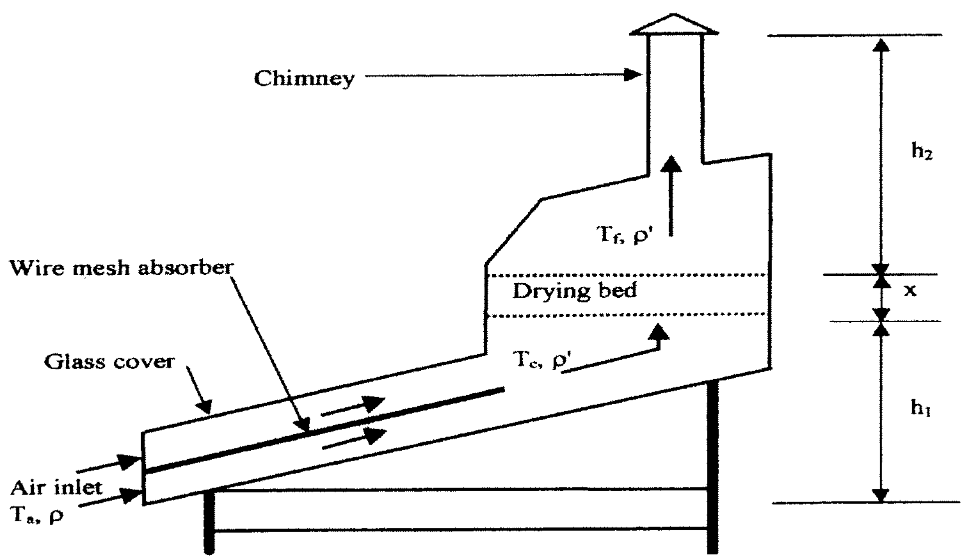


Figure 6: Schematic of an Indirect Passive Solar Dryer

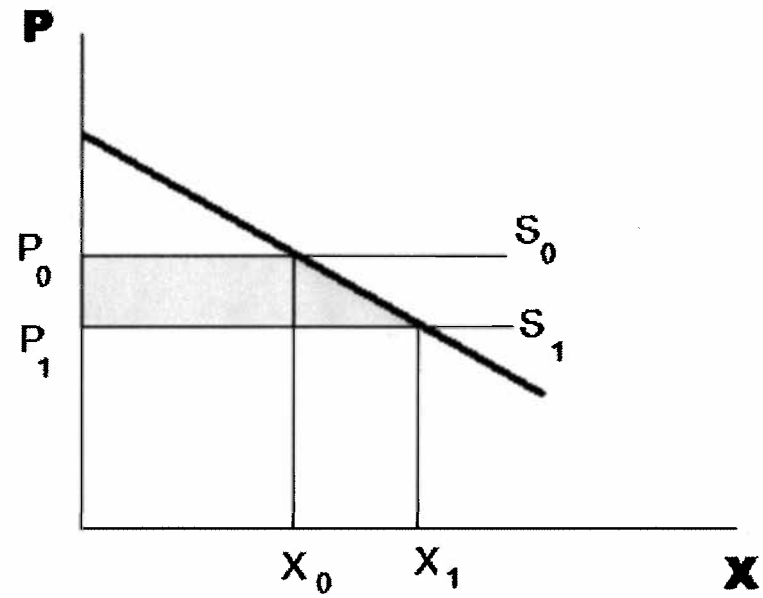


Figure 7: Graph showing decrease in price due to an increase in supply

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