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How to cite this thesis
Human Centred Design of an off-grid food processing system for micro-enterprises within Johannesburg.

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“Breaking cultural and economic dependence is a bold and decisive step in the development of the motherland. But building the new life and the new society requires a new human, a new will, a new responsibility and for this we have to prepare ourselves.”

ABSTRACT

This document describes the process conducted to develop an off-grid food processing system reliant on solar energy for micro-enterprises in Johannesburg, South Africa, following the Human Centred Design process. Around 20% of South African households do not have enough food available to meet their daily dietary requirements, while food processing and preserving allows for it to be available during dry seasons. Furthermore, this decreases post-harvest crop losses. Food processing relies heavily on energy consumption, mainly due to heating the food or the boiling of water to sterilise bottles or jars. Energy is often expensive, unreliable and sometimes unavailable. This research project was conducted in four phases, with the collaboration of three micro-food-processor enterprises as well experts in the field of renewable energy. The four phases consisted of problem identification, followed by concept generation including sketches and prototypes. In the third phase laboratory prototype testing was undertaken which was followed by the last phase, being participant testing. During the first phase, a literature review was conducted to understand the principles and methods to preserve food and the energy requirements of the machinery used to process food in micro-enterprises; recognising that the solar energy is a viable source of renewable energy in Johannesburg. With this background, field research was conducted with three micro enterprises that preserve and process raw ingredients into Chilli Sauce, Body Soap and Ginger Beer. During the visits the step by step process was observed, the machinery used and their energy requirements were noted. The need for a stove, a kettle and a blender were identified as the main machinery required in the process. Based on the requirements of energy identified for these machines, the second phase consisted of the conceptualisation of the three appliances named as: Heliotropic Solar Stove, a Solar Thermosiphon Water Heater and a Photovoltaic Food Processor Workstation, with a prototype for each machine being developed. During the third phase the prototypes were tested in a laboratory setting, evaluating how effectively they performed the required activities. Finally, the fourth phase consisted of the testing of the prototypes in the field, with the participants of the study preparing their products and receiving feedback during the sessions. This allowed for final improvements of the prototypes to be considered in a final design outcome.
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<tbody>
<tr>
<td>HCD</td>
<td>Human Centred Design</td>
</tr>
<tr>
<td>SMMEs</td>
<td>Small, Medium and Micro Enterprises</td>
</tr>
<tr>
<td>BC</td>
<td>Before Common Era</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agricultural Organisation of the United Nations</td>
</tr>
<tr>
<td>SWH</td>
<td>solar water heater</td>
</tr>
<tr>
<td>PMMA</td>
<td>Polymethyl-methacrylate</td>
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<tr>
<td>PV cell</td>
<td>photovoltaic cell</td>
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<tr>
<td>N-type layer</td>
<td>Negative type layer</td>
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<tr>
<td>P-type layer</td>
<td>Positive type layer</td>
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<tr>
<td>AC</td>
<td>Alternating current</td>
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<tr>
<td>DC</td>
<td>Direct current</td>
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<tr>
<td>RE</td>
<td>Renewable energy</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<tr>
<td>UV</td>
<td>Ultra Violet</td>
</tr>
<tr>
<td>LDR</td>
<td>Light Dependent Resistor</td>
</tr>
<tr>
<td>R</td>
<td>South African Rand</td>
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<tr>
<td>3D</td>
<td>Three Dimension</td>
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<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
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<tr>
<td>CO2</td>
<td>Carbon Dioxide</td>
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<tr>
<td>GTZ</td>
<td>German Organisation for Technical Cooperation</td>
</tr>
<tr>
<td>P1</td>
<td>Participant one</td>
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<tr>
<td>OSE</td>
<td>Open Source Ecology</td>
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CHAPTER ONE: INTRODUCTION

1.1. Context

The South African government as well as Non-Government Organisations, have encouraged the cultivation of crops for small scale farmers in order to reduce food insecurity in the country (Department of Agriculture, Forestry and Fisheries 2011:72; World Wide Fund for Nature 2017:9). Other ways of increasing food security include the processing of raw food, preventing it from spoiling and making it available during off seasons when the food is scarce or unavailable (Sethi 2007:7). To facilitate this work on the farms and increase productivity, tools and machinery are used to process the food. These machines rely on an energy supply for operation, which is generally powered through fossil fuels or electricity generated from fossil fuels (Szeląg-Sikora Cupiał & Niemiec 2015:97). This is increasingly expensive, detrimental to the environment, and sometimes difficult to access in remote locations (Riddell, Ronson, Counts, Spenser [sa]:[sp]).

For its part, the advancement of renewable energies has seen growth for the past four decades resulting in more energy that is clean, sustainable and constantly becoming more economical through technological improvements (Farmer & Lafond 2016:648). However, the use of renewable energy requires a change of paradigm of how people utilise the energy since its use is dependent on geographical location and availability (Ruiz-Mercado, Masera, Zamora, & Smith 2011:7559).

An estimated 20% of South African households have inadequate or severely inadequate food access to meet their daily dietary requirements (Statistics South Africa 2010:6). To ensure the availability of food during dry seasons and to decrease the crop losses, food preservation is useful. Micro-enterprises¹ that process food rely heavily on energy consumption from fossil fuels, which are expensive, create pollutants, are unreliable and unavailable in many areas across South Africa (Department of Environmental Affairs 2012:240-241). This results in a dependence on

¹ According to the Department of Trade and Industry of South Africa, micro-enterprises are conformed for one to five employees, usually the owner and family (Department of Trade and Industry of South Africa 1996:15).
non-renewable fossil fuels, which are not sustainable and damaging to the environment. The increase of food security, reduction of crop losses and the addition of economic and cultural value to the food can be undertaken through the designing of a food processing appliance, powered by renewable energy. This allows for the sustainable processing of food without the reliance on non-renewable fossil fuels.

1.2. Objectives of the study

- To understand the patterns of different activities around food processing in order to identify problems, risks and opportunities.
- To identify the tasks during food processing which demand high energy usage.
- To identify the most suitable renewable energy within Johannesburg that can power the intended solution.
- To develop an appropriate food processing appliance system powered by renewable energy, satisfying the needs of identified micro enterprises. This is to be undertaken with the involvement of identified participating micro enterprises within Johannesburg.
- To present and discuss with the participants of the study the appliances powered by renewable energies and integrate their comments into the final design.
- To test and assess the technical performance and usability of the appliances in a laboratory setting and then with the participating micro enterprises.
- To document the process developed during the study and present it in a dissertation format.

1.3. Outcomes

The outcomes from this research are:

- A food processing appliance, powered by renewable energy.
- A dissertation and document that shows the process of the developed appliance.
- A journal article ready for publication.
1.4. Project description

The project was undertaken in four phases, each involving the participants' practices, comments and suggestions. The first phase involved situational assessment and the gathering of primary data by means of user observations, video recording, photography and semi structured interviews, as well secondary data from literature. In the second phase, the data was analysed and a concept for the project was proposed, developing it through sketches, mock-ups and finally a prototype. For the third part the technical performance of the prototype was assessed in a laboratory setting. During the fourth phase the final product was presented to the participants, allowing for final improvements to be considered. Finally, the project was documented.
CHAPTER TWO: RESEARCH METHODOLOGY

2.1. Research Paradigm

This research project is determined by the constructivist paradigm, also known as interpretivism. This paradigm is based on the holistic understanding of the subject of study and the importance of the context to interpret the findings (Shkedi 2005:13). The research is based on the interpretation of qualitative data, which is a way to better understand human beings by watching, talking and listening to them in their own environment. Taking into account that different people have different perspectives of a given situation and the researcher’s own experiences, beliefs and values are also incorporated into the research design and the data analysis (Ibid 2005:7), the collection and interpretation of data is subjective. The emphasis is therefore on the socially constructed nature of reality (Willis 2007:160; Patton 2002: 99). In a constructivist approach, the participants are included because it is their meaning and constructed reality that the research is attempting to understand (Willis 2007:162).

Inasmuch as the research paradigm encourages the involvement of the participants of the study, Human Centred Design (HCD) is the central methodology which leads this project and situates the intended users at the centre of the study. The purpose is to gain an understanding of the users’ behaviour whilst they are undertaking daily activities in a close relation between the design-researcher and the participants.

Human Centred Design

Human Centred Design is a methodology where the design-researcher learns from potential users about the product that is to be developed, in order to understand the users’ practices, needs and preferences (Steen 2011:1). The term HCD has its origins in the 1980s in the area of human-computer interaction (Kahraman 2010: 2071), from whence it has migrated to different design practices. Tools such as interviews and focus groups are used during the design process enabling users to interact with sketches, mockups and prototypes until the final product is developed. The role of the design-researcher is to engage with the participants to create appropriate design solutions, with the objective of facilitating the tasks of the users and to ensure that the product is able to be used as intended (Abras, Maloney-Krichmar & Preece 2004:2).
2.2. Sample Groups

Three micro-enterprise food processors, who sell their products in local markets around Johannesburg at Locrate Market in Soweto, Market on Main in Maboneng Precinct and Neighbourgoods Market in Braamfontein, agreed to participate in the study. The researcher visited the places where the participants conduct their food processing in order to become familiar with the associated operations. This allowed the researcher to observe opportunities for energy use optimisation and attempt to gauge participants’ willingness to adopt new technologies. Furthermore, experts in the field of renewable energy and food processing were approached to advise and provide feedback throughout the project. Finally, a personal journey of building prototypes and cooking with solar cookers was held to better understand the function through experience.
2.3. Research process

The research process was separated into four phases, where each phase used a specific data collection strategy, analysis and outcomes as described in Figure 1. The four phases of the overall project include the Phase 1: Problem identification, separated into Phase 1A: Literature Review and Phase 1B: Field Research. Followed by, the design development of an appropriate solution presented in Phase 2: Concept, sketches and prototype. Phase 3: Laboratory prototype testing, allowing for the on-field test of these prototypes with the participants in the Phase 4: Participants Testing.

![Figure 1: Project steps (Diagram by the author).]
2.3.1. Phase 1A: Literature review
During the first phase, extensive secondary data gathering was undertaken from literature in fields including: food processing, energy use during this process, renewable energy, off-grid solutions and the adoption of new technologies. This guided the primary data gathering, which involved the input from the participants identified from the above mentioned Johannesburg food markets.

2.3.2. Phase 1B: Field research
Participatory observation was utilised in order to understand the step by step of the participants during the process. The observation was recorded in video and notes were taken. The observations provided insight into the activities of the process, the energy needs, the tools and machinery used and the participant’s personal perspective (Patton 2002:262; Krippendorff 2006:225). To conduct the observations, the following topics were analysed, with data gathering forms attached to the specified annexures:

- Activities during the production process (annexure II): A “Process Flow Sheet”, was used to document the sequence of the activities. A video was recorded and edited (Marín 2017:A) (Marín 2017:B) (Marín 2017:C) to facilitate the analysis and to identify the machinery and tools utilised during the production (Wang 2008:49).

- Energy audit during the food process (annexure II): An energy audit is a system used to keep track of the energy consumption and costs throughout a process. It was utilised to determine how and where energy is used, identify opportunities to reduce energy usage, estimate the cost of the production and with this data, identify the energy requirements to design an appliance powered with renewable energy (Wang 2008:45).

- Workplace layout (annexure III): A description of the workplace and a diagram of the layout was developed, with the dimensions of the facilities and the location of the machines and tools used; registering the participants’ displacements during the activity.
Semi-structured interview (annexure IV): To collect primary data a semi-structured interview was held, allowing the researcher to enter into the participant’s personal perspective, exploring issues that could not be observed during the process (Patton 2002:262). The interview was audio recorded and notes taken to facilitate the analysis, discovering patterns and discrepancies between the participants (Patton 2002:453).

These observations were summarised through inductive analysis, and pattern trends and similarities of each participant were identified through the process, emphasising the researcher’s immersion in the data (Patton 2002:453-454). Problems were highlighted and with these findings the researcher was able to develop the design requirements related to usability, functional, technical, economic, and aesthetic aspects. The results of this inductive analysis were finalised with the design brief.

2.3.3. Phase 2: Concepts, sketches and prototypes

The second phase started with the design brief, guiding a brainstorming session undertaken by the designer and informed by the findings of the first phase (Vilchis 1998:105). The methodology followed during Phase 2 is a combination of methods and comprises four steps: Design concept, mood board, form development and prototypes, encouraging the use of recycled materials or those locally purchased. Several concepts, mood boards, sketches and mockups were developed, as well as the comparison between the feasibility of the proposals conducted, taking into account technical, functional, economic, formal, environmental, ergonomic and aesthetic aspects identified in the first phase.
2.3.4. Phase 3: Laboratory prototype testing

In the third phase a laboratory test was held. The purpose of the laboratory test protocol (annexure VI) is to test and evaluate the energy performance of the prototypes guiding further optimisation of the prototype.

2.3.5. Phase 4: Participants testing

During the fourth phase, the final product was refined and presented to the participants to demonstrate that they can use the artefacts in their activities, as an alternative to their regular processing system. During an unstructured interview all relevant ideas, observations or complaints were registered through video, photographs and written notes (Krippendorff 2006:224). A protocol analysis was used to understand and compare what the people said and what they did. Users were asked to ‘think aloud’ while performing a task; observing what the users said about their interaction with the artefact (2006:226). The perspectives and views of the participants were analysed for further improvements to the prototypes. Finally, all content, process and findings are presented in this dissertation document.

2.3.6. Project timeline breakdown

The following table shows the schedule during the development of the project:

Table 1: Schedule during the development of the project

<table>
<thead>
<tr>
<th>Phase 1: Problem identification</th>
<th>March 2016 – December 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Phase 1A: Literature review</td>
<td></td>
</tr>
<tr>
<td>- Phase 1B: Field research</td>
<td></td>
</tr>
<tr>
<td>Phase 2: Concepts, sketches and prototypes</td>
<td>January 2016 – May 2017</td>
</tr>
<tr>
<td>Phase 3: Laboratory test</td>
<td>June 2017 – August 2017</td>
</tr>
<tr>
<td>Phase 4: Participants testing, final product and dissertation document</td>
<td>September 2017 – November 2017</td>
</tr>
</tbody>
</table>
2.4. Ethical considerations

2.4.1. Participants
The participants who participated in this study were asked to sign the informed consent form (annexure I) in order to follow the ethical regulations of the University of Johannesburg. The study was completely voluntary, and participants could withdraw at any point. Participants were not rewarded for participating in the study. All participants were over 18 and were to be experienced in food processing tasks.

2.4.2. Prototype testing
When users interacted with the prototypes that created heat, they were supplied with suitable protection wear. When users did not feel comfortable during the testing of prototypes, they provided their opinions without necessarily engaging with the prototypes. Nevertheless, the participants were able to withdraw at any time.

2.4.3. Cost to participants
This study deals with food processing, therefore some of the food was supplied by the researcher for testing. The free time of the participants was required to follow their food processing activities, and for the focus group.

2.4.4. Intellectual property
The intellectual property of the project is in accordance with the University of Johannesburg’s policy on the protection, management and commercial exploitation of intellectual property (University of Johannesburg 2017:[sp]).
CHAPTER THREE: DESIGN PROCESS

3.1. PHASE 1A: LITERATURE REVIEW

This chapter presents an overview of literature associated with micro-enterprises that process food and the importance and benefits thereof to consumers, with particular relevance to the South African context. A description of the principles and methods on how food can be preserved is given, identifying the machinery needed during the process and the energy needed to power those machines, mostly heat to cook. The availability of renewable energy resources in South Africa is presented, where solar is identified as the most available source of renewable energy in Gauteng. The heat required to cook food can be harvested from the sun; how much energy can be accumulated during the day depends on the time and the position of the earth towards the sun. An explanation of the solar movement during the day and year is presented and to understand how solar energy can be used to heat. The functional principles of different technologies that take advantage of the thermal energy of the sun are described, presenting available products, their advantages and disadvantages. Lastly, the challenges of the adoption of new technologies, with an emphasis on the ones powered with renewable energy are discussed.

3.1.1. Small, Medium and Micro Enterprises (SMMEs)

In South Africa, the SMMEs play an important role in the country’s economy, as drivers of economic growth, innovation and job creation (Bureau for Economic Research 2016:5). The categorisation of the scale of an enterprise is considered by the number of employees, the volume of sales, the value of the assets and/or the use of energy (Imani Development 2000:[sp]). The Department of Trade and Industry of South Africa (1996:2), defines a small business as an entity managed by one or more owner and which can be further classified as a micro, very small, small or medium enterprise. This definition differs among sectors and sub-sectors of the economy; both the agricultural and manufacturing sectors are shown in Table 2: Definition of business size (Department of Trade and Industry of South Africa 1996:15),, where it can be seen that micro enterprises have a maximum of five employees, usually the owner and family as the workers.
Table 2: Definition of business size (Department of Trade and Industry of South Africa 1996:15).

<table>
<thead>
<tr>
<th>Sector or sub-sectors in accordance with the Standard Industrial Classification</th>
<th>Size or class</th>
<th>Total full-time equivalent of paid employees Less than:</th>
<th>Total annual turnover Less than:</th>
<th>Total gross asset value (fixed property excluded) Less than:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Medium</td>
<td>100</td>
<td>R 4.00 m</td>
<td>R 4.00 m</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>50</td>
<td>R 2.00 m</td>
<td>R 2.00 m</td>
</tr>
<tr>
<td></td>
<td>Very small</td>
<td>10</td>
<td>R 0.40 m</td>
<td>R 0.40 m</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>5</td>
<td>R 0.15 m</td>
<td>R 0.10 m</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Medium</td>
<td>200</td>
<td>R 40.00 m</td>
<td>R 15.00 m</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>50</td>
<td>R 10.00 m</td>
<td>R 3.75 m</td>
</tr>
<tr>
<td></td>
<td>Very small</td>
<td>20</td>
<td>R 4.00 m</td>
<td>R 1.50 m</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>5</td>
<td>R 0.15 m</td>
<td>R 0.10 m</td>
</tr>
</tbody>
</table>

According to the Bureau for Economic Research (2016:10), the majority of micro-enterprises survive for an average of less than 3.5 years. One of the key impediments to growth is the lack of access to infrastructure, access to communication/markets, equipment and transport, and cost-effective sources of energy, which is a significant cost of the business (Bureau for Economic Research 2016:7). If micro-enterprises had better access, for example, to appropriated equipment for their activities and cheaper and more efficient sources of energy, they might be able to survive longer and ensure a sustainable income. To contribute to the sustainable development of the food processing micro-enterprises, this study is focused on the design of suitable equipment that is powered by renewable energy.

3.1.2. Food processing and preservation

3.1.2.1. Importance of food preservation

Food processing can be described as a series of activities conducted to process, convert, prepare, package and preserve raw food; including fruits, vegetables, root and tuber crops, spices, mushrooms, honey, floriculture, medicinal and aromatic plants, nuts, fish and meat (International Labour Organization 2011: [sp]). Food preservation refers to the activities taken to stop or greatly slow down the spoilage of the food, maintaining the nutritional value and flavour qualities and increasing the shelf life (Sethi 2007:3).
Food preservation originated in the Palaeolithic era about 15 000 BC, when humans discovered a way of preserving food by smoking it (International Labour Organization 2011; Sisson 2012) making it available for periods of scarcity. Later developments in food preservation were steaming, fermenting, sun drying and salting (Mescher 2016:1). Thereafter, food preservation methods were developed where food was stored in sealed glass jars and metal cans, prolonging its shelf life for a much longer time, maintaining the food that was preserved without spoilage (Sethi 2007:4; St. Rosemary Educational Institution 2016; Mescher 2016:3).

The importance of preserving food is detailed below and can be summarised in three main aspects: to increase food security, adding value to food and reducing food losses:

- Increasing food security: Making food available during the off season increases food security. Food security is defined by the Food and Agricultural Organisation of the United Nations (FAO) (2010:8) as “…when people, at all times, have access to safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”. Usually during mango season there is a huge surplus, thus if not preserved the mangoes may spoil. To dry the mangoes or prepare mango jam is a way to preserve them, allowing it to be stored and the preserved product available during off season.

- Adding value to food: Processing raw ingredients increases the value of the food. It adds culture, authenticity and sustainability, which increase economic returns (Dare, Jönsson & Knutsson 2013:670; The World Bank. 2011:27). To sell dry tomatoes is a clear example of how to increase the value and the price of a raw food.

- Reducing food losses: Vegetables and meat are liable to spoil and are irregular in their supply; preservation helps to overcome this (Mescher 2016:1). According to FAO, globally, roughly one-third of food produced for human consumption is lost or wasted (Gustavsson, Cederberg & Sonesson
The Department of Agriculture, Forestry and Fisheries (2016) informs that in 2014 the loses for roots and tubers were at 10-40%, fruits and vegetables at 15-44% and fish and sea food at 10-40%. Preservation of these type of products helps to dramatically reduce the food losses.

To understand the technical requirements of preserving food, the principles and methods are described and the machinery needed and its energy inputs explained.

3.1.2.2. Principles and methods to preserve food

The causes of food spoilage are microbiological (bacteria, yeasts and moulds), chemical (enzymatic discolouration, rancidity, oxidation) and physical (bruising) factors (Sethi 2007:3). To prevent spoilage, food preservation can be divided into two categories, bacteriostatic and bactericidal. The bacteriostatic process is where microorganisms are unable to grow in the food because of the alteration of environmental conditions (dehydration, pickling, salting, smoking or freezing), and the bactericidal process is when most of the microorganisms present in the food are killed (pasteurisation, canning, cooking or irradiation) (Sethi 2007:4; Wang 2008:3-22; International Labour Organization 2011:4).

In accordance with this, the methods of food preservation can be divided into physical, chemical, and biological means, presented in Figure 2. Physical preservation includes blanching, pasteurisation, sterilisation and drying; chemical preservation involves adding sugar, pickling with either salt and/or vinegar, or adding chemical additives, such as preservatives such as antioxidants (classified as Class I, natural chemicals and Class II, synthetic chemicals); and biological preservation which involves alcoholic or acidic fermentation by natural and artificial acidification (Sethi 2007:3).
Physical preservation relies mostly on heat as energy input, as this is the method that uses more energy in food preservation. The availability and cost of the energy is one of the major considerations when selecting a method to process food, while the energy required can vary depending on the cooking methods used, and the machines involved to transfer the heat by means of conduction, convection and radiation into or out of foods (Bastin 2011:1). Cooking alters and improves the eating quality of food and more importantly, it inactivates or destroys enzyme and microbiological elements through pasteurisation, which extends shelf life (Sethi 2007:5). In order to propose an alternative energy input, this project focuses on physical food preservation, through thermal treatment by a renewable source of energy.

3.1.2.3. Machines and energy requirements used during food preservation

Food processing involves a series of operations where machinery and tools are used depending on the kind of physical preservation process being followed during cooking, sterilisation or drying. An example of this is illustrated in Figure 3, which shows the steps to preserve food, from harvesting through to storage. Three of the activities that
require heat for processing are indicated in the red dotted rectangles, in this case blanching, preheating and sterilisation. Furthermore, different types of food have different energy requirements based on their processing methods.

Figure 3: Activities to process food and it energy needs (Food and Agricultural Organisation of the United Nations [sa]).

The equipment or machinery used during the most common activities to process food is summarised in Table 3. Blanching, cooking, evaporation and pasteurisation are the activities which have the highest energy demands, highlighted with a red rectangle.

Table 3: Activities and equipment used during the food processing activities (Sethi 2007:33). Adapted by the author.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material preparation</td>
<td>Washing machines, peeling machines, cutting machines, preparation tables</td>
</tr>
<tr>
<td>Preparation of pulp / juice extraction</td>
<td>Continuous simple crusher, continuous extractor, hydraulic press</td>
</tr>
<tr>
<td>Blanching / cooking / concentration / evaporation</td>
<td>Cooking kettle, steam jacketed pans, large stainless steel tank, steam generator, double bottom tank for scalding / blanching</td>
</tr>
<tr>
<td>Pasteurization / deaeration</td>
<td>Pasteurizer, horizontal steriliser, steam heated processing retort, plate heat exchanger</td>
</tr>
<tr>
<td>Drying / dehydration</td>
<td>Cabinet dryers, SO₂ generator / chamber, sulphuring box, solar dryer, tunnel dryer, drum dryer, spray dryer, freeze dryer</td>
</tr>
<tr>
<td>Packing machines</td>
<td>Pouch filler, bottle filling machines, seaming machine, pouch sealing machine, crown</td>
</tr>
<tr>
<td>Canned products</td>
<td>Can reformer, flanger, exhausting tunnel, water sprays, vacuum gauge, retorts, seam testing machines,</td>
</tr>
<tr>
<td>Miscellaneous equipment</td>
<td>Storage tank, mixing tank, hot plate, weighing machine, boilers, exhausts, fans, blowers, weighing scale, filter cloth, bottles, jars, cans</td>
</tr>
</tbody>
</table>
The machinery used during food processing differs between activities (Table 3), and is mostly used to produce heat to cook or to boil water. The main sources of energy for such machines are, electricity, wood or gas (Adams & Herman-Milmoe 2001:247). Different fuels have advantages and limitations in terms of cost, safety, risk of contamination of the food, flexibility of use and availability (Fellows 2009:354). Table 4 shows the energy use in kWh for an electric oven and a gas oven (Citizens Campaign for the Environment 2003:[sp]).

**Table 4: Comparison of energy use between electric and gas stove. Adapted by the author.**

<table>
<thead>
<tr>
<th>TYPE OF OVEN</th>
<th>TEMPERATURE °[C] (CELSIUS DEGREES)</th>
<th>TIME (HR.)</th>
<th>ENERGY USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRIC OVEN</td>
<td>176</td>
<td>1 hr.</td>
<td>2.0 [kWh]</td>
</tr>
<tr>
<td>GAS OVEN</td>
<td>176</td>
<td>1 hr.</td>
<td>3.2 [kWh]</td>
</tr>
</tbody>
</table>

During cooking, approximately 25% of the heat is used to bring food to boiling temperature, 35% in vaporisation and 45% of the heat is lost from the utensils or the pot. A stove with multiple power levels, adequate insulation and the use of a lid reduce heat losses (Muthusivagami, Velraj, Sethumadhavan 2009:693).

The energetic flow while cooking can be summarised in three stages: The type of fuel input (electricity, petrol, gas or charcoal); the heat transfer equipment (usually a gas or electric stove) that transforms the fuel or electricity to heat; and the container in which the food is cooked (pan or pots).

### 3.1.3. Renewable Energy availability in South Africa

Wood, coal and paraffin -fossil fuels derived from petroleum-, were formed over millions of years from the decomposition of carbon-based plants and animals, making it impossible to renew these fossil fuels over the course of a reasonable time frame (Worldatlas 2016:[sp]; Project H Design 2015:7). Burning fossil fuels produces high levels of carbon dioxide (CO2) which is a major cause of global warming (NASA 2008:[sp]), moreover, the extraction and transportation of these fuels is environmentally risky and increasingly costly. However, the advantages of these types of energy sources are that they are portable, possess a high concentrated energy
potential and there is already an established industry and infrastructure to use them (BBC 2016:[sp]; Global Energy Assessment 2012:909). During the 20th century humans became highly dependent on fossil fuels in almost every aspect of daily life; for transport, to cook or light a room (Polack, Wood, Smith 2010:142).

According to the South African Statistics (2006:4), the manufacturing sector is one of the three biggest users of energy and electricity in South Africa with 74% of the total, while transport is 10% and residential 8%. The 41% of the households in South Africa use wood, animal dung, coal, crop residues and paraffin to cook, while the other 59% use gas or electricity, generated mostly from coal-fired power stations (Wichmann & Voyi 2006:[sp]; Statistics South Africa 2006:6; Forbes, 2017:[sp]).

On the other hand, renewable energy comes from natural sources such as wind, solar, biomass or water. These can be used to generate electricity by various means, including aero generators powered by the wind, photovoltaic panels powered by solar light, and rotate a generator with the power of the water; or produce heat, concentrating the thermal energy of the sun or burning biogas (Department of Energy 2013:2). Renewable energy (RE) sources are cyclical, being potentially an infinite energy supply, producing little or no pollution. They are available at the source of consumption, allowing a single dwelling to produce its own energy needs in urban and remote areas, more suitable for small applications (BBC 2016:3). One of the disadvantages is the reliability of the supply, depending on the weather conditions, although most of the time it is predictable (BBC 2016:3; Global Energy Assessment 2012:774). Depending if is needed to generate electricity, the implementation can be costly in the case of solar photovoltaics, although decreasing in cost at an average rate of about 10% per year (Farmer & Lafond 2016:648). In the case of solar water heaters, almost 60% of the cost of household water heating can be reduced; this has been widely implemented especially in new houses around South Africa (Solarcooking.org 2000; Sustainable Energy Africa 2007:[sp]).
South Africa is endowed with a variety of renewable energy resources (Department of Energy 2015:54; United Nations Economic Commission for Africa 2011:17); its coastline, provides favourable conditions for wind power; while most of the country has a high solar power potential and significant biomass resources. Although a water scarce country, small-scale hydropower systems have been developed in the Free State and The Eastern Cape (Figure 4) (Department of Energy 2015:46) and wave potential along the Cape coastline is estimated as significant, but no exploitation is taking place to date (Department of Energy 2013:6). There is an opportunity to diversify and sustainably develop the energy sources. The type and extent of RE opportunities in South Africa vary among provinces with solar energy being the most available RE in Gauteng province (Department of Energy 2015:54). In the next sections, wind, solar, biomass and hydropower presence in South African territory is explained in detail, in order to specify which renewable energy may be most appropriate for this project.
3.1.3.1. Wind energy

The amount of energy that can be extracted from the wind depends on its speed, the higher the speed the more energy can be harnessed to generate electricity. Wind as an energy source is only practical in areas that have strong and steady winds. The wind power for South Africa is generally good along the entire coast with localised areas where potential is very good, as shown in the Figure 5, with annual speeds above 6 m/s; a moderate wind power potential includes the Eastern Highveld Plateau, Bushmanland, the Drakensberg foothills in the Eastern Cape and KwaZulu-Natal (Department of Energy 2013:3; Department of Energy 2015:53; Department of Energy 2017:sp).

*Figure 5: South Africa wind power potential. Map showing wind speed (m/s) at 100 m hub-height (Department of Energy 2015:53).*
3.1.3.2. Solar energy

South Africa has high levels of solar irradiation, as shown in Figure 6 (see 3.1.4); one of the highest in the world. With a daily average between 4.5 and 6.5 kWh/m2, solar energy is the most accessible renewable resource in the country, with a high potential in Johannesburg (Department of Energy 2013:2; Department of Energy 2015:52; Department of Energy 2017:[sp]).

![Solar resource maps for South Africa, Lesotho and Swaziland. Direct normal irradiation in kWh/m² (Solargis 2017:[sp]).](image)

*Figure 6: Solar resource maps for South Africa, Lesotho and Swaziland. Direct normal irradiation in kWh/m² (Solargis 2017:[sp]).*
3.1.3.3. Biomass

The main sources of biomass in South Africa are firewood in the rural sector, bagasse\(^2\) in the sugar industry, and pulp and paper waste in the commercial forestry industry. Figure 7 shows the biomass potential for wood, agricultural and grass residues in South Africa. In the forestry sector, the volume of waste remaining in the forests is substantial and potentially a renewable energy resource that can be used for charcoal, gasification or direct generation of power (Department of Energy 2013:5).

\[\text{Figure 7: Biomass energy potential in South Africa (Department of Energy 2013:5).}\]

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\(^2\) Bagasse is a dry pulpy fibrous matter that remains after sugarcane is crushed to extract its juice, used as a biofuel and in manufacture as a building material.
3.1.3.4. Hydropower

There is a significant potential for development of hydropower in South Africa. Small-scale hydropower plants have been developed in the Free State and the Eastern Cape (Figure 8) (Department of Energy 2013:6; Department of Energy 2015:53).

![Micro hydro power potential](image)

Figure 8: In South Africa potential small-scale Hydro development exists in the rural areas of the Eastern Cape, Free State, KwaZulu-Natal and Mpumalanga (Department of Energy 2013:6)

Due to the fact that solar energy is widely available in the country, there is an opportunity for solar power to be a supplement or a substitute for the energy needs in small-scale, decentralised productive applications, energy mostly produced from fossil fuels (Panwara, et al. 2012:3777; Schäfer Kebir & Neumann 2011:327; Food and Agriculture Organization 2000:25). This project utilises the sun’s energy as the main energy source, focused on the thermal use of it as an alternative to fossil fuels, and the opportunity to utilise it for food preservation. In the following section the sun’s
energetic potential and availability in Johannesburg is presented. This informs and determines the technical requirements for the proposed solution.

3.1.4. Principles of solar energy

The earth's rotation around the sun initiates day and night and the yearly movement and tilt of the earth towards the sun is responsible for the seasons (Knudson 2002: 2).

Solar energy can be used in three forms: Helio-chemical, helio-electrical and helio-thermal. The helio-chemical process can be seen through photosynthesis, a process by which green plants and certain other organisms use the energy of light to convert carbon dioxide and water into the simple sugar glucose; the helio-electrical process is the direct conversion of light into electric energy using photovoltaic panels; and finally, the helio-thermal process uses solar radiation to produce heat, that can provide the thermal energy required for cooking, to heat water, thermic production processes or space heating (Office of Energy Efficiency & Renewable Energy 2013:[sp]; Encarta Encyclopedia 2000:[sp]).

To efficiently harness the energy from the sun taking full advantage of its potential, it is required for solar technology to directly face sunlight. Daily and yearly the sun moves, making it necessary to track the sun's movements. The solar energy that can be used is a combination of the hours of sunlight in a specific site, and the strength of that sunlight. This combination is called solar irradiance, and can be expressed as watts per square metre [W/m²].

3.1.4.1. Solar irradiation

Solar irradiance is the power per unit area received from the sun in the form of electromagnetic radiation, with an average of 1 000[W/m²] at solar noon in the middle of summer at the equator (Ftexploring 2017:[sp]; Boxwell 2012:889). An average electric stove uses 1 000[W] per hour, similar to the theoretical sun power available in an area of 1[m²]. The total solar irradiation, also called global radiation, is the sum of direct, diffuse and reflected radiation, illustrated in the earth's energy balance in Figure 9. Direct radiation is described as the solar radiation traveling on a straight line from the sun to the surface of the earth, minus the losses due to absorption and scattering.
of clouds or moisture. Diffuse radiation describes the sunlight that has been scattered by clouds or moisture but that has still made it down to the surface of the earth. Reflected radiation is the component of radiation which is reflected from surfaces, other than air particles, such as hills, trees or water, accounting for a small percentage in global radiation. To harness the thermal energy from the sun, direct radiation is utilised in parabolic solar concentrators and direct and diffuse radiation in solar box types (Boxwell 2012:49).

Figure 9: Earth’s Energy Balance. Ratio of direct to diffuse radiation. Atmospheric conditions like clouds and pollution increase the percentage of diffuse radiation (Diagram by the author).
3.1.4.2. Solar spectrum

The solar spectrum is the range of electromagnetic radiation emitted by the sun from three regions: ultraviolet with 6% of the spectrum, visible 48% and infrared 46%. As shown in Figure 10, the majority of solar energy comes in the form of light and heat in the visible and infrared regions of the electromagnetic spectrum (Kullabs 2017:[sp]). When the heat from the sun is concentrated and absorbed by an object it increases its temperature, being able to use the heat in thermal applications like food preservation.

![Spectrum of Solar Radiation](image)

*Figure 10: Solar radiation spectrum for direct light at both the top of the Earth’s atmosphere (represented by yellow area) and at sea level (red area) (Diagram by the author).*

Depending on the day of the year and the time, the availability of solar energy, known as solar insolation, will increase or decrease.

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3 Ultraviolet extends between 0.2-0.38 micrometres [μm], the 6% of the solar spectrum; visible, with a wavelength between 0.38-0.78 [μm], the 48% of the solar spectrum; and infrared, with a wavelength between the 0.78-4.0 [μm], 46% of the solar spectrum.
3.1.4.3. Solar movement during the day and the year

During the year, the Sun’s position in the sky is defined by two angles, altitude (α) and azimuth (β). Altitude refers on how high the sun is above the horizon, where at sunrise and sunset the sun’s altitude is 0°, and about 90° at noon during summer, as shown in Figure 11. Azimuth describes the position of the sun on the horizontal plane from east at +90°, 0° when reaching north, and -90° at west. The sun’s path varies with latitude due to the earth’s tilt, with Johannesburg situated in the latitude 26° 11’ 42” south.

During the day the sun reach the maximum solar radiation from 9h00 in the morning to 16h00 in the afternoon, time when a solar device collects the maximum solar radiation, known as solar peak hours. The solar insolation is determined by summing solar radiation (in Kilowatts [kW/m²]), over time (in hours [h]), per day, and is expressed in units of [kWh/m²/day], as presented in Table 5. In order to take advantage of the sun during the day a solar device has to face the sun directly during the solar peak hours.

![Diagram of solar movement during the day and the year](image-url)
Table 5: The solar radiation distribution throughout the year in Johannesburg (The Solar Electricity Handbook 2017:[sp]).

<table>
<thead>
<tr>
<th>Month</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
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<td>5.91</td>
<td>5.61</td>
<td>5.66</td>
<td>5.97</td>
<td>6.18</td>
</tr>
<tr>
<td></td>
<td>6.32</td>
<td>6.55</td>
<td>6.38</td>
<td>5.91</td>
<td>6.19</td>
<td>6.50</td>
</tr>
</tbody>
</table>

In Figure 12 the intensity of the direct radiation [W/m²] throughout the day is presented. An estimation of the amount of power that a solar device would receive, for example, on October 30 can be done, if it is pointing directly to the north in Johannesburg (26°S, 28°E), in the absence of clouds.

![Figure 12](image)

*Figure 12: The figure shows the intensity of direct radiation in W/m² throughout the day (PVeducation, 2017:[sp]).

In the next section, five solar thermal concentrator technologies are presented: a brief history of their development; the principles of function to take advantage of the heat of the sun to process food; and solar concentrator products, currently available for purchase.
3.1.5. Solar thermal concentrator technologies to process food

Through history one can find an isolated example on what is now called solar cooking. The Essenes, an early sect of Jews from the second century BC, used to warm up wafers on rocks heated by the sun between 80°C and 90°C, a point which did not kill the living enzymes in the grains (Radabaugh 1998:1). Because of the relatively low energy density, humans have developed technology to make this energy useful. The capacity of a solar cooker to collect sunlight is directly related to the area of the collector perpendicular to the incident solar rays, and usually requires regular and frequent tracking to follow the sun. Over time, different types of solar cookers have been developed all over the world, classified by the method of how the cooking vessel receives the sun’s radiation (Panwara, et al. 2012:3778), or the capacity to store heat (Muthusivagami, et al. 2010:692). In this study the solar cookers are categorised, depending on the kind of collector, into five different typologies presented in Figure 13, to determine is best suited for the intended solution: Parabolic concentrator, Scheffler reflector, solar oven, solar water heater, and Fresnel lens.

![Figure 13: Diagram of the five different types of solar cookers to be analysed (Diagrams by the author).](image)

Each collector can be separated in sub-processes that constitute a solar harvester system; concentration, absorption, retention, duration and solar tracking, explained as follows (Cuce & Cuce 2013:1400; Cantinawest 2015:[sp]; All Season Solar Cooker 2017:[sp]).

- Concentration is the way that the collector concentrates the sun rays, by means of a sealed glass lid on the top of a box or a reflecting surface. The area of collection is important because, as was presented earlier, in one square meter one receives 1 000 [W];
- Absorption, refers to how the stove collects the light, usually in a black pot heating the food directly;
- Retention, is the means to keep the heat on the pot from escaping;
- Duration, is how a solar cooker can maintain the heat for enough time to cook the food; and
- Solar tracking, the way to adjust the solar cooker directly towards the sun, so as to better concentrate and absorb the sun’s rays.
3.1.5.1. Parabolic concentrator

In the early 1700s Andreas Gartner cooked using a wooden parabolic solar cooker lined with gold foil in Dresden Germany, and in 1774 Antoine Lavoisier developed a large device that had a glass lens that focused the sunlight into a focal point over material for combustion, Figure 14.

![Figure 14: Antoine Lavoisier parabolic concentrator prototype (Demonteverde 2015:sp)].

A more recent version of a parabolic cooker was developed by Ghai in the 1950s at the National Physical Laboratory in India (Cuce & Cuce 2013:1405), and in 1981 Dr. Seifert developed the SK line of parabolic solar cookers. Some of them were tested in South Africa, during a study carried out by the German Organisation for Technical Cooperation (GTZ) in 1996 (Department of Minerals and Energy 2004:2), a version of which has been used as a base for the design of many other parabolic cookers (Wentzel & Pouris, 2007:1912; Arba Minch Solar-Cooking Initiative, 2011:sp)).

The parabolic dish reflector utilises the optical properties of the parabolic curved surface to concentrate direct light to the focal point, shown in Figure 15. Other
applications of the parabola as a reflector can be seen in automobile headlights, radar, and to receive transmissions from broadcast satellites (Appropedia.org, 2013:[sp]).

Figure 15: A parabola is a curve where any point is at an equal distance from the focus and a vertical line, the directrix (Diagram by the author).

Parabolic concentrating collectors are employed to cook, focusing the solar beam to where the pot is placed (Panwara, et al. 2012:3779). These collectors are analogous to traditional stove top burners and grills as they heat the pot from the bottom, and some solar stoves can heat up faster than traditional stoves. The power of a solar stove’s output is determined by the material (aluminium, stainless steel or reflective plastic), its size (usually no less than 1 square meter), and the curvature of the reflector surface (Figure 16). Because solar stoves heat up so fast and get so hot, they are ideally suited for grilling, boiling, steaming and frying (Muhyiddine & Saffa 2012:221), but the choice and design of the concentrator depends on the specific characteristics of each application source (Ibid 2012:222). The advantages of parabolic cookers include high cooking temperatures and short heat-up times. Disadvantages are their
size, the risk of fires if unattended and the need to adjust the cooker every 20 minutes to track the sun (Muthusivagami, et al. 2009:695).

Figure 16: Parts of a parabolic dish that concentrate the sun light to a focal point (Diagram by the author).

Parabolic concentrating collectors available in the South African market are presented in Figure 26. There are two companies in South Africa that sell parabolic cookers online: www.sustainable.co.za and www.sunfire.co.za. Sunfire representatives were contacted for an interview as experts (3.2.1.2), and kindly they provided a version of their stove to test as part as the study.

3.1.5.2. Scheffler reflector
A Scheffler reflector is the lateral section of a paraboloid, which concentrates the sun radiation over a fixed focus outside the dish as seen in Figure 17. It was developed by the engineer Wolfgang Scheffler in 1986 at a mission in North Kenya (United Nations Development Programme 2014:7; Munir, et al. 2010:1491).
The Scheffler concentrator maintains a fixed focus rotating the reflector about the horizontal axis mechanically imitating the sunflower’s movements, tracking the sun from east to west during the day (Alberti 2014:2). Figure 18 shows a representation of a Scheffler concentrator in a solar cooking application. This includes an array of mirrors that concentrate the sunrays, and re-directs them to the cook site of a kitchen.

The invention is not patented, and its construction plans are available following the open-source philosophy defined as a decentralised development model that encourages open collaboration for free access to software and hardware⁴ (Tamera, 2017:[sp]). The Scheffler reflector is not suitable for purposes that require high

⁴ The plans of the Scheffler reflector can be downloaded from http://www.solare-bruecke.org
accuracy, and a vast space is needed to set up the system. Some implementations in community kitchens can be seen Figure 26.

3.1.5.3. Solar oven

A solar oven is an insulated container with a single or double glass cover (Figure 19). This kind of oven utilises the green-house effect in which the transparent cover allows for the shorter wavelengths of solar radiation -visible and near infrared- to trespass the glass and be absorbed by the objects inside the insulated box. These objects will release heat -longer wavelength- that cannot escape from inside. Mirrors may be used to reflect additional solar radiation into the cooking chamber where the speed of the cooking depends on the design and thermal efficiency of the cooker (Muthusivagami, et al. 2009:693).

Figure 19: Solar box diagram of function (Diagram by the author).

The first known experiments on solar ovens were carried out by the German physicist Tschirnhausen around 1690. In 1767 the Swiss naturalist Horace de Saussure built a solar oven in the form of several boxes with a top glass layer inside one another and placed on a dark surface, presented in Figure 20. In 1830 the English astronomer, John Herschel, cooked food in an insulated box on an expedition to South Africa while in 1894 the Xiao’s Duck Shop in Sichuan, China, served roasted ducks from solar

![Illustration of the solar box cooker designed by Horace de Saussure](Solarcooking.org 2000)

The solar oven is analogous to a gas or electric oven, with the virtue that it can be unattended during cooking, without causing any danger as solar technologies like parabolic cookers may cause. Solar ovens available in the market are presented in Figure 26. The same two South African companies that sell parabolic concentrator cookers, also offer solar ovens online.

### 3.1.5.4. Solar water heater

A solar water heater (SWH) works on two basic principles. Firstly, when water gets hot it rises due to density differences between hot and cold water known as the thermosiphon effect, and secondly that black objects absorb heat (Figure 21).
Figure 21: Solar thermosiphon diagram (Diagram by the author).

There are two main types of SWH, the flat-plate collectors and the evacuated tube collectors, both constituted from three main parts: the collector, the storage tank and an energy transfer fluid. The flat-plate collector (Figure 22 A) comprises the collector, a sealed box with a transparent glass on top, and the absorber black pipe (HDPE or painted cooper) filled with the fluid.

The evacuated tube collectors (Figure 22 B) comprise a closed glass tube with a copper pipe inside which contain the heat transfer fluid. The outer casing is borosilicate glass that absorbs the solar radiation and transmits it to the copper pipe (Siddharth, et al., 2011:76). These tubes are sealed at each end, evacuating the air inside the interior.
of the tube to reduce convective and conductive heat loss (Sabiha, et al. 2015:1039). The efficiency of the evacuated tube collector is greater than the flat plate collector thanks to the vacuum inside the glass tube, but they are more expensive, fragile and require special machinery to build them.

Finally, SWH can be classified as active, using a pump to circulate the fluid between the collector and the storage tank; or passive, using natural convection called thermosiphon to circulate the fluid (Sustainable Energy Africa 2007:14). In Figure 23 examples of the two technologies are presented.

In Figure 26 evacuated tube collectors designed especially to cook inside the tube are shown, with the food acting as the fluid to be heated.
3.1.5.5. Fresnel lens

The Fresnel lens was developed by the French physicist Augustin Jean Fresnel in 1822 and installed in the Cardovan Tower lighthouse (Figure 24), a collimator that bends the light rays from an open flame and makes them parallel, narrowing the beam (Leutz & Suzuki 2012:5).

![Figure 24: The first Fresnel lens installed in the Cardovan Tower lighthouse, France (Wikipedia B. 2017:[sp]).](image)

A Fresnel lens consists of concentric rings of prisms, where each prism represents the slope of the lens surface (Xiea, et al. 2010:2589) as shown in Figure 25.

![Figure 25: Light reflection diagram of a Fresnel lens (Diagram by the author).](image)
Although the glass is an option to fabricate lenses to be used at high temperatures, this material makes it expensive, difficult to manufacture and very fragile. The polymethyl-methacrylate (PMMA) is a light-weight, clear, and stable polymer with characteristics similar to glass and is the actual material for the manufacturing of Fresnel lenses (Valmiki, et al. 2011:1615). The use of Fresnel lenses for solar cooking concentrates the sun rays to a point, raising the temperature up to 300°C. Its application is suitable for solar cooking and several prototypes have been developed (Figure 26), but no commercial products are available.

Figure 26: Solar cooker technology typologies. Available products in the market and concepts. (Gosol.org 2017; Oneearthdesigns 2017; Inforse 2017; Symingtonsolarfire 2017; Solarcooking 2017; Gosol.org 2017; Gonewiththewynns 2017; Sahel-energie 2017; Jamesdysonaward 2017; Realgoods 2017; Slicksolarstove 2017; Blazingtubesolar 2017; Inhabitat 2017; Enekan 2017; Treehugger 2017).
3.1.6. Photovoltaic energy

Photovoltaic phenomenon is the direct conversion of light into electricity. The photoelectric effect was first noted by a French physicist Edmund Bequerel in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1954 the first photovoltaic silicon module was built by Bell Laboratories (NREL 2017:[sp]; NASA 2008:[sp]).

A photovoltaic cell (PV cell) is a semiconductor that converts visible light into direct current (DC). When sunlight hits the surface of a cell, “knocking” the loose electrons, they then travel through a circuit from the N-type layer (red) to the P-type layer (blue) (Figure 27), providing a flow of electricity. A third-generation of solar cells are being made from a variety of new materials other than silicon, and some PV cells can also convert infrared (IR) or ultraviolet (UV) radiation into DC electricity (NASA 2008:[sp]; Whatis.com 2017:[sp]).

![Figure 27: Photovoltaic cell function diagram (Diagram by the author).]
To effectively use the electric energy from the solar panel a “Solar Power System” (Figure 28) consisting of a solar panel, a charge controller, an inverter, and one or more batteries, must be utilised. The following is a description of the components:

- The solar panel supplies electricity and charges the batteries, transforming the sun’s light into electrical energy. There are three types of solar panels: monocrystalline, polycrystalline and amorphous solar panels, depending on the quality of the materials used and the process to build them. A set of solar panels can be connected together to form solar arrays.

- Charge Controller: A charge controller is needed to prevent overcharging the batteries, protecting them from damage and increasing its life and performance. At the same time, the charge controller prevents the charge from draining from batteries if there is no longer any sun.

- Inverter: An inverter is an electronic device that changes direct current (DC) to alternating current (AC), and can convert the 12[V] input from a solar panel to power a 220[V] kitchen appliance.

- Batteries: The batteries store electrical power and release it in the form of a chemical reaction. Without storage the power is only available when the sun is shining.

*Figure 28: Solar power system components (Diagram by the author).*
3.1.7. Technological styles and the adoption of renewable energy technologies

Six different technologies that use the sun as the main power source have been presented. These technologies can replace the gas stove, for cooking with a parabolic solar concentrator; how the water is heated in an electric kettle, with a solar water heater; or how electricity is generated using a diesel generator, with photovoltaic panels. In his book *Technological Styles*, Oscar Varsarsky (2013:34) states that all the characteristics of a chosen technology constitute the “technological style”, and that style will be different in a capitalist driven economy or in a socialist one. The technology style that a society chooses to perform their activities will determine the relation with each other and the environment. Arturo Escobar (2016:128) states that each tool and technology is ontological, because it presents new ways of doing and a different way to be, and quotes Fernando Flores about his statements on ontological design: “we find the profound question of design when we recognize that when designing tools, we are designing ways of being”. When designing objects powered with renewable energy, new practices are required to perform similar activities with a non-renewable energy source. For example, to cook with the sun is determined by the weather, the time needed to cook the food, and the solar peak hours when the sun is shining. Therefore, a new way of cooking ensues.

According to Everett Rogers (1983:15-16), there are five main qualities of a new technology that affect its rate of adoption:

- The relative advantage over an existing technology in terms of economics, usability, and status;
- The compatibility between the innovation and the existing values of the users;
- The complexity and difficulty of understanding the use of the technology;
- The degree to which an innovation may be experimented with until the user is satisfied;
- The degree to which the results of an innovation can be seen by others.

Summarising several studies that discuss the implementation of systems that are mainly powered by renewable energy, the main challenges to implement them were: the user experience; technological problems; regulations; and business models,
presented in the Figure 29 and that can be seen in detail in the annexure VII (Schäfer et al. 2011; Ruiz-Mercado et al. 2011; Department of Minerals and Energy 2004; Hermann-Sanou 2016). The adoption of an innovation is a social process, as well as a technical matter (Rogers 1983:5), this requires the new idea or product to be well-communicated to the individuals in order for it to be accepted by the majority of the population (Ruiz-Mercado et al. 2011:7559). The adoption of a new technology is a dynamic and complex process, which requires cultural adaptation and appropriation of the technology (Ruiz-Mercado et al. 2011:7559).

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The challenges of implementing renewable energy sources such as biogas or solar power have been widely studied in the South African context (Schäfer et al. 2011; Ruiz-Mercado et al. 2011; Department of Minerals and Energy 2004; Hermann-Sanou 2016; Tumwesige, Fulford & Davidson 2014; Wentzel & Pouris 2007:1912). These studies particularly focus on replacing the use of fossil fuels during cooking with solar stoves and solar ovens and lighting with photovoltaic panels.

The solar-cooker-field-test carried out by the German Organisation for Technical Cooperation in South Africa started in 1996 (Department of Minerals and Energy 2004:2), to investigate the social acceptability of solar cookers and to facilitate local production and commercialisation of the technology (Wentzel & Pouris 2007:1909). During the study, the most popular model for small families was the REM5 (Figure 30) a solar oven, and the SK12 (Figure 31) a parabolic solar stove. The REM5 is a solar cooker box (see 3.1.5.3) with a cover of single panel glass, aluminium frame and a
polycarbonate box, with three exterior reflectors. Because its design required complex assembly which is overly time consuming, a more improved design of a solar stove was developed, the \textit{T16}, a version easier to produce. The \textit{SK12} cookers (see 3.1.5.1) are parabolic dishes approximately 1.2 meters in diameter, designed with the focal area inside the dish (Wentzel & Pouris 2007:1912; Cocina Solar 2013:[sp]; solarcooking.org 2000:[sp]).

\textit{Figure 30}: The solar cooker model REM5, a solar oven with three reflectors (Wentzel & Pouris, 2007:1909).

\textit{Figure 31}: The solar stove model SK12 (Wentzel & Pouris, 2007:1909).

The solar-cooker-use-rate is defined as the number of times a household opts to use a solar oven or stove to cook food (Wentzel & Pouris 2007:1914-1917). Many factors influence the solar-cooker-use-rate and different aspects concerned with the user experience, ergonomics and technological limitations of a solar cooker were identified:
• The change in cooking patterns or habits made the participants of the study stop using the stove, because they found the process too complicated.
• Must be an adequate motivation to use the cookers, like potential savings and curiosity.
• Successful adoption of solar cookers requires a basic form of training.
• Using solar cookers requires adaptation of kitchen practices in terms of cooking time.
• The stove was too slow to cook.
• There was a space for only one pot.
• There was no baking tray.
• The external conditions, like strong wind, rain or clouds.
• The lack of black pots recommended to use in a solar cooker, was described as a reason for not using a solar cooker.

One of the conclusions of the study was that for solar cookers to be used successfully, the cooker must be functional, efficient, durable, attractive and user friendly. Solar cookers need to move towards a highly desirable product. Attention therefore, needs to be paid to product design, finish, packaging and marketing (Wentzel & Pouris 2007:1918). If the technical aspects are not accommodated to people’s needs, the solar cooking technology will never be able to gain any real popularity (Biermann 1999:2).

As Joseph Radabaugh presents in his book Heaven’s Flame: A Guidebook to Solar Cookers (1998:3), cooking with the sun has been promoted as a solution to poor people’s problems, not as cooking tools useful in developed countries. Other researchers argue that designs promoted are too complicated or too expensive for the intended users. Social scientists, who had never integrated solar cooking into their own lives, have been in charge of most of the studies and the promotion of the technology, causing solar cookers to be perceived as a second-class machine.

To encourage the adoption of a new technology, for example in studying the adoption of stoves powered by renewable energy, it is necessary to move the emphasis from the stove in isolation to the entire cooking system. This results in culturally and
technologically appropriate outcomes that dynamically interact in a user’s cooking system (Ruiz-Mercado et al. 2011:7559).

3.1.8. Literature review summary

Food preservation has been an important practice in the history of humanity for three main reasons: to increase food security, add economic and cultural value to the food and to reduce food losses by preventing spoilage. Food processing machinery require energy mainly to generate heat to cook, boil and dry the food from non-renewable sources such as liquid fuels, gas or charcoal. On the other hand, South Africa is gifted with a variety of renewable energy resources, with solar power as the widest and most available in the whole country especially in the Johannesburg area. As a result, this project is focused on the thermal use of the sun as the principal energy source for the proposed solution. There are different technologies that take advantage of solar power to cook food, that emulate a stove, oven or a kettle depending on how they harness the solar power, where one of the main constraints is the need to follow the sun to take advantage of its full potential.

The adoption of a new technology is a dynamic and complex process, which requires cultural adaptation and appropriate technology. For example, to design a stove powered by RE, it is necessary to move the emphasis from the stove only to the entire cooking system. Studying the users from the beginning of the project and working with them co-designing the intended solution during the whole process is imperative in order to understand the patterns of use and relations between the different activities (production process, use or energy, space and equipment) involved during food processing activities, and include their recommendations in the final product.

The next section presents the field research process undertaken to understand the activities and identify the requirements of actual food processors, interviews with experts in renewable energy and sustainability, and a personal journey utilising solar technologies available in South Africa.
3.2. PHASE 1B: FIELD RESEARCH

Through incorporating the input of participants who regularly process food, it allows for a deeper understanding of the requirements of the intended product users. In this section the in-field research is presented: observations and analysis of food processors that were utilised in the study; an interview with experts in the field of sustainability; and a personal journey cooking with the sun’s power.

3.2.1. Observation and analysis of food processors

Between March and December 2016, in the initial stages of the research, I visited different markets around Johannesburg such as the Locrate Market in Soweto, Market on Main in Maboneng Precinct, the Neighbourgoods Market in Braamfontein and the Bryanston Organic Market, in order to identify participants for the study. These markets bring together different small-scale farmers who sell raw and processed food such as chilli sauce, atchar and gourmet pop-corn. During the visit, I spoke with many food vendors in order to attempt to identify them as possible participants for the study, and ask them if they would like to be part of the project. I prepared a leaflet (annexure XV) to explain the project, the methodology and why it is valuable research. This was relatively difficult due to the fact that each of them had secret recipes and valuable trade secrets over which they were extremely protective because they could be copied.

To gain the confidence of the participants is crucial in this kind of project, as I was asking them to share their time in their private space. Being able to engage with the intended participant of the study is a skill needed to perform a HCD based project. To ensure the privacy and voluntary participation in the study, the participants were asked to sign a consent form (annexure I), following the ethical regulations of the University of Johannesburg, making sure that they could withdraw from the study at any point.

To select the participants, the idea was to study a range of different types of food, observing similarities and differences during the process. The participants who agreed to assist with the study included the following: Participant 1 (P1) Isiziba Roasted Chillies, Figure 32; Participant 2 (P2) Honey Pod Body Soap, that is not food, but
the process and size of the company is similar as the required, Figure 33; and Participant 3 (P3) **Yamama Ginger Beer**, a company that processes a liquid, Figure 34. To proceed with the observations, I asked them if I could document the process using video recording during the activity. This would be valuable to understand and describe the steps of the whole process, unpacking details of it, to hold an energy audit (annexure II), to recognise the kind of energy and fuel used by the machines, as well as the tools and equipment needed. Also, this could benefit the users, utilising the edited video for their own marketing if they would like to do so. During the recording, a semi-structured interview was conducted (annexure IV) to enter into the participant’s personal perspective, delving into issues that couldn’t be observed during the process.

![Figure 32: Chilli sauce display in the market (Photo by the author).](image1)

![Figure 33: Body Soap bottles on display (Photo by the author).](image2)

![Figure 34: Ginger beer display at the market (Photo by the author).](image3)
Chilli sauce preparation process

I meet the P1 in Market on Main, Maboneng, where she sells roasted chilli sauce. After I explained the project with its phases and asked her to sign the consent form, she invited me to visit her house in the East of Johannesburg, where she cultivates organic chillies and prepares the sauce.

*Figure 35: Preparation of the fire to roast the chillies and the producer smelling the chillies, to be sure that they are ready (Photo by the author).*

The first task after I meet P1, was to buy ingredients and glass bottles to preserve and store the sauce. With all the necessary equipment and ingredients, she began the process by harvesting the chillies from her garden, and collecting pine cones to make a fire in a braai to roast the chillies. This roasting process takes about two and a half hours, with a large amount of smoke generated during the process (Figure 35), that was partially inhaled by her. During the roasting time, she smells, touches and feels the chillies until she decides that they are ready. Due to the direct contact with the flames, around 30% of the chillies cannot be used because they are burnt, and thus discarded.

*Figure 36: Close view of the burning gas stove. The producer preparing the sauce under the light of the candles (Photo by the author).*
After roasting has been completed, the process continues in the kitchen preparing the sauce on a gas stove. The whole process took about 45 minutes. She lives outside Johannesburg and her house doesn’t have electricity, so during the preparation she used the light of candles and a torch to illuminate the space (Figure 36); a kitchen of 6 X 6 meters with surfaces to cut and store the utensils such as pans, knives, spoons and condiments. The space is also equipped with a stainless steel surface washing area.

The next step is to blend the sauce. The blender needs electricity to be used, so a diesel electric generator, shown in the Figure 37, is switched on for about half an hour. The blender is used for no more than 15 minutes, but because the generator is far from where the blender is used and takes time to walk and switch it off, it stays on longer than is needed. Furthermore, the generator produces excessive noise, air pollution and due to running for longer than needed, it burns fuel unnecessarily.

Figure 37: The diesel electric generator switched on to power the blender. The producer blending the sauce (Photo by the author).

Figure 38: The process of sterilise the bottles and re-heating the chilli sauce (Photo by the author).
The following step in the process is the sterilisation of the bottles (Figure 38) where the sauce will be stored, boiling them for around an hour in a large pot, using the gas stove. Then, the sauce is re-heated for 15 minutes on the same stove. During the whole process it was observed that P1 needed hot water supplied by a kettle powered by gas, usually to clean the surfaces for the preparation.

Figure 39: Filling the bottles and the point of sale in the market (Photo by the author).

Finally, the bottles are filled as shown in the Figure 39. During the process of filling the bottles, it was observed that a great amount of sauce is wasted due to the lack of proper equipment. A total of 30 bottles where labelled and stored for the next day to be sold at the market.

Data analysis chilli sauce: Step by step process and energy audit

Table 6: Synthesis of the process to prepare chilli sauce, the type of fuel used, the duration of the activity and the type of energy utilised (Table by the author).
Table 6 presents the step by step process to make chilli sauce. It has been identified that thermal energy generated by means of charcoal in step 3 is used, to roast the chillies for 2 1/2 hours, and by means of a LPG gas stove in steps 4, 7 and 8 to cook the sauce and sterilise bottles for 2 hours in total. Furthermore, in step 6 the use of rotational energy is identified by means of electricity from a diesel generator, to power a blender for around 15 minutes. Not shown in the table, but described in the chilli sauce preparation process, is the need for available hot water at a temperature between 70°C to 90°C was identified, during the whole process for various activities.

Machinery and tools

![Image](image.png)

*Figure 40: The machines needed to prepare chilli sauce: a gas stove, an electric kettle and a blender (Photo by the author).*

The three machines needed to prepare chilli sauce were identified (Figure 40) and are summarised in Table 7:

*Table 7: Machines needed to prepare chilli sauce, their power source, type of energy and purpose. (Table by the author).*

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>POWER SOURCE</th>
<th>TYPE OF ENERGY</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRAAI STAND</td>
<td>Charcoal</td>
<td>Thermal</td>
<td>Smoke and roast</td>
</tr>
<tr>
<td>GAS STOVE</td>
<td>LPG gas</td>
<td>Thermal</td>
<td>Cook</td>
</tr>
<tr>
<td>KETTLE</td>
<td>Gas</td>
<td>Thermal</td>
<td>Hot water</td>
</tr>
<tr>
<td>BLENDER</td>
<td>Electricity</td>
<td>Rotation</td>
<td>Mix ingredients</td>
</tr>
</tbody>
</table>
Workplace layout

During the process of preparing chilli sauce, the activities were performed in different zones around the workplace (Figure 42) in a room of 6 X 6 metres. Figure 41 presents a diagram of the zones: Cold Storage, water supply, cooking zone, tools storage, and a surface-working-area. The zones are located in the perimeter of the workplace, leaving the centre empty for displacements.

Figure 41: Diagram of the zones identified in the workplace to prepare chilli sauce (Diagram by the author).

Figure 42: A diagram of the size of the space identifying zones to perform the activity (Photo by the author).
Body Soap

The second participant (P2) to be approached was a woman who produces organic body soap with herbs that she buys in a sangoma market. After the visit to P1, the chilli sauce producer, she gave me the details to contact P2. I later contacted P2, explained the project and asked her to sign the consent form to participate in the research. She invited me to visit her house in the south of Johannesburg, to record the process of making soap.

![Image](https://example.com/image1.jpg)

Figure 43: The measure of the ingredients in the correct proportions is crucial for a quality product (Left). Water supply station of work is shown (Right). Photograph by author, used with permission (Photo by the author).

The first part of the process is to weigh a mix of herbs, oil and caustic soda with a scale (Figure 43); the correct proportion of the ingredients in this activity is crucial to assure the quality of the product.

![Image](https://example.com/image2.jpg)

Figure 44: The producer is interaction with the electric stove is shown (Left). When caustic soda is added to a hot liquid toxic fumes are released, with the consequent health risk (Right). Photograph by author, used with permission (Photo by the author).

After this, she prepares an infusion by boiling herbs for about 15 minutes on an electric stove, as shown in the Figure 44. Then she combines it with caustic soda that reacts
with the hot water, producing toxic fumes inhaled by P2 while she is mixing the preparation. After the reaction occurs, she keeps mixing it with a hand-blender, for about 5 minutes. When mixing the two solutions they need to be at the same temperature, and once mixed, stirred for half an hour. During the whole process, the availability of hot water is required, to clean the equipment or add more water to the preparation.

![Figure 45: The storage place for the ingredients and some of the final product, liquid soap is showed (Photo by the author).](image)

The last part of the process is to cool down the preparation to ambient temperature over a period of approximately two weeks, in a mould in the case of bar soap or in a bottle in the case of liquid soap (Figure 45). P2’s soap brand, “Honey Pod”, is selling in her own store in Melville, where she also teaches skin care techniques.

**Data analysis body soap: Step by step process and energy audit**

Table 8: Synthesis resume of the process to prepare soap, the type of fuel used, the duration of the activity and the type of energy utilised (Table by the author).
Table 7 presents the step by step process to make soap. It has been identified that thermal energy is used by means of an electric stove in steps 2, 6, and in step 8 to heat the mix of ingredients for one hour in total. In steps 5 and 7 the use of rotational energy has been used, which is generated by means of grid-electricity to power a blender for 30 minutes in total (Figure 46). Not shown in the table, but described in the previous section, the need to have hot water available during the whole process with temperatures between 70°C to 90°C was identified.

**Machinery and tools**

The identified machines needed to prepare body soap (Figure 46) are summarised in Table 9:

![Figure 46: In the figure can be seen the producer and the interaction with two of the most used machines during the process, an electric stove and a hand-blender. Photograph by author, used with permission (Photo by the author).](image)

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>POWER SOURCE</th>
<th>TYPE OF ENERGY</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRIC STOVE</td>
<td>Electricity</td>
<td>Thermal</td>
<td>Cook</td>
</tr>
<tr>
<td>ELECTRIC KETTLE</td>
<td>Electricity</td>
<td>Thermal</td>
<td>Hot water</td>
</tr>
<tr>
<td>BLENDER</td>
<td>Electricity</td>
<td>Rotation</td>
<td>Mix ingredients</td>
</tr>
</tbody>
</table>
Workplace layout

During the process to prepare body soap, the activities are performed in different zones located on the perimeter of the workplace (Figure 47), leaving the centre empty for displacements. The size of the workplace is a room of 5 X 3 metres. Figure 47 presents a diagram of the zones: Cold Storage, water supply, cooking zone, tools storage, and a surface-working-area.

Figure 47: Diagram of the zones identified in the workplace to prepare body soap (Diagram by the author).

Figure 48: Workplace to prepare body soap (Photo by the author).
Ginger beer

In the case of the “Yamama Ginger Beer” the third participant (P3), was contacted through some of their clients who buy their products and gave me the details to contact them. After explaining my project with the phases and goals of the research, they agreed to sign a consent form and let me record the process in the space where they prepare ginger beer, in the north of Johannesburg. The production occurs in a space typically associated with larger scale production, as opposed to the preparation of the chilli sauce and the soap performed in the houses of the producers. In this enterprise there are three employees, two of whom undertake the production and one who deals with the financial side of the business and accountability.

![Figure 49: The first part of the process is to mix the ingredients and boil them (Left). A detail of the gas stove burner (Right). Photograph by author, used with permission (Photo by the author).](image)

The process starts with a measuring of the ingredients, ginger powder and water in a 10 litre pot, which is boiled for about 30 minutes on a gas stove. Once complete, the mixture is left to cool to ambient temperature which takes approximately 2 hours. Then, the process continues with the addition of sugar to the preparation, boiling it for another 30 minutes, and cooling it down again for about 4 hours. Once cooled, the ginger beer concentrate is decanted into glass bottles and is ready for sale. Some concentrate is used to create ready-to-drink bottles of ginger beer (Figure 49).
The demand for the product increases depending on the season. In a high season, they have five stoves working simultaneously during the day, as shown in the Figure 50.

Moreover, other machines needed during the process are a scale to measure the ingredients and an electric kettle (Figure 51). The availability of hot water is necessary during the whole process. The ginger beer is sold in stores around Johannesburg, and also at events and markets around the city.
Data analysis ginger beer: Step by step process and energy audit

Table 10: Synthesis resume of the process to prepare ginger beer, the fuel used, duration of the activity, the type of energy and the machinery used (Table by the author).

Table 8 presents the step by step process to make ginger beer. The use of thermal energy by means of LPG gas stove in the steps 1 and 2, for one hour in total has been identified. Not shown in the table but described in the previous section, the need to have hot water available during the whole process with temperature between 70°C to 90°C, was identified.

Machinery and tools

The identified machines needed to prepare ginger beer (Figure 52) are summarised in Table 11:

Figure 52: Interaction with the most used machine during the process, five gas stoves, and the working surface area where the ingredients are measured and the electric kettle is stored (Photo by the author).
Table 11: Machines needed to prepare ginger beer, their power source, type of energy and purpose. (Table by the author).

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>POWER SOURCE</th>
<th>TYPE OF ENERGY</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS STOVE</td>
<td>LGP gas</td>
<td>Thermal</td>
<td>Cook</td>
</tr>
<tr>
<td>ELECTRIC KETTLE</td>
<td>Electricity</td>
<td>Thermal</td>
<td>Hot water</td>
</tr>
<tr>
<td>BLENDER</td>
<td>Electricity</td>
<td>Rotation</td>
<td>Mix ingredients</td>
</tr>
</tbody>
</table>

Workplace layout

To prepare ginger beer the activities are performed in different zones, also located on the perimeter of the workplace (Figure 53), leaving the centre empty for displacements. The size of the workplace is a room of 5 X 10 metres. Figure 54 presents a diagram of the zones: Cold Storage, water supply, cooking zone, tools storage, and a surface-working-area.

Figure 53: A general photograph of the installations to prepare chilli sauce (Photo by the author).

Figure 54: Diagram of the zones identified in the workplace to prepare ginger beer (Diagram by the author).
3.2.2. Experts Interview

An interview with Geoff Green, Tony Lopes and Crosby Menzies, three experts in the field of renewable energy and organic food was conducted. They gave me insights on how different daily life and activities are when one is connected with nature’s cycles.

Geoffrey Green

Geoffrey Green (Figure 55) is a geographer who works as a small-scale farmer. He founded *Green Acre Living*, a small-scale farm that produces organic food and teaches farmers to grow and maintain an organic farm. During the interview he was focused on the importance of growing and consuming organic vegetables and the positive impacts on our bodies and the environment.

*Figure 55: Geoff Green showing his organic green house (Photo by the author).*

Tony Lopes

At a point Tony Lopes changed his direction from a construction project manager in mining and petrochemicals, to a low-tech sustainable technologies lifestyle. Integrating his background in electrical engineering with industrial construction, he now builds artefacts to supply, for example, the need for hot water, heating it with the sun (Figure 56). He produces his own biofuel, to drive a diesel car converted to run with vegetable oil. During the visit to his house I could see the different appliances and
machines that he mostly builds and uses every day. As he commented, a holistic change in daily habits has to be done, not only in energy requirements, but in how to reuse water, dispose of garbage and even in what one eats.

Figure 56: Solar water heater installation, the system is constituted from black pipes, PET bottles around them and a PVC structure (Photo by the author).

In 2013 he was invited to present at the TED x Johannesburg his talk “Put back into the earth what you take out” (TEDxTalks, 2013:[sp]) (Figure 57) and to share his experience in changing his daily patterns.

Figure 57: Tony Lopes in the TED talks x Johannesburg 2013 (TEDx Talks, Johannesburg 2013).
Crosby Menzies

Crosby Menzies (Figure 58) founded “SunFire Solutions” in 2004, after he studied permaculture and noticed that Rural Schools use mostly firewood to cook students’ daily meals. SunFire is one of the few companies in Africa focused on clean energy appliances, promoting solar cooking. During the interview, insights were gained on how the people interact with the solar cooker, their expectations and why they choose to cook or not to cook with the sun’s energy. He pointed out the importance of teaching how the sun can provide the energy needed to cook; that most people asked to have a place to cook two pots at the same time; and the need to improve the quality of materials used in the existing products.

Figure 58: Crosby explaining on how to heat water with a solar concentrator stove (Gosol.org, 2017)
3.2.3. Findings

After an extended literature review and field research analysing the preparation of “Isiziba Roasted Chillies”, “Honey Pod Body Soap” and “Yamama Ginger Beer”; it was identified that the machines required to process food are: a stove, a water heater and a blender (Figure 59), powered by means of diesel, LGP gas, electricity or biomass fuel. Additionally, it is necessary to provide a working-surface, a place to store the ingredients and tools, and a shelter to be protected from the sun.

![Figure 59: The machines required to process the food are a stove, a water heater and a blender. (Diagram by the author).](image)

The main problem identified was that there is a lack of a system to cook, blend and have hot water available, powered by renewable energy for food processing at a micro scale.

The most available renewable energy in Johannesburg is solar energy, therefore this is the energy input for the intended appliances, using one or a combination of the technologies presented in section 3.1.5. The final design of an off-grid food processing system, should include a solar stove, solar water heater, and a solar blender.

The parabola shaped products are the most used solar cooking artefacts to concentrate the heat of the sun, and are the easiest to build. There are solar concentration parabolas available in the market, but these devices have to be repositioned to follow the sun during the day which means having to attend to them during the cooking time. In accordance with section 3.1.7, this could mean that the benefits of cooking with solar energy could be outweighed, because of the permanent attention to the solar stove. In accordance with the above mentioned findings, the following section describes the current design requirements to be attended to, to propose a solution.
3.2.4. Design requirements

The design of an off-grid food processing system consisting of a stove, a water heater and a blender, powered by the sun’s energy. The following considerations of usability, function, construction and aesthetic aspects determined the design requirements to develop the intended prototypes and the final product.

Usability: Design considerations during the operation of the product while cooking.

- Anthropometrics
  - The size of the product has to consider the South African woman’s dimensions, from the Master research by Janice Korte (2013:44) (annexure VIII).

- Ergonomics
  - Minimise the efforts when items need to be moved (for example provide wheels), by one or two people.
  - Provide a suitably sized horizontal working surface for food preparation.
  - The devices need to include multifunctional storage areas to make the storing of implements convenient.

- Maintenance
  - The product should be designed for cheap and affordable maintenance, without any complex or specialised machinery needed by the user or by a local contractor.
  - Available standard components, in case a replacement is needed.

- Safety: All areas of use and operation need to take into consideration the safety of the user. As the product relies on sunlight for energy, the user needs to be aware of the dangers of the sun’s rays, and ideally allow for appropriate protection from these rays. The devices use the sun’s rays in the heating of the food for processing, for this reason the areas of possible heat exposure need to prevent (as much as possible), the possibilities of the user being burnt by this heat.
  - The product has to indicate the dangerous parts that can cause sun burn.
  - Reduce the possible problems caused by prolonged sun exposure such as sunburn, heat exhaustion, and skin damage or cancer.
- Include shade to work outside, under the sun.
- The surfaces have to consider food manipulation hygiene.
- Include sunglasses as part of the product, to reduce glare from the sun as much as possible.

**Transport and portability**
- Needs to be modular to allow for the transportation to various places, or for being taken from storage. This movement needs to be done by one person, but more easily by two people.
- As an outdoor appliance, it must have the capacity to be moved over different terrains.
- Be able to be transported by a van (transport cargo).

**Storage and cleanliness**
- The product should be modular, collapsible and easy to clean.

**Functional:** Technical and structural considerations of the product.

**Functional principles of the product:**
- Provide sufficient heat to process the food in the same ways that current heating methods (around 120°C for at least 40 minutes) are used.
- Concentrate the sun’s thermal energy of 1m² to collect around 1 000 [W] (See section 3.1.4).
- The product should ideally follow the sun automatically in a diurnal motion, similar to the tracking of flowers to the sun called heliotropism.
- Support an 8 litre pot (diameter 28cm, depth 13cm), weighing eight kilograms approximately.
- Hot water (approximately 80°C) should be available during the cooking process (a minimum of 3 litres).
- Rotational power for liquidising, chopping and blending should be included in the solution.
- On-off mode or safety standby mode for rendering the solar cooking solution safe and not hazardous.

**Mechanisms:**
- Mechanisms have to be protected for outdoor conditions.
- Locally manufactured or available in local shops at relatively low costs.
**Construction**: The choices of materials and tools utilised to build the product.

- **Materials**:
  - Consider locally available, affordable and quality materials.
  - Materials that can resist outdoor conditions such as humidity, UV and dust.

- **Construction process**:
  - Tools and machines used for production should be easy to access and not rely on special machines or processes.

**Aesthetic**: According to Varley (1980:44), the appearance plays a subjective role in the satisfaction and comfort during the use of a product, influencing mood and feeling. Colour is a symbol for many cultures (Varley 1980:52-54). The formal coherence of an object is achieved when there is an adequate resolution of the functional aspects of the object and its relationship with the aesthetical aspects such as colour, texture and shape. (Antuñano, et al. 1992:26).

- **Formal coherence**:
  - The products should be perceived as part of one system through the structure, materials, colour or finishing.
3.3. PHASE 2: CONCEPTS, SKETCHES AND PROTOTYPES

Phase 2 can be identified as the “creative” phase, where all the learnings and findings from the Phase 1A: Literature review and Phase 1B: Field research, compiled in the design requirements are summarised to explore different solutions. The role of the designer in this phase is to take decisions on usability, function, constructive and aesthetic aspects. The methodology followed during Phase 2 is a combination of methods from the designers Bruno Munari, Victor Papanek and Gui Bonsiepe, compiled in the Vilchis’s book *Design Methodology* (1998:89), and comprises four steps: Design concept, mood board, form development through brainstorming and sketches and the selection of proposals and prototype construction. Below a description of each step is presented:

- Define a **design concept** that leads the design decisions during the following steps of the process. The above mentioned design requirements are the baseline to define a design concept. This concept defined in words the characteristics that the intended solutions have to accomplish in order to guide the decisions when developing sketches and prototypes.

- Compile references in different areas and elaborate a **mood board**, a compilation of key images of materials, colours, similar products and textures that follow the concept and evoke a particular style to be followed in the brainstorming and sketches sessions.

- Explore different alternatives based on the concept and referents, to **develop the form** with several brainstorming and sketch sessions. During this step the proposals are open, allowing the designer to be as open as possible.

- Select proposals according to the usability, functionality, constructive and aesthetic requirements. Build the **prototypes** and describe the parts of the system, materials and machines used.
Figure 61 presents a compilation of sketches exploring different alternatives of solar technologies. The first source of inspiration was to discover how nature harvests light and concentrates it. The eye of a lobster is made out of square tubes with a mirror layer inside, forming a parabola that reflects the rays of the incoming light into a single point on the retina (Figure 60). This concentration principle in nature can be related to how the reflectors of a solar box works.

Following the exploration in the technical development to concentrate the sun and based on the state of the art solar stoves, the Fresnel lens, the Scheffler reflector and the parabolic concentrators were identified as the most suitable solar concentrators to replace the source of the heat needed during cooking in a stove. The Fresnel lens can be found in old overhead projectors (Mrclarkrbhs 2017) to project transparencies in schools, therefore lenses can be recycled from them. One Fresnel lens of 40cm x 40cm was recycled from those projectors, and some early tests to assess the concentration power were held. Although a piece of cardboard easily burns in a matter of seconds when the lens is directed toward the sun, the problems uncovered were that the focal point was only at 20[cm], which is too close for a a pot.
General brainstorming and sketches: Solar-energy-harvest outdoor appliances, for food processing

Figure 61: Sketches exploring solar technologies to perform the activities during the processing the food. (Sketches by the author).
A mirror is needed to reflect the light and focalise it to function as a stove, focused onto the underside of the pot. There are not many projectors available and they have been replaced with digital projectors and it wasn't possible to buy a new Fresnel lens big enough in South Africa. The utilisation of the Fresnel lens for the project was therefore not pursued. The Scheffler reflector has been widely used in countries like India for community cooking purposes (AksonSolar 2012:[sp]), however the space needed is bigger than that for a parabolic concentrator generating the same power (see section 3.1.4.1, pg. 36), due to the fact that the focal point is far outside the pot holder zone. Therefore, a parabolic solar concentrator is identified as the most suitable to concentrate the heat of the sun, as it is the most widely used technology to cook with the sun’s power.

For the purposes of heating water, a comparison between the principles of the vacuum tubes and the solar box was undertaken. The idea was to find a solution where the materials used are easily sourced.

In the case of the blender, the possibilities explored to power it were through a human powered blender, or the use of an electric blender powered with a photovoltaic module. A bicycle blender, the ones that the Non-governmental organisation Mayapedal build (Mayapedal 2010:[sp]), was discarded because it is too big. In addition it uses a mechanism that had to be maintained, and the fact that the blender is used for no more than 15 minutes, doesn’t justify such installation. A manual blender was discarded as the force needed to blend can cause problems for the user if is repeatedly utilised during the time, and due to hand powered blenders not being widely available. The powering of an electric blender with a photovoltaic module was chosen as an appropriate solution, because this kind of machinery and components are readily available locally.

Finally, a working surface area to cut, peel and wash the ingredients is needed to complete the off-grid food processing system. The general design concept for the project is “Solar-energy-harvest outdoor appliances, for food processing”. In the next sections the design process for the following components is described: a parabolic stove, a solar water heater and a photovoltaic blender with a working surface.
3.3.1. Heliotropic Parabolic Stove

Design Concept

The design concept is derived from heliotropism, a phenomenon that refers to the diurnal or seasonal motion of flowers and leaves in response to the direction of the sun. The stove has to track the sun’s movements automatically, liberating the user from doing it manually and concentrating instead on the cooking activities. Besides, as was described in the findings, the stove should concentrate the heat of the sun through a parabola. Therefore, the design concept is a “Heliotropic Parabolic Stove”.

Mood board

The mood board (Figure 62) shows a selection of images that can assist with understanding the defined concept “Heliotropic parabolic stove”. In the images a mechanism to follow the sun in the horizontal axis or azimuth and the vertical axis or altitude are shown (see section 3.1.4.3, pg. 39), identifying manual and automatic mechanisms. The manual mechanisms are the most used, which are needed to redirect the sun beam to the pot every 10 to 15 minutes. To concentrate the sun, several parabolic shapes are identified differentiated by materials, with fiberglass and metal sheet as the most used. One of the discoveries during the exploration was the use of a recycled satellite dish as a concentrator that is widely available all over the world, with many of them discarded in dump sites. Another characteristic was identified if the parabola was shaped in one piece or from modular pieces, which provided the option for disassembly in the case of the modular configuration. The second characteristic is preferred for transportation and storage. It was observed that after the first assembly, the parabolic stove usually stays assembled due to the time needed to assemble it and the number of pieces. Finally, different reflective surfaces were explored. Two options where identified in this case: small pieces of mirror arranged and glued to a parabolic surface, and a reflective vinyl that is glued to the surface. The vinyl is preferred because it is light, easy to find in local stores and relatively cheap. Finally, to support the components, a chassis made out of rounded or square metal profiles was mostly used, easy to build, repair, and widely available and robust enough for this application and it would generally be low cost.
Figure 62: Mood board of solar parabolic stoves and mechanisms to follow the sun (Smartflowersolar 2017; Inhabitat 2015; UK-preppers 2017; Fogaosolar 2017; Scidev 2017; Yankodesign 2017; NYtimes 2017; Saracentre 2017)
After the development of the mood board, the necessity for a personal experience was evident, where I could experimentally cook using existing products that concentrate the heat of the sun, and where I could experience and identify the strengths and weakness of the technology. Crosby Menzies, from Sunfire Technologies (Pg. 65) lent me one of his solar stoves “Sun Fire 1.2”, a parabolic concentrator with a diameter of 1.2 meters (Figure 63). This afforded me the opportunity to use the technology and become accustomed to physically interacting with and utilising the sun for cooking. During some mornings at about 11:00, I cooked different dishes such as vegetable stew, beans, and even bread cooked in a pot. On a sunny day a stew took 2.5 hours of simmering until fully cooked. The heat generated is comparable to that of a hot-plate, with the ingredients within the pot getting easily burnt if not attended. This illustrates the available energy, and the power. Some of the problems during the cooking were the transport of the stove due to its size, strong wind which can turn over the stove, the need to redirect the stove towards the sun every 10 minutes, the loss of heat while clouds cover the sun (that is recovered immediately after they pass), and the dangers if the stove is unattended because the sun beam can burn items around the edge of the pot.

![Figure 63: Cooking with the sun with the Sun Fire 1.2 parabolic concentrator (Photo by the author).](image)

At the same time, a solar box oven was fabricated to understand how this operates compared to the parabolic stove in the way that the sun’s rays pass through the glass. In this case the maximum temperature obtained was 80°C, enough to cook pasta or rice, but not enough to bake bread that needs a temperature of approximately 120°C (Figure 64). After this experience I understood what it is to cook with the sun and I was ready to develop the designs.
Form development

The form development of the Heliotropic Stove was undertaken by dividing the system up into the core sub-systems. These are as follows: a solar concentrator through parabola; a chassis to support the parabola, a pot holder to act as a base of the structure; and a solar tracking system in the vertical and horizontal axis that comprises hardware and software.

For the development of the parabola, the considerations to build it were: the catchment area of at least 1[m²], being able to concentrate approximately 1 000[W/m²], to include a reflective surface in the parabola (Figure 65 B), and to determine the focal point where the pot is placed (Figure 65 A).

In the case of the chassis, the considerations to develop it were to determine the dimensions of the structure according to the average South African woman's height for the 5% percentile of the population, that is 1.51[m] (Figure 65 C) (annexe VIII). Therefore, the distance between the elbow and the floor, around 90[cm], was determined as an adequate distance to place the pot-holder (Figure 65 B). The pot-holder has to support the pot and its contents, thus the structure is reinforced in this zone in case of overload. The pot holder is designed so that it can move up and down, controlling the amount of heat that it receives (Figure 65 E). The parabola is linked to the chassis through two pivots in the sides, allowing it to freely move in the vertical plane (Figure 65 F). Because of the outdoor condition of the stove, the base has to support the whole structure as well allow it to be mobile (Figure 65 B-D), looking for the structure to be as light as be possible. For all these requirements, several configurations were explored as can be seen in Figure 65 D.
Finally, the chassis has to allocate the solar tracker system for the vertical and horizontal movements (Figure 66 D). Several configurations of the system were explored, including the possibility to move the structure with a clock mechanism that was discarded because of its complexity. An electronic mechanism was determined as the most suitable to follow the sun movements. The sun’s incoming light is measured with sensors that send that information to a microcontroller where the data is processed and which in turn send a signal to move a pair of stepper motors, following the sun.

For the vertical and horizontal movements three possibilities of tracking mechanisms were explored: to place the motors directly into the axis of revolution (Figure 66 E); to use drive belts attached to a pulley and then to the motors (Figure 66 C); and one motor coupled to a linear shaft, which in turn is attached to the parabola for the vertical movement (Figure 66 A), as well as to divide the chassis that holds the parabola and the base with a swivel couple, and attaching another motor to a wheel in the chassis allowing it to move in the horizontal plane (Figure 66 D). These mechanisms are essential for the correct function of the solar tracker system so they were built to compare their effectiveness (Figure 72).
Figure 65: A brainstorming of sketches exploring the components of the system: parabolic concentrator, chassis and solar tracker (Sketches by the author).
Figure 66: Sketches exploring mechanism and the position of the motors for the solar tracker system (Sketches by the author).
Prototype

With the systems and components of the solar stove identified, the first attempts to develop the prototype were through scale models and mockups exploring (Figure 67) different configurations for each system. Next, the build of the prototype and its systems: parabola, chassis and base and the hardware and software of the solar tracking system is presented.

Figure 67: Study mockups of the size of the solar stove, identifying the relations with the intended users, and possible mechanism to follow the sun (Photos by the author).

Parabola

The size of the parabola was defined to be 1[m²] concentrating around 1 000[W/m²] (Section 3.1.4.1. pg. 36), enough heat power for cooking purposes. During the study exploration, the use of a recycled satellite dish with a diameter of 1 [m] was identified as an affordable possibility, a “ready-made parabola” widely used in South Africa, purchased in a dump site. After some cleaning of the satellite dish, a window glass tint mirror reflection film sheet was used as the reflection surface. This film is a sticky on the back and was attached to the surface of the satellite dish (Figure 68).

Figure 68: Adhesion of the reflection film sheet to the satellite dish sequence (Photos by the author).
Chassis and base

The parabola, the base, the pot holder and the solar tracking system has to be distributed and allocated in the chassis. Taking into account the size of the satellite dish and a woman’s height for the 5% percentile that is 1.51[m] presented in annexure VIII, the chassis structure was developed.

The structure was built from a steel square tube of 90[cm] x 40[cm] x 90[cm] and 19[mm]. To follow the sun’s movements, the chassis has to allow the vertical and horizontal movements of the parabola. For the vertical movement a coupling is included to hold the parabola from the sides and attached to the solar tracking system from the bottom area (Figure 68). For the horizontal movement the parabola is supported separately from the base and linked with a swivel coupling, allowing the parabola to revolve without turning the base. Following the design considerations to use readily available components, in this prototype a reused swivel (from a supermarket-trolley-wheel) was used (Figure 69).

![Figure 69: Swivel coupling mechanism, recycled from a supermarket-trolley-wheel (Photos by the author).](image)

The base supports the whole structure with its components and also has to allow the movement of the solar stove to be positioned outdoors. A base consisting of four legs was built as a first attempt; but it wasn’t stable. A steel plate of 10[cm] thickness with four bolts attached was used, allowing to the swivel coupling from the chassis to be unmounted, and four wheels were added to the structure (Figure 70).

![Figure 70: Swivel coupling mechanism, recycled from a supermarket-trolley-wheel (Photos by the author).](image)
For the pot holder, a circumference to support an 8 litre pot with a diameter of 28[cm] (Figure 71) is attached to the chassis following the horizontal movement of the parabola. The pot holder was designed to adjust the pot up and down regulating the amount of heat that reaches the pot.

The whole structure is painted with a white anti-rust water based coat for outdoor protection, taking advantage of the white colour as reflector of the light to keep the structure cold, in opposition to black that absorbs wavelengths of light transforming them into heat.

*Figure 71: Pot holder (Photos by the author).*

**Solar Tracking system**

Solar-tracking systems are used to modify the angle of incidence of light and align the solar concentrators to maximise the amount of solar radiation absorbed, improving the energy production between 20% to 80% over the day and from 20% to 40% annually (Muhyiddine & Saffa 2012:221). Plainly put, the components of an automatic solar-tracking system include electro-optical photo-sensors that provide feedback signals that measure the light and shade in the environment, those signals are processed in a microcontroller, that send control signals to the actuators, two stepper motors moving the parabola in the vertical and horizontal plane.

For this project an active tracking system was chosen, liberating the chef from the responsibility to redirect the sun’s beams to the pot during the process. After extended literature and internet research, research with practitioners as well as personal experience, the microcontroller Arduino was identified. This is an open source platform used for building electronic projects (Arduino 2017:[sp]). Arduino consists of a programmable microcontroller and software or IDE (Integrated Development
Environment) that runs on a computer. To write the code, Arduino IDE uses a simplified version of C++\(^5\), making it easier to learn to program, a feature that has been helping artists, designers and architects to implement Arduino in their projects (Ibid 2017:[sp]). On the web it is possible to find several projects that use this platform as a solar tracker; most of them as do it yourself\(^6\) (DIY) experiments. Using those experiments as reference, a novel hardware arrangement for vertical and horizontal movements was developed. For the software development, Arduino codes for a solar tracker system are widely and freely available for different kinds of hardware configurations. Based on those codes, and adapting them for the specific stepper motors used in this project, the code was written. Next, a description of the electronics of the solar tracker system is given.

**Solar Tracking system. Hardware.**

The solar-tracker system, a sub-system of the solar stove prototype consists of hardware and software (Figure 74). The hardware comprises four light dependant resistor (LDR) sensors that measure the incident light. The sensors are placed in the bottom of a box separated by walls between them, allowing them to separately sense the incident light. The input signals then are sent through cables to the Arduino where they are processed, sending an output control signal to two stepper motors, one for the vertical movements (MotorV) and another for the horizontal movements (MotorH).

![Figure 72: Solar tracking system configuration study (Photos by the author).](image)

In Figure 66 sketches of the study for different tracking system configurations are presented, and in the Figure 72 prototypes of these configurations are shown: a drive

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\(^5\) C++ is a general-purpose programming language providing facilities for low-level memory manipulation, standardised by the International Organization for Standardization (ISO).

\(^6\) Do it yourself (DIY) is the method of building, modifying, or repairing things without the direct aid of experts or professionals.
belt pulley system, an arm mechanism, a linear shaft for the vertical movement and a wheel for the horizontal movement, elected as the most suitable tracking mechanism.

The MotorV is connected to a linear shaft, attached to the bottom of the parabola, running back and forward depending on the signals received from the LDR. The MotorH is attached to a wheel placed at the front of the structure, following the azimuth angle towards the sun from east to west. In the annexure X the parts of the solar tracker system are described in detail.

The components of the solar-tracking system are as follows, and the schematics and presented in Figure 73:
- 4 LDR sensors
- Electronics
  - Arduino + Code, powered with a Lithium Polymer battery 7.2[V]
  - DVR8825 motor controller powered with a battery 12[V]
- Y Axis, vertical movement. Stepper Motor attached to a linear shaft
- X Axis, horizontal movement. Stepper Motor attached to a wheel

**Solar Tracking system. Software.**

The code of the solar-tracking system consists of three main sections: the declaration of the variables, the initialisation of the program; and a loop of the program, sending control signals to the stepper motors. In the first section, the LDR as an input signal and the stepper motors as an output signal are declared. The second section initialises the program reading the LDR input signals, calculating the average of the Top-Bottom and the Left-Right variables. The third section is the calculation of the average input from the Top-Bottom LDR and moves the parabola with the stepper motor until the average zero is reached. After that, the same process is executed for the Left-Right LDR. The third section is looped during the whole day. In the annexure XII the code of the program is presented, encouraged to be used and improved if necessary.
Figure 73: Sketches and diagrams of the connections and the code of the solar tracker system (Sketches by the author).
During the development of the prototype the solar tracking system was the most complicated part, matching hardware and software. Part of the process is presented in the Figure 74. In the annexure XI a report of the communication problems between Arduino and computer is presented. Figure 73 presents a hand written section of the code, for easier understanding of it.

*Figure 74: Photographs showing the development of the software and hardware for the solar tracker (Photos by the author).*
Cost of the prototype

In Table 12 a list of the materials with their approximated cost to build one unit of a parabolic stove is presented. The total cost of the materials used to build the prototype was a bit less than R 2 500 and all the components were purchased in South Africa, with some of them acquired as upcycling discarded items as in the case of the parabolic dish, and the stepper motors reused from an old printer plotter. In the case of the couplings for the stepper motors, they were 3D printed. For the labour the price is not estimated yet, because further optimisation to calculate how many units could be produced in a week is needed. Nevertheless, at least two technicians should be involved in the production, a mechanical technician for the concentrator and the chassis, and an electronic technician to build and program the electronics in the solar tracker system.

Table 12: Heliotropic Parabolic Stove Prototype costs (Table by the author).

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost per Unit (Rand)</th>
<th>Total (Rand)</th>
<th>Supplier</th>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Parabolic dish</td>
<td>Unit</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Window film dark Silver</td>
<td>Unit</td>
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<td>30</td>
<td>30</td>
<td>Commercial auto parts</td>
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<td>Bolts and nuts</td>
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<td>1</td>
<td>10</td>
<td>10</td>
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</tr>
<tr>
<td><strong>Chassis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parabolic support. Tube 19mm</td>
<td>6m</td>
<td>0.5</td>
<td>92</td>
<td>46</td>
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</tr>
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<td>Pot holder. Tube 19mm</td>
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<td>0.5</td>
<td>92</td>
<td>46</td>
<td><a href="http://www.njrsteel.com/">http://www.njrsteel.com/</a></td>
</tr>
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<td>300</td>
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</tr>
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<td>1</td>
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<td>53</td>
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</tr>
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<td>50</td>
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</tr>
<tr>
<td><strong>Solar tracker</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDR sensors RL=100[K] RD=20M</td>
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<td>4</td>
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</tr>
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<td>Resistor 1[K]</td>
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<td>275</td>
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<td>Li-Ion Battery 7.5[V] 2600[mAh]</td>
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<td>10</td>
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<td>Stepper Motor Bipolar 23LM-K202V</td>
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<td>600</td>
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<td>185</td>
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<td><strong>Total cost</strong></td>
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<td></td>
</tr>
</tbody>
</table>
3.3.2. Thermosiphon Solar Water Heater

Design Concept

The design concept for the solar water heater is derived from the thermosiphon phenomenon, a passive heat exchange, which uses natural convection to circulate a fluid without the necessity of a mechanical pump. The concept is a “Thermosiphon Solar Water Heater”.

Mood Board

In the “Thermosiphon solar water heater” mood board, is presented an exploration of commercial and homemade solar water heaters is presented (Figure 75). The homemade solar water heaters consider the access to materials and local production. The components of the system are: a container, where the water is stored, a pipe where the water flow is being heated and a structure that supports the components. The container is always above the zone where the water is heated, insulated usually with foam. The water is heated while circulating through a black pipe that can be plastic -usually HDPE- or a copper pipe painted black, taking advantage of the conductive properties of this metal. The disposition of the pipe can be in a parallel arrangement connecting each other with elbows or in a spiral, where the water can flow without interruptions through the spiral shape and utilising the material as per commercial presentation, reducing the welding spots. To accumulate enough energy to heat the water inside the pipe, a flat solar box is utilised, catching and storing the solar heat. All of the alternatives have to face the sun directly and depending where they are placed and the specific use, they can be static, attached to a roof, or mobile.

For the insulation of the tank, the thermal transmittance of different organic materials was researched. The thermal transmittance is defined as the measure of how much heat passes through a square meter of a structure, when air temperature on either side differs by one degree, called the “U Value”, expressed in [W/m² K]. A lower “U Value” means a lower transfer of heat through a thermal element. A table with the values for different materials is presented in the annexure XIII.
Figure 75: Mood board of solar water heaters, identifying materials and shapes (Poolheaterguide 2017; Hunker 2017; Lifehacker 2017; Bigissueshop 2017; 6sqft 2017; Energiaestrategica 2017; Labioguia 2017; Taringa 2017)
Form development

After the exploration in the literature review chapter a mood board (Figure 75) and sketches (Figure 77), the components of a Solar Water Heater system can be identified as follows: an insulated water tank, a solar heating zone, and a chassis to support the components (Figure 77 B). In terms of usability, the three main interactions between the user and the solar water heater are: to get hot water through a tap (Figure 76 A), to refill the tank with water (Figure 76 B), and to move and direct the system towards the sun, making it a mobile product (Figure 76 C). With the three human-object main interactions identified, the idea was to resize a conventional solar water heater to a smaller scale. As a reference of size, a water dispenser is taken where the tap is placed about 1 meter above the floor for easy access. This height defines the size of the whole object.

In the design considerations the amount of available water needed during the process was at least 3 litres, therefore a commercial tank of around 3 times that capacity, was considered to ensure sufficient water for the process. The tank has to be connected with a pipe that carries the water to the heating zone, making a closed loop of flow. The solar heating zone is based on the flow of the water through a pipe exposed to the sun. A pipe painted black captures and transfers the heat to the water and, taking advantage of a solar oven heat retention, the pipe is enclosed in a solar oven type box to capture and retain the heat gained (Figure 77 C-D). Finally, the chassis has to support all the components, hence different configurations were explored as shown in Figure 77 E. The solutions with the least amount of materials to support the tank and the solar heating zone were considered. A tripod was chosen as the structure to act as chassis.
Figure 77: Sketches exploring the components of the water solar water heater system: Water tank, chassis, solar box and copper pipe (Photos by the author).
Prototype

Insulated water tank

For the prototype development, the tank used is recycled from an 8 litre electric urn. The electric components were dismantled, utilising the stainless steel tank for water storage. The water tap located at the bottom of the tank, determined its height according to the distance elbow-ground of the 5% percentile of the population (annexure VIII), around 1[m]. With this distance fixed, a three leg wooden chassis to support the structure was built. In the first structure the wooden legs were placed straight, resulting stability problems. With the legs placed at an angle of 30 degrees and joined with curved steel plates at the top and the bottom of the tank, the structure was stable (Figure 78). For the insulation of the tank a solution similar to a retaining heat cooker bag is proposed.

![Figure 78: The development of the wooden chassis (Photos by the author).](image)

Solar heating zone and chassis

The chassis has to support the zone where the water is heated, a spiral copper pipe painted black through which the water flows while it is heated by the sun. When water gets hot and rises, a phenomenon known as the thermosiphon effect occurs, explained in the section 3.1.5.4. A 10 metre copper pipe of 9[mm] diameter is installed inside a modified solar oven, a sealed wooden box of 450 x 450 x 50[mm] painted black, with a 2[mm] doubled glass lid to capture and retain the heat, as can be seen in Figure 79.
The connection between the copper pipe and the tank is through bronze couplings, one at the bottom of the tank and the other in the middle. The cold water flows through the coupling, placed at the bottom, heated while circulating in the pipe and rising when it is hot and moving back to the tank through the upper coupling (Figure 80).

Finally, the solar box with the pipe is installed at the bottom front of the tank, and a new leg was added due to the weight of the copper pipe once filled with water. The entire structure is painted black for uniformity (Figure 81). Although wooden brandering was used for this prototype, a more appropriate material would be thin square metal tubing as was utilised in the Heliotropic Stove.
Figure 81: Development of the prototype and the first tests to heat water (Photos by the author).

Cost of the prototype

The approximated costs to build the prototype for the Thermosiphon Solar Water are shown in Table 13, approximately R3 000. Some of the costs were assumed, as in the case of the stainless steel pot and its insulation, because they were upcycled from an old electric urn. The construction cost has to be calculated with a single technician, due to no complicated parts having to be built. All the materials are available in South Africa.

Table 13: Thermosiphon Solar Water Heater prototype costs (Table by the author).

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost per Unit (Rand)</th>
<th>Total (Rand)</th>
<th>Supplier</th>
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</tr>
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</table>
3.3.3. Photovoltaic food-process workstation

Design Concept

In the case of the blender, it was determined that an electric blender would be utilised, powered with a Solar Power System. Because a surface to process the food is also needed, a working station that includes a photovoltaic powered blender, a surface to cut or peel the ingredients, a space to store ingredients and tools, and a shelter to protect the user from the sun were proposed. The concept is a "Photovoltaic food-process workstation".

Mood Board

The mood board prepared for the "Photovoltaic food-process workstation" (Figure 82) shows images that serve as a reference and inspiration for materials, size of the surface, mobility, solutions for storage and how to include a solar panel in the working station. For the materials, a combination of wood and a metal frame are the option that would best suit the requirements of the station. The same considerations for the previous solutions were taken namely easy access and relatively low cost of the materials and possibilities to be built. The height of the station responds to the needs of cooking, an activity that is on foot, so the distance from elbow to floor is considered, about 90[cm], while the size of the surface has to consider the needs of processing the ingredients. Different types of wheels are used for mobility, castor or bicycle wheels where bigger wheels are preferred if the terrain is not uniform. For the storage the solution of plastic boxes was explored, similar to those usually used to transport vegetables or bottles, providing a cheap and easy solution. A beach umbrella is identified as a solution to solve the need for shade and for the photovoltaic installation a solar panel, and a battery and an inverter that can power a blender is identified as the equipment needed to be included.
Figure 82: The mood board for the working station presents inspiration for materials, surface, mobility and storage (Core77 A 2017; Core77 B 2017; Bluepacificsolar 2017; Dwell 2017; Coolhunting 2017; Workshopped 2017; Worldarchitecturenews 2017; Antic-chic 2017; Core77designawards 2017; Moncoindesign 2017; 45kilo 2017).
Form development

After the exploration presented in the mood board (Figure 82) several sketches were developed (Figure 83), and the components of the “photovoltaic food-process workstation” were identified as follows: a working surface, a storage space, structure, shade, and a solar power system including a blender powered by a solar panel, controller, inverter and battery. A structure to support the components is finally needed.

On the working surface the main activities are to cut or peel the ingredients using tools such as spoons, knives and bowls to finally blend the ingredients. Figure 83 D, shows the distribution of the tools on the surface that is defined as a minimum space of 400 X 900[mm]. During the activity it is necessary to provide shade for the user to be comfortable while working with the ingredients. A beach umbrella is proposed as shade as it is relatively cheap and easy to find (Figure 83 B).

Defined as an outdoor product, the tools and ingredients have to been transported from a place such as an indoor kitchen, utilised during the activity and then taken back to be cleaned and safely stored. For this application, a mobile crate is proposed, taking advantage of the plastic crates widely available in grocery shops and stores, having a place in the structure from which they can be removed (Figure 83 D).

An electric outlet to principally power a blender and also to charge, for example a mobile phone, is included, being powered by a solar power system (Figure 83 E). This system includes a solar panel, a controller, a battery and an inverter to connect the load in this case a blender.

Finally, the structure of the working area has to allocate a place for the surface, the crates and the solar power system. Being a mobile station, the structure is designed with wheels allowing for easy displacement on a grass or soil surface (Figure 83 A).
Figure 83: Sketches exploring the components of the “Photovoltaic food-process workstation” (Sketches by the author).
Prototype

The following section describes the development of the prototype and the materials used.

Working surface

The cutting, peeling and measuring of ingredients and blending them are the most common activities while processing food. A surface of 90[cm] x 40[cm] was determined as the minimum space needed to perform these activities. For the surface 18[mm] thick plywood was used, and because is for outdoor use an exterior wood sealant was applied.

Structure

The structure was built from a steel square tube of 90[cm] x 40[cm] x 90[cm] and 19[mm] (Figure 84 A), making it light and robust, so that it can be moved outdoors. An L shape steel angle was added to the structure to support the two plastic crates, which in each extreme were bent to maintain the boxes in place (Figure 84 B). The structure is painted with a white anti-rust water based paint, the same paint used on the Heliotropic stove. Four wheels are added ensuring the mobility of the structure that are painted with anti- rust water based paint (Figure 84 C).

*Figure 84:* (A) Structure of the working station; (B) L shape with bend extremes; (C) wheels in the structure (Photos by the author).
Storage space

Vegetables and spices are some of the ingredients that need to be cooked, and together with pans and other cooking tools are used during the activity. A place to store them is necessary to perform the activity. A pair of plastic crates of 42[cm] x 32[cm] x 30[cm] is used as drawers. These crates are widely available locally, can be purchased at a low cost and can be easily replaced.

Shade

For the shade a beach umbrella is used. A tube installed in the structure works as the support for the umbrella that is easily bought on the streets of Johannesburg.

Solar Power System

In order to power an electric blender, one of the activities needed during the processing of the food, and also to be able to charge devices such as a cell phone or a laptop, electricity is provided from a photovoltaic module (See section 3.1.6) (Figure 85 A). This module of 40[cm] x 20[cm] is connected to a controller—an electronic device that regulates the input energy from the photovoltaic module to a battery- and this in turn is connected to a 12[V] and 7[Ah] battery. The battery—the same used to power the stepper motors in the solar stove— are connected to an inverter 12[V] DC to 230[V] AC (Figure 85 B), an electronic device that changes direct current (DC) to alternating current (AC). Finally, the blender of 200[W] is plugged into the inverter.

Figure 85: Solar power system components (A), and a power inverter (B) (Photos by the author).
Cost of the prototype

In the Table 14 presents the approximate cost of the components that conform the Photovoltaic food-process workstation. The components are not complex to build as the electronics use simple connections, therefore the labour cost has to be estimated with a single technician. All the materials and components are available in South Africa.

Table 14: Photovoltaic food-process workstation prototype cost (Table by the author).

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost per Unit (Rand)</th>
<th>Total (Rand)</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frame</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square tube 19mm</td>
<td>6m</td>
<td>2</td>
<td>96</td>
<td>192</td>
<td><a href="http://www.njrsteel.com/">http://www.njrsteel.com/</a></td>
</tr>
<tr>
<td>L shape 25X25mm</td>
<td>6m</td>
<td>1.6</td>
<td>62</td>
<td>99</td>
<td><a href="http://www.njrsteel.com/">http://www.njrsteel.com/</a></td>
</tr>
<tr>
<td>Anti-rust Coating</td>
<td>20L</td>
<td>0.05</td>
<td>1600</td>
<td>80</td>
<td><a href="https://www.builders.co.za">https://www.builders.co.za</a></td>
</tr>
<tr>
<td><strong>Storage space</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic crate</td>
<td>Unit</td>
<td>2</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td><strong>Shade</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beach umbrella</td>
<td>Unit</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Working surface</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plywood board 2440mm x 1220mmX15mm</td>
<td>Board</td>
<td>0.5</td>
<td>400</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Woodoc 50 Marine Sealer</td>
<td>500ml</td>
<td>1</td>
<td>148</td>
<td>148</td>
<td></td>
</tr>
<tr>
<td><strong>Wheels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80X60XD70mm</td>
<td>Wheel</td>
<td>4</td>
<td>75</td>
<td>300</td>
<td><a href="https://www.builders.co.za">https://www.builders.co.za</a></td>
</tr>
<tr>
<td><strong>Electronics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Panel 20[W] 400X300mm</td>
<td>Unit</td>
<td>1</td>
<td>285</td>
<td>285</td>
<td><a href="https://www.sustainable.co.za">https://www.sustainable.co.za</a></td>
</tr>
<tr>
<td>Controller</td>
<td>Unit</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverter 12[V]-230[V]</td>
<td>Unit</td>
<td>1</td>
<td>300</td>
<td>300</td>
<td><a href="http://www.westdenecycles.co.za/">http://www.westdenecycles.co.za/</a></td>
</tr>
<tr>
<td>Battery 12[V] 7[Ah]</td>
<td>Unit</td>
<td>1</td>
<td>185</td>
<td>185</td>
<td><a href="http://www.mantech.co.za">http://www.mantech.co.za</a></td>
</tr>
<tr>
<td>Blender 200[W]</td>
<td>Unit</td>
<td>1</td>
<td>180</td>
<td>180</td>
<td><a href="https://clicks.co.za">https://clicks.co.za</a></td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>1989</td>
<td></td>
</tr>
</tbody>
</table>
3.3.4. Brand image

To give an image to the project, the Heliotropic Parabolic Stove concept was used as the most iconic part of the Solar Harvester System. The idea was to conceptualise the capacity of plants to follow the sun during the day. A development of these concepts is shown in Figure 86 where two names were proposed Landela-Ilanga which is a Zulu phrase which translates to "follow the sun" as a plant does during daylight hours. The second name was Intilanga, a free mix of the word Inti, that in Quechua -the language of the Incas -means sun, and Ilanga that in Zulu means sun.

![Image](image-url)

*Figure 86: Development of the logotype for the project (Sketches by the author).*

In Figure 87 the final imagotype is presented, following the concepts stated. The typography used is African Culture font created by Dan P. Lyons in 2016, licensed as freeware, and can be downloaded at www.fontspace.com (Lyons, 2016:sp)).

![Image](image-url)

*Figure 87: Final imagotype for the Intilanga project (Sketches by the author).*
3.4. PHASE 3: LABORATORY PROTOTYPE TESTING

The purpose of the laboratory test was to evaluate how effectively the prototypes performed the required activities. The tests for the three appliances were performed in an open space inside the Faculty, where the sun was shining most of the day without shade (Figure 88). Three tests were undertaken, one with each appliance: For the Heliotropic stove the Test A: Bring a litre of water from 20˚C to 70˚C; for the Thermosiphon solar heater the Test B: Variation of water temperature during the day; and for the Test C: Photovoltaic food-process workstation, the capacity to power a blender. These results guided the optimisation of the solar appliances, and in the annexure VI the test procedure is presented.

![Figure 88: Open space in the university where the test was held (Photo by the author).](image)

3.4.1. Instruments

During the test, the following instruments were used (Figure 89):

- Temperature and Humidity USB data logger, SSN-22ET.
- Waterproof digital food thermometer, FLUS Technology.
- Solar insolation estimation, based on the equation of the sun's position in the sky throughout the year. See section 3.1.4.3.
- Digital multimeter, to measure electrical values.
3.4.2. Test A: Bring a litre of water from 20°C to 70°C

For the first test the time needed to bring a litre of water from 20°C to 70°C was measured. A comparison between the “Heliotropic solar stove” and the “Sun Fire 1.2” was held performing the same experiment, presenting the results in the following graphs. The horizontal axis represents the time; the vertical axis on the left side represents the temperature in °C; and the vertical axis on the right side the solar irradiance in W/m². In a light blue line, the ambient temperature is graphed, in grey the temperature of the water, and in orange the solar insolation estimation is graphed (PVeducation, 2017:sp). The annexure XIV presents the tables with the data collected.

![Graph](image)

Figure 90: The values for the experiment to bring a litre of water from 20°C to 70°C, with the Heliotropic Parabolic Stove, 03 November 2017. (Graph by the author).

During the Heliotropic Parabolic Stove test, the changes of temperature of one litre of water were measured with the waterproof digital food thermometer every 5 minutes...
(Figure 91). The initial water temperature was 28.5°C at the 13:30 with an irradiance of 1.03 [W/m²]. It took almost one hour to heat the water to 73°C.

On the 30 of October 2017, a partly sunny day, the same experiment was performed with the Sun Fire 1.2 parabolic stove, comparing its capacity to heat the water with the Heliotropic Solar Stove. The initial water temperature was 24.5°C at 14:50 with an irradiance of 0.98[W/m²], shown in the Figure 92. The temperature was measured every 5 minutes and took around 15 minutes to reach the 73.5°C at 15:05. Ten minutes later the temperature was 94.3°C. During the test the position of the stove was manually adjusted in the vertical and horizontal axis every 5 minutes, for the sun’s beam to focus on the underside of the pot (Figure 93).
Both stoves reached the desired temperature of 70°C and it was observed that the Sun Fire 1.2 stove took 15 minutes to reach the temperature, while the Heliotropic parabolic stove heated 1 litre of water in just under an hour. These results can be explained due to: the different catchment area between the stoves, with a parabola diameter of 1[m] in the case of the Heliotropic stove, and a diameter of 1.2[m] for the Sun Fire; and the accuracy of the beam that reached the pot. In the case of the Heliotropic stove the shape of the beam is a line, reaching only a part of the concentration power to the pot, while in the case of the Sun Fire stove a perfect point
reaches the base of the pot. Finally, it was the need for manual adjustment of the Sun Fire stove was checked every 5 minutes for a successful performance, while the Heliotropic Stove adjusted its position automatically towards the sun. The capacity of the solar tracking system to follow the sun during the day was observed and the movements of the stepper motors following the azimuth and altitude angle variations of the sun during the day were checked (See section 3.1.4.3.).

### 3.4.3. Test B: Variation of water temperature during the day.

For the Thermosiphon water heater, the variation of the temperature was measured from 10h00 in the morning to 15h00 in the afternoon and every hour the data was recorded.

![Figure 94: Thermosiphon Solar Water Heater test, July 25 2017 (Graph by the author).](image-url)

![Figure 95: Thermosiphon Solar Water Heater test, July 26 2017 (Graph by the author).](image-url)
The test results are shown in the Figure 94 and Figure 95, where it can be seen that the temperature of the water (grey) inside the Thermosiphon Water Heater rose to 22°C, while the ambient temperature (light blue) increase until 29°C. The test results were not favourable because what was expected was that the temperature of the water could reach around 70°C. The Thermosiphon Water Heater was checked, observing that the copper pipe wasn’t filled with water and some air inside was blocking the flow, and therefore the thermosiphon effect is not reached. Further improvement to get the thermosiphon operating effectively is necessary.

3.4.4. Test C: Photovoltaic food-process workstation

Finally, the Photovoltaic food-process workstation capacity to power the blender was confirmed. During October 29, in a cooking experience the electric blender was powered with the Solar Power System included in the workstation. In this case six eggs were blended for 2 minutes, enough time to mix all the ingredients (Figure 96).

Figure 96: Test C, the blender was powered with the Solar Power System (Photo by the author).
Three tests were performed to check the performance of the solar appliances. Test A proved the capacity to heat water from 20°C to 70°C of the Heliotropic Parabolic Stove and compared with the SunFire stove. In Test B, the variation of the water temperature inside the Thermosiphon Water Heater was measured. Even if the water temperature raised, it’s was not successful due to problems to assure the water flow inside the pipe. Further improvements are needed to finalise the test. Test C confirmed the capacity to power a hand blender with the Solar Power System. For a standardised development, it's possible to join the Technical Committee 285 of the International Organization for Standardization (2017), to develop standards for clean cook stoves where harmonised laboratory protocols, a conceptual framework and test the social impacts of this kind of technologies, can be discussed.
3.5. PHASE 4: PARTICIPANTS TESTING

The last phase of this research was the testing of the prototypes in the field with the participants of the study. Three experiences were held during the end of September and October 2017, in an open terrace at the Faculty of Art, Design and Architecture of the University of Johannesburg (Figure 97). The participants were invited to spend the morning in an open interview. Refreshments were provided (water, tea, coffee), as well the ingredients with which to cook.

During the sessions the participants were asked to prepare their products in the Heliotropic parabolic stove, as much as possible, in the same way as they do in their working places. While cooking with the sun and when finished, the benefits and disadvantages of the appliances to perform their activities were discussed, understanding the concerns of the participants and their willingness to use the prototypes. Participants were requested to think aloud, and if they wanted to, to write or draw the improvements and suggestions for further discussion. The sessions were recorded in audio and video and notes and photographs were also taken. The comments from the participants during the sessions lead to final improvements of the prototypes.

Figure 97: Open terrace at the Faculty of Art, Designs and Architecture where the participant tests were performed (Photo by the author).
The structure of the in-field tests with the participants were as follow:

- Illustrate and explain the aspects of the solar stove, use, function and composition.
- Align to the sun and start to cook.
- Start the cooking with the participants, simulating how they perform their activities.
- During the cooking, discuss the likes and dislikes about the appliance, asking for improvements: Taking notes, video and photo records.
- Finalise the interview.

The next sections describe three experiences where the participants of the study were invited. To gather more and different opinions, people familiar with food preservation and/or cooking were invited to test the solar appliances and share their opinions about the experience of solar cooking. Participant 2 (P2) “Honey Pod Body Soap” took part in the test, but due to time constraints participant 1 (P1) “Isiziba Roasted Chillies” and participant 3 (P3) “Yamama Ginger Beer” were unable to visit for testing the prototype. A fourth (P4) and a fifth (P5) participant also took part in the test. During the sessions, the solar stove “Sun Fire 1.2” was available to cook with two pots at the same time if needed and to compare the improvements of the technology for the participants (Figure 98).

*Figure 98: The Heliotropic Parabolic Stove and the Sun Fire 1.2 (Photo by the author).*
3.5.1. Experience I

The organic body soap producer participant 2 (P2), was invited to visit the Faculty on the Friday 13\textsuperscript{th} of October 2017. The participant arrived at 12h30 to the Faculty, and after a conversation and drinking some water we started to work with the appliances at around 13h00. First, a mix of caustic soda and water was heated in the pan for 30 minutes until almost boiling. Olive oil was separately heated, and the temperature was taken of both liquids; 80°C for the mix of caustic soda and 60°C for the oil, letting them cool until the temperatures matched and then they were mixed. To finalise the soap preparation, it was heated in the stove for about two hours, and then left to cool and packaged in a glass jar, closing the session (Figure 99) at around 15h00.

![Figure 99: Experience I, preparing liquid soap (Photo by the author).](image)

After the experience the participant noted some suggestions for improvements, such as the inclusion of a support for two pots and a zone to braai, presented in the Figure 100 and summarised in Table 15.
3.5.2. Experience II

For the second experience, a fourth participant was invited for lunch and to cook rice and a vegetable stew. We started to cook the rice around 13h00 on Sunday 15th October which was a relatively sunny day. After one and a half hours the rice was ready, and then the vegetables were stirred and cooked, around 14h30. For this occasion, the solar stove “Sun Fire 1.2” was used to accelerate the process, because of its bigger catchment area concentrating more energy. Once prepared, we ate together and discussed the process. After the meal at around 15h15 a coffee was prepared on the solar stove using a Bialetti type coffee maker. It took around 30 minutes for the coffee to be ready (Figure 101). After the coffee the session was finished.
3.5.3. Experience III

For the third experience a fifth participant was invited to cook a late breakfast, starting at 11h00 in a partly cloudy morning during October 29 (Figure 102). The preparation started, heating the oil and frying onions, the base to prepare an omelette. At the same time, the solar oven built at the beginning of the research was used to defrost and warm sliced bread while cooking. The eggs, tomato and herbs were mixed with a hand blender, using the photovoltaic workstation for food processing. After 30 minutes the onions were fried, and the egg mix was added into the pot, stirring for 30 more minutes, being ready at 12h00. Finally, the bread was warm, and we eat at around 12h15.

Figure 102: Experience III, preparing an omelette (Photos by the author).
3.5.4. Participant’s comments for improvements

A summary of the participant’s comments are presented below in Table 15. These are the points discussed with the participants once cooking was completed and the summary includes recommendations for improvement.

Table 15: Participant’s comments (Table by the author).

<table>
<thead>
<tr>
<th>EXPERIENCE</th>
<th>FOOD COOKED</th>
<th>IMPRESSION OF USE</th>
<th>RECOMMENDED IMPROVEMENTS</th>
</tr>
</thead>
</table>
| Experience I| Organic body soap.                    | “Amazing”. “This could be applied in rural areas”.     | • Specify the dangerous zones  
• Include health and safety instructions  
• Include a braai stand  
• Adjust the height of the stove for different sizes of users  
• Disassemble the structure  
• Stabilise the structure from strong wind  
• Include a working station to prepare the ingredients  
• Include a second mobile pan holder |
| Experience II| Rice and vegetables stew.             | “Good, but will work better with improvements”.        | • Try a shape of the satellite dish for accurate and precise heating point  
• Include an indication of temperature  
• Adjust the temperature |
| Experience III| Omelette. A mix of eggs, garlic and onion. | “I didn’t believe that it will work, it’s great”. “It will help me save electricity”. | • The photovoltaic panel should be integrated into the workstation, to have enough space to prepare the ingredients.  
• A place to leave the lid of the pot while stirring the food. |

All of the participants who tested the cooking prototypes have indicated their acceptance and overall positive reaction to the use thereof. What was extremely beneficial is that through using the prototypes only once, the participants were able to provide beneficial critical comments to what they think could make the units easier to use to be applied in a further study.

3.5.5. Design requirements review

The design requirements (section 3.2.1.4) that guided the construction of the prototypes are revisited and presented in Table 16, summarising the decisions taken during the development.
Table 16: Design requirements review. (Table by the author.)

<table>
<thead>
<tr>
<th></th>
<th>HELIOTROPIC PARABOLIC STOVE</th>
<th>THERMOSIPHON SOLAR WATER HEATER</th>
<th>PHOTOVOLTAIC FOOD-PROCESS WORKSTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthropometrics</strong></td>
<td>The pot holder is placed at 1[m] from the floor.</td>
<td>The position of the tap is placed at 0.9[m].</td>
<td>The working surface is placed at 0.95[m].</td>
</tr>
<tr>
<td><strong>Ergonomics</strong></td>
<td>The structure is lightweight and easy to move.</td>
<td>The structure is equipped with wheels for easy transport.</td>
<td>The structure is equipped with wheels for easy transport.</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>Available standard components were used.</td>
<td>Available standard components were used.</td>
<td>Available standard components were used.</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>The pot holder zone is painted in red to identify it as a dangerous zone.</td>
<td>No dangerous parts in the product, only hot water can cause damage.</td>
<td>No dangerous parts in the product. Shade is included to protect from sunburn.</td>
</tr>
<tr>
<td><strong>Transport and portability</strong></td>
<td>The structure is constituted for three main parts that can be disassembled: concentration parabola, chassis; and solar tracker system.</td>
<td>The product is not suitable for disassembly, but is equipped with wheels for easy transport.</td>
<td>The structure is equipped with castor wheels for easy transport.</td>
</tr>
<tr>
<td><strong>Storage and cleanliness</strong></td>
<td>The concentration parabola and the chassis can be wiped. Electronic components are protected inside a plastic box.</td>
<td>The inside of the tank can easily be wiped, as well as on the outside.</td>
<td>The structure is protected with a sealant for outdoor use and can be easily wiped.</td>
</tr>
<tr>
<td><strong>Functional principles</strong></td>
<td>The Test A, probes the capacity of the stove to cook and heat water from 20˚C to 70˚C degrees.</td>
<td>Further development is needed to reach the thermosiphon effect.</td>
<td>The capacity to power the blender was probed in Test C.</td>
</tr>
<tr>
<td><strong>Mechanisms</strong></td>
<td>No complex mechanisms were used, and they were protected for outdoor use.</td>
<td>No complex mechanisms were used, and they were protected for outdoor use.</td>
<td>No complex mechanisms were used, and they were protected for outdoor use.</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>All components are available in South Africa, with no complex machinery needed to build the stove.</td>
<td>All components are available in South Africa, with no complex machinery needed to build the water heater.</td>
<td>All components are available in South Africa, with no complex machinery needed to build the work station.</td>
</tr>
<tr>
<td><strong>Construction process</strong></td>
<td>Standard machinery was used to build the prototype.</td>
<td>Standard machinery was used to build the prototype.</td>
<td>Standard machinery was used to build the prototype.</td>
</tr>
<tr>
<td><strong>Commercial price</strong></td>
<td>The cost of the prototype was approx. R2 500. Workforce needs to be estimated.</td>
<td>The cost of the prototype was approx. R3 000. Workforce needs to be included.</td>
<td>The cost of the prototype was approx. R2 000. Workforce needs to be estimated.</td>
</tr>
<tr>
<td><strong>Formal coherence</strong></td>
<td>The structure was built from steel square tube of 90[cm] x 40[cm] x 90[cm] and 19[mm], painted white.</td>
<td>Although wooden brandering was used for this prototype, the steel square tube that was utilised in the Heliotropic Stove is more appropriate.</td>
<td>The structure was built from a steel square tube of 90[cm] x 40[cm] x 90[cm] and 19[mm], painted white.</td>
</tr>
</tbody>
</table>
To conclude the study, the objectives declared at the beginning of the research and those that guided the four phases proposed are re-visited. This allows one to summarise the observations, findings and lessons learned throughout the project. The design requirements are evaluated against the developed prototypes in order to identify where they have been met or require further development.

The primary objective was to understand the patterns of different activities around food processing to identify problems, risks and opportunities. This was undertaken with the involvement of the participants who provided extremely valuable insights into their daily activities. The energy audit, video recording and interviews allowed for a comprehensive list of identified project directions. The need to heat, blend and have available hot water, as well a working surface to prepare the ingredients were the patterns identified during food processing. This was successful due to the appropriate undertaking of the Human Centred Design process.

The second objective was to identify the tasks during food processing which demand high energy input. Through the undertaking of the energy audits with each participant, it was possible to narrow down the high energy use into the areas of heat with a stove, to blend with a blender and to have available heated water. These appliances were powered by means of diesel, LGP gas, electricity or biomass.

Thereafter, the identification of the most suitable renewable energy within Johannesburg was undertaken in order to attempt to replace the high energy demands with the appropriate renewable energy. Solar power was identified as the most available renewable source in the territory, selecting direct solar energy as the power source for the development of the off-grid, food processing system.

With the energy source identified, the design of a food processing appliance system powered with renewable energy started. The system was conceptualised as a Solar-energy-harvest outdoor appliance, for food processing and in turn, these appliances
were conceptualised separately as a guide to develop the prototypes named *Heliotropic Parabolic Stove, Thermosiphon Solar Water Heater, and a Photovoltaic food-process workstation* respectively. Following these concepts, a moodboard was prepared and sketches and mockups developed. Finally, three prototypes were built that could satisfy the needs of the micro enterprises.

After the construction of the prototypes, the technical performance and usability of the appliances was tested in a laboratory setting. In the case of the *Heliotropic Parabolic Stove* the test was to measure the time needed to heat water from 20°C to 70°C. For the *Thermosiphon Solar Water Heater*, the test consisted of measuring the variation of the water temperature during the day, and in the case of the *Photovoltaic food-process workstation*, the test was to probe the capacity to power a blender.

Finally, a food processing experience was held with one participant of the study as well with guests who are familiar with food preservation practices or cooking. During the sessions different kinds of foods were cooked, observing the relation between the user and the object. During those interactions, opinions and sketches of the participants were recorded, incorporating their suggestions to improve the next prototypes.
CHAPTER FIVE:
RECOMMENDATIONS FOR
FURTHER RESEARCH

As an industrial designer the output of our work seeks to solve daily life problems with a novel approach, as well to identify possibilities to perform those activities in an easier, safer, faster, more pleasant, cheaper or more efficient way among other considerations. The importance of participant’s input during the study is crucial, and the designer needs to have the capacity to engage with the users in a practical way through learning, observing and discovering. With the assistance and guidance of participants in this study, the researcher was able to identify problematic situations.

5.1. Design for and in collaboration with micro enterprises
During the study, micro food processing enterprises were asked to participate, and visiting their workplace made it possible to understand their energy usage during the production process and the possibility to replace it with renewable energy. While documenting the energy needs, it was clear that the possibilities to intervene as a designer was much more than only about the energy use. Further research in situations related to safety procedures were identified, as was observed when P2 mixed caustic soda with hot water, producing toxic fumes and inhaled; efficiency in the use of machines and tools, as observed when P1 used a diesel generator to power a blender; and waste of ingredients during the process, as was observed while P1 roasted the chillies, burning around the 30%. The designer can intervene during the activities of the food processing mentioned, adding value to the final product, and safety procedures while the ingredients are manipulated.

5.2. Renewable energy and education
This research has been exploring the possibilities to implement renewable energy in daily life activities. During the study it was noted that even if many people are interested in the topic on how to access these types of energy sources, the literacy about renewable energy was low in children and adults. This opens the possibility for
designers and educators to develop equipment that could demonstrate the functional principles and the possibilities to integrate renewable energy during daily tasks. This could be through educational kits for school students of different ages, and through workshops where adults can build prototypes, demonstrating for example how to cook with solar technologies.

On other hand, inefficiencies in the use of electric and thermal energy in the work and home were also observed. For example, it was observed that during winter people use electric heaters while the insulation of the home wasn’t appropriate. This opens the possibility for designers to develop educational programs to reduce the waste of energy for ineffectively insulated homes.

5.3. **Renewable energy as a power input for objects**

The philosopher Enrique Dussel (1984:192) states that design, as the text, has a context. To design is not an absolute act, but related to the totality where it is located. When designing, the context determines the functional aspects, economic restrictions, characteristics of the materials and other decisions. This project sought to relate the context in terms of the natural resources available in the territory with the practice of food processing, determining the object’s function by the sun’s energy. When designing objects that need to be powered with electricity or other energy source, designers should include in their brief renewable energy sources as inputs to power these objects. Further research on how to integrate renewable energies as input power on objects, will lead to a new paradigm of how an object is used and new methodologies will emerge to confront a design project.

5.4. **Final thoughts**

This project has been an attempt to reorient the direction of how design has been implemented until now, in the same ways as projects like Open Source Ecology (OSE) (2017:[sp]), which lays out the fifty most important machines for modern life to exist. Without having to buy those machines, OSE shares the blueprints and the digital codes to build these machines, incorporating technologies like 3D printing and open source platforms such Arduino, similar as the ones utilised in this project. As was
discussed in the section 3.1.7, every social system has a project that needs certain mediations to fulfil this project. Objects and machines are these mediations materialised by things whose meaning is "to serve-for" the project. Therefore, design is not about an object but about the society that we want to build. This research is a proposal to transit to an alternative society on a smaller scale and with a closer relation with nature.
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ANNEXURES

Annexure I: Informed Consent Form

INFORMED CONSENT: MICRO-SCALE FOOD PROCESSING AND ENERGY USAGE

Dear Sir / Madam,

On behalf of the Department of Industrial Design, Faculty of Art, Design and Architecture (FADA), University of Johannesburg, I wish to request your cooperation and participation in a micro-enterprise food processing and energy use project that I am undertaking. The purpose of this research is to develop a better understanding of the use of energy during the processing of food, as the availability and cost of energy are some of the biggest problems associated to micro-enterprise food processing. It has been identified that there are two circumstances where food is processed:

1. When people preserve their food, storing it for a long time to eat during
2. To add cultural and economic value into the raw food, selling their products and earning an extra income.

With this information, I intend to develop an off-grid appliance that will use renewable energy during food processing, decreasing the dependence on fossil fuels and electricity. The research began in March 2016 and will run until year-end 2017. During the first phase of the study, I will explore step-by-step from the crop harvest until the final processed product has been made, documenting with photographs, audio, video, drawings and surveys. In the second phase, I will discuss with you possible solutions and ask for your suggestions for the improvement of the ideas. During the final phase of the project, I will develop several prototypes that you can test in order for you to provide your feedback, hopefully arriving at the best solution possible for your needs.

Your details will remain anonymous and confidentiality will be respected. Please note that you are not under any obligation to participate in this exercise and you are free to withdraw at any point if you so desire. However, your participation is invaluable to the success of this endeavour as it is your experience in these matters that will add the most value to this study. There will not be any monetary payment for assisting me with this project. I would be glad to answer any questions you may have about the participation in this test. If you agree to participate in the testing, please give your consent by signing your name below and saying yes or no to the following questions.
### SMALL-SCALE FOOD PROCESSING AND ENERGY USAGE INFORMED CONSENT FORM:

<table>
<thead>
<tr>
<th>Would you like to participate in the study</th>
<th>Mark the correct: YES or NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you grant me permission to document this process using photographs, audio, video, drawings and surveys?</td>
<td>Circle the correct: Yes or No</td>
</tr>
<tr>
<td>Do you grant me permission to use your name and photos showing your identity in the research thesis as a Case Study (only for study purpose)?*</td>
<td>Circle the correct: Yes or No</td>
</tr>
<tr>
<td>* If not, your participation will be anonymous</td>
<td></td>
</tr>
<tr>
<td>Any additional comments:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sign:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name (optional):</td>
<td></td>
</tr>
<tr>
<td>Area/address:</td>
<td></td>
</tr>
<tr>
<td>Cell (optional):</td>
<td></td>
</tr>
<tr>
<td>Date:</td>
<td></td>
</tr>
</tbody>
</table>

Student: Jose Antonio Marin  
M-Tech Industrial Design (Student)  
Department of Industrial Design  
Faculty of Art, Design and Architecture  
Contact: +27 6 2747 6807  
Email: josemarinp@gmail.com

Supervisor: Martin Bolton  
Lecturer: Department of Industrial Design  
Faculty of Art, Design and Architecture  
University of Johannesburg  
Contact: m011 559 1580  
Email: mbolton@uj.ac.za

Co-Supervisor: Dr. David Kimemia  
Institute for Social and health Sciences  
University of South Africa  
Contact: 0826227387  
Email: dkimemia@gmail.com
Annexure II: Phases in production process and energy audit

The Process Flow Sheet and Energy Audit, will be used during the observations to the participants to:

i. Determine how and where energy is used during food processing;

ii. Identify opportunities to reduce energy usage;

iii. Gather data regarding the cost of the use of energy;

iv. Formulate prioritised recommendations for implementing process improvements to save energy.

<table>
<thead>
<tr>
<th>FOOD PROCESS</th>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
<th>STAGE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of the task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food Quantity [Kg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinery used</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photo of the task</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ENERGY AUDIT</th>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
<th>STAGE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine description:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine power ratings (photograph)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine nominal consumption [kW]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Energy [Heat-Rotation, cooling]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel used [Paraffin, charcoal, gas, electricity]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time used [Hours]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature [C]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy used [MJ/kg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of energy $ [Rand]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Emissions/MJ*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:

Annexure III: Workplace layout

A diagram and a photo record of the workplace layout, will show the displacements that the user undertakes to perform each task, and the location of the machines and tools used. In order to know the displacement patterns during the food process the following points will be consider:

- Approximate measurements of the workplace
- Machinery and tools location
- Workflow (Stage 1, 2.3)
- Waste disposal (place and amount)
- Type of light used
- Measurement with tape measure, measurements sketched on diagram.
Annexure IV: Semi-structured interview for food processors

Question guideline to describe the activities during the food processing:

- Can you describe your productive activity?
- How long have you been doing this activity?
- What made you begin to do this activity?
- How did you learn to perform this activity?
- Do you do this activity yourself, or do you have workers who assist with the activity?
- How long does it take to you to make a batch of your product?
- Do you have any support (direct or indirect) from other institutions or organizations to perform this activity?
- Do you have any conflict with other institutions or organizations because you perform this activity?
- Which tools / machinery are needed to perform this activity?
- Who repairs or maintains the tools / machines that you use during the activity?
- Which problems do you recognise during the process?
- Where does the food that you process come from?
- What do you do with the waste during the process?
- How much does it cost to you to process the food (per unit / batch)?
- How large is the batch production (volume, quantity)?
- Is the volume of production constant or seasonal during the year? Please explain.
- Which factors affect the increase or decrease of the volume of production? (Climate, institution, seasons)
- Where do you sell your products?
- Who are the customers that buy your product?
- Who are the intermediaries between you and the end consumer?
- Are you interested in reaching a different market?
- Can you notice any negative impacts because of this activity?
- Do you have a favourite stage during the process?
- During the years, have you made any significant change during the process? Explain what was changed, and how it has affected your production process?
- What lead to you making this change, how did you know to implement the change?
- Do you know about the renewables energies? Have you used them for any purpose? Are you willing to use them to perform any of your activities?
Annexure V: Participants Testing

The participant testing is to present the developed prototype of a micro-enterprise food processing appliance powered through renewable energy to the participants. In the session will be discussed the benefits and disadvantages of the appliances to perform their activities, understanding their concerns and the willingness to use. Participants will be requested to write or draw the improvements and suggestions for further discussion. The event will be recorded in audio and/or video and notes and photographs will be taken. The comments from the participants during the session will lead to final improvements of the prototype.

- **Participants**: 1 to 3 participants.
- **Duration**: 45-90 minutes.
- **Location**: A place will be proposed to the participants according to their time and location availability. The place will have seats and a table where the discussion will be held.
- **Ethics**: A participation consent form will be given to the attendees to be signed.
- **Materials**: Sheets of paper and pencils of different colours to draw, and a camera for photos and video recording.
- **Proposed questions**: The questions during the session will seek to know the impressions of the participants on technical, functional, ergonomic, aesthetic, safety aspects of the presented prototype, and how it fits into their current practices.

Proposed Schedule:

*Table 17: Interview schedule*

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00</td>
<td>Welcome and explanation of the purpose of the study and objectives.</td>
</tr>
<tr>
<td>09:10</td>
<td>Presentation of the functional prototype. Encourage the participant to use the prototype and open the discussion of the suitability to perform the food processing activities.</td>
</tr>
<tr>
<td>09:40</td>
<td>Discussion about the technical, functional, ergonomic, aesthetic, safety aspects, and how it fits into their current practices, taking note of the improvements proposed by the participants</td>
</tr>
<tr>
<td>10:40</td>
<td>Close of the session</td>
</tr>
</tbody>
</table>
Annexure VI: Laboratory Test Protocol

The purpose of the “laboratory test protocol” is to test and evaluate the energy performance of the prototypes, will guide further optimisation of the prototype to a performance level that is similar or better than the current system. The tests will be conducted on a system that includes the energy input, the heat transfer equipment, stove or oven; and the container and tools where to cook the food.

These tests will measure:

- Time needed to bring a litre of water from 20˚C to 70˚C for the Heliotropic solar stove;
- Observe the behaviour of the electronics to follow the sun during the day;
- Temperature variation during the day
- The electric power output of the Solar Power System;
- The relative cost of the energy expended in performance of a specific task.

There are three major testing standards for solar cookers employed throughout the world, differing in their scope, complexity, and deliverables (Shaw, 2002, p. 14). The American Society of Agricultural Engineers Standard ASAE S580, has the goal to produce a simple measure of a cooker performance, not so complicated and inexpensive; The Basis for the Bureau of Indian Standards Testing Method, use a more technical framework than ASAE S580; and the European Committee on Solar Cooking Research Testing Standard is a test for the thermal performance and other subjective observations as safety factors, ease of cooking pot access and estimated durability of the heat in the vessel.

Because it simple and inexpensive procedure, this study will utilise the ASAE S580 test, that monitors the average temperature inside a pot filled with water while the cooker is operated over 10 minute intervals. Even qualitative aspects as ease of use, safety, or financial issues associated with the cookers are important, although they are not included in this test will be discussed with the participants during the presentation of the prototypes, in order to include their recommendations in the final solution.
The follow equation is used in the ASAE S580 test, and can be compared with different methods to cook or another solar technology options.

\[ P = \frac{T_2 - T_1}{600} mc_p \]  
(Equation 1)

Where:
- \( P \) = cooking power (W)
- \( T_2 \) = final water temperature
- \( T_1 \) = initial water temperature
- \( m \) = mass of water (kg)
- \( c_p \) = heat capacity (4168 kJ/kgK)

* Equation 1 is divided by 600 to account for the number of seconds in each 10-minute interval.

**Safety precautions:**

The technical procedures can be dangerous because of the heat of the appliance and the heating water. Parts of the prototype that are likely to have elevated temperatures will be marked out for easy identification. The tests will be carried out by two operators for accuracy and safety purposes.

**Quality control:**

The tests shall be conducted under the following conditions:

- Wind speed of less than 1 m/s, measured at the elevation of the prototype.
- Ambient temperature of between 15°C and 35°C.
- The initial water temperature shall be 20°C.
Step 1: General inspection

Inspect the prototype for misassembled parts, sharp edges that can injure, and general readiness for the water heating task.

Step 2: System performance

- Apparatus: aluminium pot (220[mm] ± 5[mm] in diameter and 125[mm] ± 5[mm] in depth); immersion type thermometer (thermocouple); stopwatch; 1 litre bottle.
- Ready the appliance for the cooking test.
- Measure 1 litre of water into the pot.
- Immerse and secure the thermocouple wire at the centre of the pot, 10[mm] above the bottom.
- Record the initial water temperature (T1)
- Put the pot filled with water onto the appliance.
- Start the test – note the starting time (T1) and record temperature rise every 10 minutes.
- Stop the test when water temperature reaches 70°C (T2).
- At end of the test, record final water temperature.

Form to be used for data collection:

<table>
<thead>
<tr>
<th>Date:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature [°C]</td>
<td></td>
</tr>
<tr>
<td>Solar Irradiance [W/m2]</td>
<td></td>
</tr>
<tr>
<td>Water temperature [°C]</td>
<td></td>
</tr>
<tr>
<td>Air Flow [m/s]</td>
<td></td>
</tr>
</tbody>
</table>
Annexure VII: Challenges of implementing systems of decentralized energy supply

**CHALLENGES OF IMPLEMENTING SYSTEM OF DECENTRALIZED ENERGY SUPPLY**

<table>
<thead>
<tr>
<th>USER EXPERIENCE</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>User need should be integrated</td>
<td>Incorrect handling, use and maintenance</td>
</tr>
<tr>
<td>Consider educational level of the user</td>
<td>Learning by implementing approach</td>
</tr>
<tr>
<td>Understand the daily life routine</td>
<td>Proper installation &amp; regular maintenance</td>
</tr>
<tr>
<td>Developing informational material regard educational level</td>
<td>Adapt to local conditions</td>
</tr>
<tr>
<td>Consider cultural background</td>
<td>Need a skill user</td>
</tr>
<tr>
<td>Productive uses and consumer uses</td>
<td>Consider local weather conditions</td>
</tr>
<tr>
<td>Incomplete info about the capacity of the system</td>
<td>Consider possible damage for animals</td>
</tr>
<tr>
<td>undersized – oversize the systems</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REGULATIONS</th>
<th>IMPLEMENTATION &amp; BUSINESS MODELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy supply integrate the regional develop programs</td>
<td>Lacked of micro credit finance models</td>
</tr>
<tr>
<td>Joint efforts with: education – health – agriculture – regional developments</td>
<td>Gravity during the payment</td>
</tr>
<tr>
<td>Embedded with regional economic development strategies</td>
<td>Provide technology /= provide “energy product service system”</td>
</tr>
<tr>
<td>Integrated role players</td>
<td>Increase decentralized incentives</td>
</tr>
<tr>
<td>National and international programs of funding</td>
<td></td>
</tr>
<tr>
<td>Business innovation</td>
<td></td>
</tr>
<tr>
<td>Productive uses would result in higher incomes</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 103: Challenges of implementing system of decentralised energy supply by sector. (Scheme adapted by the author).*
Annexure VIII: South African dimensions

South African population anthropometric measures, from the study Masters Research project “South African anthropometric dimensions for the design of an Ergonomic office chair”, by Janice Korte (2013, p. 44).

Table 18: Female sample characteristics. (Korte, 2013, p. 44).

<table>
<thead>
<tr>
<th></th>
<th>AGE (yrs.)</th>
<th>STATURE (mm)</th>
<th>SHOULDER HEIGHT (mm)</th>
<th>MASS (kg)</th>
<th>BMI (kg.m(^{-2}))</th>
<th>WAIST CIRCUM. (mm)</th>
<th>HIP CIRCUM. (mm)</th>
<th>WHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td>36.2</td>
<td>1624</td>
<td>1319</td>
<td>78.3</td>
<td>29.7</td>
<td>953</td>
<td>1128</td>
<td>0.9</td>
</tr>
<tr>
<td>SD</td>
<td>10.6</td>
<td>71</td>
<td>60</td>
<td>20.4</td>
<td>7.6</td>
<td>166</td>
<td>155</td>
<td>0.1</td>
</tr>
<tr>
<td>CV</td>
<td>29.2</td>
<td>4</td>
<td>5</td>
<td>26.0</td>
<td>25.6</td>
<td>17</td>
<td>14</td>
<td>11.5</td>
</tr>
<tr>
<td>95TH%ILE</td>
<td>56.0</td>
<td>1740</td>
<td>1410</td>
<td>115.7</td>
<td>44.3</td>
<td>1230</td>
<td>1397</td>
<td>1.0</td>
</tr>
<tr>
<td>50TH%ILE</td>
<td>34.0</td>
<td>1620</td>
<td>1320</td>
<td>75.5</td>
<td>29.0</td>
<td>960</td>
<td>1110</td>
<td>0.8</td>
</tr>
<tr>
<td>5TH%ILE</td>
<td>22.0</td>
<td>1510</td>
<td>1220</td>
<td>50.0</td>
<td>19.6</td>
<td>700</td>
<td>920</td>
<td>0.7</td>
</tr>
<tr>
<td>MAX</td>
<td>65.0</td>
<td>1870</td>
<td>1490</td>
<td>149.0</td>
<td>56.6</td>
<td>1650</td>
<td>1720</td>
<td>1.8</td>
</tr>
<tr>
<td>MIN</td>
<td>18.0</td>
<td>1450</td>
<td>1110</td>
<td>40.0</td>
<td>15.6</td>
<td>590</td>
<td>620</td>
<td>0.6</td>
</tr>
</tbody>
</table>

SD = standard deviation; CV = coefficient of variation; MAX = maximum; MIN = minimum; 95th%ILE = upper 95th percentile of the population; 50th%ILE = half of the population; 5th%ILE = lower 5th percentile of the population; CIRCUM = circumference.

Table 19: Male sample characteristics. (Korte, 2013, p. 44).

<table>
<thead>
<tr>
<th></th>
<th>AGE (yrs.)</th>
<th>STATURE (mm)</th>
<th>SHOULDER HEIGHT (mm)</th>
<th>MASS (kg)</th>
<th>BMI (kg.m(^{-2}))</th>
<th>WAIST CIRCUM. (mm)</th>
<th>HIP CIRCUM. (mm)</th>
<th>WHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN</td>
<td>42.0</td>
<td>1745</td>
<td>1420</td>
<td>82.4</td>
<td>27.2</td>
<td>959</td>
<td>1052</td>
<td>0.9</td>
</tr>
<tr>
<td>SD</td>
<td>11.8</td>
<td>88</td>
<td>68</td>
<td>17.6</td>
<td>5.8</td>
<td>153</td>
<td>113</td>
<td>0.1</td>
</tr>
<tr>
<td>CV</td>
<td>28.0</td>
<td>5</td>
<td>5</td>
<td>21.4</td>
<td>21.3</td>
<td>16</td>
<td>11</td>
<td>9.1</td>
</tr>
<tr>
<td>95TH%ILE</td>
<td>59.0</td>
<td>1910</td>
<td>1536</td>
<td>114.0</td>
<td>36.5</td>
<td>1171</td>
<td>1220</td>
<td>1.0</td>
</tr>
<tr>
<td>50TH%ILE</td>
<td>43.0</td>
<td>1740</td>
<td>1410</td>
<td>82.0</td>
<td>26.8</td>
<td>960</td>
<td>1040</td>
<td>0.9</td>
</tr>
<tr>
<td>5TH%ILE</td>
<td>23.0</td>
<td>1610</td>
<td>1310</td>
<td>57.0</td>
<td>19.6</td>
<td>737</td>
<td>900</td>
<td>0.8</td>
</tr>
<tr>
<td>MAX</td>
<td>65.0</td>
<td>2040</td>
<td>1640</td>
<td>160.0</td>
<td>59.5</td>
<td>1800</td>
<td>1700</td>
<td>1.5</td>
</tr>
<tr>
<td>MIN</td>
<td>18.0</td>
<td>1540</td>
<td>1280</td>
<td>51.0</td>
<td>17.8</td>
<td>660</td>
<td>720</td>
<td>0.7</td>
</tr>
</tbody>
</table>

SD = standard deviation; CV = coefficient of variation; MAX = maximum; MIN = minimum; 95th%ILE = upper 95th percentile of the population; 50th%ILE = half of the population; 5th%ILE = lower 5th percentile of the population; CIRCUM = circumference.
Dr David Kimani Kimemia

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Westerdene 2092
Tel: +27 826 227387
Email: dkimemia@gmail.com

OBJECTIVE: A career in environment and energy access research.

KEY SKILLS: I possess solid knowledge and experience in -

- Environmental analysis and management skills (e.g. risk assessments, environmental impact assessments, strategic environmental assessments, social impact assessments environmental auditing, and environmental laws and regulations).
- Designing and executing research studies for monitoring and evaluation of environmental/energy projects.
- Writing grant proposals, project reports and research articles.
- Presenting project proposals and reports to stakeholders and/or conference audiences.
- Demonstrated ability to manage complex multi-stakeholder research projects.
- Line management – I have managed business enterprise of 40-plus employees. Skills acquired include mentorship, disputes/complaints resolution; training; appraisal; team dynamics and financial management.
- Conducting laboratory and field evaluations of fuel combustion stoves (e.g. biomass, paraffin, coal, gas, ethanol and methanol) for thermal and emissions performance.
- Lecturing environmental management topics to undergraduate and postgraduate students (e.g. air quality, waste and water management).

POSITIONS HELD

2010 – 2015 Researcher, SeTAR Centre, University of Johannesburg, South Africa

Duties included:
- Evaluating thermal, safety, and emissions performance of various fuel combustion stoves at the SeTAR Centre stove testing laboratory.
- Designing research surveys on various household energy and environmental topics. Issues investigated include: energy access situation, health and safety issues related to energy use; expenditure; preferences and perceptions on ways of reducing the energy burden and accidental risk; and improving environmental conditions
- Managing the research team
- Writing research proposals and project reports.
• Assisting with lecturing and the supervision of student projects.

Achievements:

• Participated in the assessment and development of safe and efficient fuel combustion devices (e.g. paraffin stoves, methanol stove, wood and charcoal stoves), some of which are selling in South Africa and further afield.
• Lead researcher in two research projects in Gauteng province South Africa (i.e. urban biomass use in Johannesburg and LPG interventions in City of Tshwane). Results of the two projects were published in peer reviewed journals.
• Part of team that wrote two major funding proposals, one to Global Alliance for Clean Cookstoves [GACC] and second to Gauteng Dept. of Agriculture and Rural Development [GDARD].
• Published at least 10 research papers and several project reports.
• Presented at several local and international conferences.
• Received the best paper award at Domestic Use of Energy Conference, 31 March to 2 April 2014.
• Represented SeTAR Centre at key meetings locally and internationally.

1999 - 2006  Manager, Candlewood Enterprises, Nakuru, Kenya
• Founded and operated family businesses dealing in horticulture and sale of hardware goods.

1991 - 1999  Area Manager, Timsales Ltd, Kenya
• The company was involved in the management of forest plantations and the manufacture of prefabricated buildings and various wood-based products.
• Responsible for day-to-day operations of sales branches in my operational area, in terms of employees, clients, and production of value-added products.
• Specific duties included: sales and marketing of company products; running joinery workshop and wood treatment plant; ensuring workplace safety; preparing weekly and monthly returns.

Achievements:
• Turned-around loss making branches into profitable entities.
• Rationalised the business units leading to lower operational costs, high efficiency and larger market share.
• Rose from management trainee to branch manager, senior branch manager and finally area manager in charge of several branches.

1986 - 1987  Audit Examiner, Auditor General Corporations, Nairobi, Kenya
• Worked as an audit clerk - scrutinizing accounts of selected government corporations.
EDUCATION

PhD. University of Johannesburg, Environmental Management, November, 2014

MSc. University of Johannesburg, Environmental Management, October 2010
• The programme consisted of tutored subjects and mini-dissertation project.
• Tutored courses:
  ➢ The biosphere and environmental studies (Air Quality and Waste Management, Environmental Law etc.)
  ➢ Environmental management skills and technology (EIA, SIA, SEA, Risk Assessment, Environmental Auditing etc.)

BSc. Hons University of Fort Hare, Geography & Environmental Science, May 2008

BSc. Hons Moi University, Wood Science & Technology, December 1990

SPECIALIZED TRAINING

Certificate in ‘air quality management’. University of Johannesburg, 2009
Certificate in ‘environmental auditing’. University of Johannesburg, 2009
Certificate in ‘computer applications’. Egerton University, 2003
Certificate in ‘effective utilization of resources’. Eureka, 1993

South Africa-Young Scientists Summer Programme (SA-YSSP). University of Free State, 2012/2013. Attended the PhD summer program (3 months) and co-authored a paper with other scientists.

RESEARCH AND PRACTICE AREA INTERESTS

• Systems of delivering renewable and low-carbon energy services to households and business enterprises. Current research work is focussed on transitioning households and SMMEs from use of pollutant and dangerous energy technologies to clean and healthier options.
• Sustainable environmental resources management (land, water, vegetation), especially projects that integrate agricultural practices with energy generation for domestic and economic activities.
• Projects that address environmental risks.
• Projects that provide input to environmental and energy policies.
• Projects that promote recycling and reuse of various waste streams, particularly the conversion of waste to energy.

**STUDENT SUPERVISION AND LECTURING (UJ students)**
2010 - 2014  Co-supervised two MSc and one BSc Hons student (Environmental Management).
2011 - 2013  Part-time lecturer, University of Johannesburg
  • Department of Industrial Design - Taught a module on social research methods to third-year industrial design students. The lectures equipped the students with tools for user-centred design work amongst township communities.
  • Department of Geography, Environmental Management and Energy Studies – Lectured third-year undergraduate students on “Air Quality and the City” and “Energy, Environment and Society”.

**JOURNAL PUBLICATIONS & CONFERENCE ARTICLES**

*Note: Most of the articles listed here are available from [http://www.setarstoves.org/](http://www.setarstoves.org/)*

**Note:** Lead author in **bold** = Peer-reviewed publication


**REFEREES**
Available upon request.
Annexure X: Solar Tracker system

Table 20: Components of the electronic solar tracker system:

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>POWER</th>
<th>COLOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDR RL=100K RD=20M (Light dependant resistor) arrange (x4) + Resistor 1K</td>
<td>5V (from Arduino)</td>
<td>INPUT</td>
</tr>
<tr>
<td>Arduino Uno R3 (atmega328 microcontroller)</td>
<td>7.5V 2600mAh Li-Ion Battery</td>
<td></td>
</tr>
<tr>
<td>Driver DVR-8825* (for Stepper Motor*) + Capacitor 100 uF</td>
<td>12V 7Ah Battery / 5V from Arduino</td>
<td></td>
</tr>
<tr>
<td>Driver DVR-8825* (for Stepper Motor*)</td>
<td>12V Battery / 5V from Arduino</td>
<td></td>
</tr>
<tr>
<td>Stepper Motor Bipolar (Horizontal)</td>
<td>0.5V from DVR-8825</td>
<td>OUTPUT</td>
</tr>
<tr>
<td>Stepper Motor Bipolar (Vertical)</td>
<td>0.5V from DVR-8825</td>
<td>OUTPUT</td>
</tr>
</tbody>
</table>

* To set the Voltage of the Driver DVR-8825 the formula is [Current Limit = VREF × 2], if you have a stepper motor rated for 1A, you can set the current limit to 1A by setting the reference voltage to 0.5V, like this case.
Figure 104: Schematic of the electronics. (Diagram by the author).

Figure 105: Position of the electronics in the prototype. (Diagram by the author).
Position of the electronics in the prototype:

- Arduino powered by a 7.5[$\text{V}$] 2600[$\text{mAh}$] Li-Ion Battery.
- Driver DVR-8825 (for Stepper Motor) + Capacitor 100 [$\text{uF}$] powered by a 12[$\text{V}$] 7[$\text{Ah}$] Battery.
- Stepper Motor Bipolar (Horizontal) 0.5[$\text{V}$] from DVR-8825.

The solar tracker is based on 4 LDR’s (Light dependant resistor) that sense the light, and after a calculation of the average between the top left - top right LDR’s and top left - bottom left LDR’s, 2 stepper motors move up – down and right – left. The 4 LDR’s are instaled on the side of the parabolic dish, inside a white rectangle with walls to separate the amount of light that can sense each LDR.
Figure 107: LDR arrangement. (Diagram by the author).

Figure 108: The installation in a breadboard (only one driver and one motor connected to the Arduino in the picture). (Diagram by the author).
Annexure XI: Communication problems between Arduino and computer.

The code (attached below) was working fine in the Arduino and the stepper motors did move, following the LDR's. But one day the computer didn’t recognise the Arduino, and didn’t allow to select the USB port (e.g. COM3) to be connected to USB. So I bought another Arduino (Chinese version CH340) and work again, but after a week it didn’t work again. I use 4 Arduinos in total and the same happen, they work at the beginning but stop working after a week or so, when the installation was already mounted in the prototype.

When I try to upload the code to the Arduino, the following message appear:

`avrdude: ser_open(): can't open device \COM8.`

This happen with with 4 Arduinos, but they didn’t burn. I measure a voltage of 5[V] between the 5V and GND, so they are not dead.
I connect the fifth Arduino (IDUINO UNO) only to the computer, but not to the electronics. It worked and I could upload the software, and then I remove the microcontroller Atmega328 to one of the older Arduino. I upload the “BLINK code” to the IDUINO (red) and then change the “microcontroller Atmega328” to the Arduino (dark blue) and did work, blinking the LED 13.

Figure 110: Screen when I try to upload the code. The Arduino is not recognised by the PC. (Photo by the author).

Figure 111: The IDUINO (red) is OK, I change the microcontroller Atmega328 to the Arduino (dark blue) and connect to the electronics. (Photo by the author).
After a few test during a couple of days, I couldn’t upload the code to the IDUINO anymore, but it shows another message in the screen: “avrdude stk500_recv() programmer is not responding”.

Figure 112: The IDUINO is recognised for the PC, but this is the screen when I try to upload the code. (Photo by the author).

As I could read (https://forum.arduino.cc/index.php?topic=442308.0), this problem happen for many reasons, but I thinks is something to do with:

- The “ATmega16U” that acts as a bridge between the computer's USB port and the main processor's serial port; and/or,
- The microcontroller “Atmega328”.

Figure 113: Arduino UNO R3 components description. (Smarterphysics, 2017).
Annexure XII: Code

//Solar Stove, Stepper Motor & driver DVR8825_Solar Tracker by Antonio Marin

#include <Stepper.h> //Integrating library for dealing Stepper.h stepper motors
#include <math.h> //Integrating design math.h library for basic mathematical operations

//Declaring Constants
#define motorStephor 64 //steps for horizontal motor
#define motorStepver 200 //steps for vertical motor

//Digital pins //position = Digital pin
#define motor1hor 8 // Motor horizontal pin 8
#define motor2hor 9 // Motor horizontal pin 9
#define motor1ver 10 // Motor vertical pin 10
#define motor2ver 11 // Motor vertical pin 11

// LDR pin connections //position = Analog pin
int ldrtopl = 3; //Top Left LDR
int ldrtopr = 2; //Top Right LDR
int ldrbotl = 4; //Bottom Left LDR
int ldrbotr = 1; //Bottom Right LDR

//Variables
int h=50; //Steps executed by the horizontal motor //Una vuelta completa 2048
int v=50; //Steps executed by the vertical motor

Stepper horStep (motorStephor, motor1hor, motor2hor);
Stepper verStep (motorStepver, motor1ver, motor2ver);

//Program initialization
void setup ()
{

    horStep.setSpeed (200); //RPM horizontal motor // Max Value 200
    verStep.setSpeed (1000); //RPM vertical motor

    //Serial Port
    Serial.begin(9600);
//Pins configuration

pinMode(ldrtopl, INPUT);
pinMode(ldrtopr, INPUT);
pinMode(ldrbotl, INPUT);
pinMode(ldrbotr, INPUT);

Serial.println("CLEARDATA");
Serial.print("LABEL,Current time,sensor value");

}

void loop()
{

//Capturing analog values of each LDR

int topl = analogRead(ldrtopl); //pin3 Top Left
int topr = analogRead(ldrtopr); //pin2 Top Right
int botl = analogRead(ldrbotl); //pin4 Bottom Left
int botr = analogRead(ldrbotr); //pin1 Bottom Right

// calculating average
int avgtop = (topl + topr) / 2; //average of Top
int avgbot = (botl + botr) / 2; //average of bottom
int avgleft = (topl + botl) / 2; //average of left
int avright = (topr + botr) / 2; //average of right

Serial.print(avgtop); //shows (avgtop) en serial print
    Serial.println(",");
Serial.print(avgbot); // shows (avgtop) en serial print
    Serial.println(",");
Serial.print(avgleft); // shows (avgtop) en serial print
    Serial.println(",");
Serial.print(avright); // shows (avgtop) en serial print
    Serial.println(",");
delay (1000);

// Vertical movements

if (avgtop < avgbot) //> ---- <
{
    verStep.step(v); //Turn motor up v=50 Steps executed by the vertical motor CW
    delay(100);
}
} 
else if (avgtop > avgbot) // ---- < 
{
    verStep.step(-v); //Turn motor up -v=-50  Steps executed by the vertical motor CCW 
    delay(100);
}

//Horizontal movements

if (avgleft < avgright) // ---- < 
{
    horStep.step(h); //Turn motor up v=50  Steps executed by the horizontal motor CW 
    delay(3000);
}
else

if (avgleft > avgright) // ---- < 
{
    horStep.step(-h); //Turn motor up -v=-50  Steps executed by the horizontal motor CCW 
    delay(3000);
}
}

// ---------End ---------

//
Annexure XIII: Materials and their thermal transmittance

Table 21: Materials and their thermal transmittance or "U Value".

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>U Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.024 [W/m² K]</td>
</tr>
<tr>
<td>Glass Fiber roll</td>
<td>0.044 [W/m² K]</td>
</tr>
<tr>
<td>Vacuum</td>
<td>0 [W/m² K]</td>
</tr>
<tr>
<td>Balsa wood</td>
<td>0.048 [W/m² K]</td>
</tr>
<tr>
<td>Paper</td>
<td>0.05 [W/m² K]</td>
</tr>
<tr>
<td>Perlite</td>
<td>0.03 [W/m² K]</td>
</tr>
<tr>
<td>Perlite + Vacuum</td>
<td>0.0137 [W/m² K]</td>
</tr>
<tr>
<td>Saw dust</td>
<td>0.08 [W/m² K]</td>
</tr>
<tr>
<td>Cork</td>
<td>0.07 [W/m² K]</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.04 [W/m² K]</td>
</tr>
<tr>
<td>Cotton wool</td>
<td>0.029 [W/m² K]</td>
</tr>
</tbody>
</table>
Annexure XIV: Laboratory Test Results

The following tables show the data recorded in the experiment to bring a litre of water from 20°C to 70°C.

**Heliotropic Parabolic Stove**

*Table 22: Data collection to heat water with the Heliotropic solar stove*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ambient temperature [°C]</strong></td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>29</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>Solar Irradiance [W/m²]</strong></td>
<td>1.03</td>
<td>1.03</td>
<td>1.03</td>
<td>1.03</td>
<td>1.03</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td><strong>Water temperature [°C]</strong></td>
<td>28.5</td>
<td>32.2</td>
<td>40</td>
<td>46.4</td>
<td>52.4</td>
<td>58.4</td>
<td></td>
</tr>
<tr>
<td><strong>Air Flow [m/s]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 23: Data collection to heat water with the Heliotropic solar stove (continuation)*

<table>
<thead>
<tr>
<th>Date: 03 November 2017 / Sunny</th>
<th>Time</th>
<th>[14:00]</th>
<th>[14:05]</th>
<th>[14:10]</th>
<th>[14:15]</th>
<th>[14:20]</th>
<th>[14:25]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ambient temperature [°C]</strong></td>
<td>31</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>Solar Irradiance [W/m²]</strong></td>
<td>1.02</td>
<td>1.01</td>
<td>1.01</td>
<td>1.01</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td><strong>Water temperature [°C]</strong></td>
<td>60.5</td>
<td>62.2</td>
<td>65</td>
<td>71.2</td>
<td>72.5</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td><strong>Air Flow [m/s]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sun Fire 1.2**

*Table 24: Data collection to heat water with the Sun Fire 1.2.*

<table>
<thead>
<tr>
<th>Date: 30 October 2017 / Partly sunny</th>
<th>Time</th>
<th>[14:50]</th>
<th>[14:55]</th>
<th>[15:00]</th>
<th>[15:05]</th>
<th>[15:10]</th>
<th>[15:15]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ambient temperature [°C]</strong></td>
<td>22 °C</td>
<td>22 °C</td>
<td>22 °C</td>
<td>22 °C</td>
<td>22 °C</td>
<td>22 °C</td>
<td></td>
</tr>
<tr>
<td><strong>Solar Irradiance [W/m²]</strong></td>
<td>0.98</td>
<td>0.97</td>
<td>0.96</td>
<td>0.96</td>
<td>0.95</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td><strong>Water temperature [°C]</strong></td>
<td>24.5</td>
<td>46</td>
<td>60</td>
<td>73.5</td>
<td>90</td>
<td>94.3</td>
<td></td>
</tr>
<tr>
<td><strong>Air Flow [m/s]</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
</tbody>
</table>
## Thermosiphon Solar Water Heater

*Table 25: Data collection table Thermosiphon Solar Water Heater*

<table>
<thead>
<tr>
<th>Time</th>
<th>[09:18]</th>
<th>[10:18]</th>
<th>[11:18]</th>
<th>[12:18]</th>
<th>[13:18]</th>
<th>[14:38]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date:</td>
<td>July 25 2017 / / Partly sunny</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient temperature [°C]</td>
<td>6</td>
<td>14.5</td>
<td>15.5</td>
<td>23.5</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Solar Irradiance [W/m2]</td>
<td>0.6</td>
<td>0.9 (clouds)</td>
<td>0.93 (clouds)</td>
<td>0.95</td>
<td>0.93</td>
<td>0.72 (shadow)</td>
</tr>
<tr>
<td>Water temperature [°C]</td>
<td>9.2</td>
<td>10</td>
<td>10.9</td>
<td>15.9</td>
<td>19.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Air Flow [m/s]</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*Table 26: Data collection table Thermosiphon Solar Water Heater*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Date:</td>
<td>July 26 2017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient temperature [°C]</td>
<td>19</td>
<td>20</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>Solar Irradiance [W/m2]</td>
<td>0.95 (clouds)</td>
<td>0.95 (clouds)</td>
<td>0.93 (clouds)</td>
<td>0.88</td>
</tr>
<tr>
<td>Water temperature [°C]</td>
<td>13.5</td>
<td>18</td>
<td>20</td>
<td>21.5</td>
</tr>
<tr>
<td>Air Flow [m/s]</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Annexure XV: Leaflet

Figure 114: Leaflet provided to the participants.