MECS-TRIID Project Report (public version)

Delivering eCook at ground level

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Executive Summary

Wood based fuel has been the only affordable fuel for cooking for many people for generations and it is not sustainable. Felling of trees for firewood is causing environmental problems including deforestation leading to soil erosion and loss of soil fertility. There are also serious health issues from smoke inhalation. The aim of this project is to design a solar powered eCook stove that is affordable and acceptable to rural communities in Sub-Saharan Africa and especially in Malawi.

The project looked at the current situation in Malawi with regard to cooking practices and reviewed the eCook stoves available at present. The local people in Malawi are aware of the situation regarding the ever diminishing wood supply as reflected in the ever increasing cost of buying wood. They were keen to have solar powered cooking capability and had an input into the design of the eCook stove.

One of the overriding design requirements was that it should be suitable for local manufacture with the minimum of components bought out of country. We are indebted to our Malawian partners, Aquaid Lifeline, for helping us to achieve this.

The initial prototype was designed and built in the UK. At all stages Aquaid Lifeline were consulted as to the availability of materials and to ensure that the proposed designs could be built locally. As research showed that meals were often cooked early morning, before sunrise, or in the evening after sunset, decision was made to use a form of heat storage system. The use of phase change material (PCM) as the heat store was selected after collaboration with California Polytechnic State University (Cal Poly). A vessel suitable for holding the PCM was designed and also an insulated box to house the PCM vessel to prevent heat loss prior to using the eCook stove for cooking.

Two forms of heater were developed, one using ceramic tiles and the second a clay based plate. Resistive wires were used as the form of heating. This required the development of a Power Optimisation Device (POD) to optimise and control the power drawn from the PV panel as this would fluctuate with the intensity of the sun. The POD was also able to prevent the unit from overheating and allowed the provision of a USB socket for mobile phone charging which was a desirable feature as determined in the user-centred design process.

The prototype was tested in the UK and there were a number of design iterations due to situations encountered. One of these was the change to using the heater immersed in an oil bath rather than in the PCM as it was shown that removal of the heater from the solid PCM material was difficult should the heater fail.

In the UK PCM was successfully melted and the heat transferred to the hotplate. The hotplate temperature was at 97°C three hours after the heater had been turned off and was still above 70°C 19 hours later. The prototype was used to cook some potatoes as a trial.

A prototype was built in Malawi using local labour and materials with the exception of the POD and heater which were brought from the UK due to time constraints. The concept and use of the eCook stove was demonstrated to the local people. There was much interest shown in the eCook stove both from a technical point of view and a practical one. Despite it being the rainy season with limited sunshine some of the local ladies were able to use the eCook stove to cook the local staple food, maize flour, and make nsima porridge.

There is still work to be done to make a product that can be used by local people. However there has been much interest shown in it not only by local households but also local sellers of street food and organisations that cook meals on a larger scale to feed children in schools where sometimes that is the only hot meal that they get in a day.

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1. Introduction

1.1 Cooking food is part of what it is to be human. For most people in low income communities wood based fuel is the only current affordable option. Wood fuel has been a sustainable form of energy in these communities for generations. However social changes including population growth, urbanisation, soil degradation and climate change have destabilised the supply and demand balance and there is now widespread recognition that an alternative to wood fuel must be found. Wood fuel is also known to be a serious smoke-derived health hazard. There are numerous secondary impacts of the health issues as well as the impact on soils and ecosystem changes resulting from deforestation.

1.2 Solar power is one of the options for sustainable cooking power in the areas where wood fuel dependency is a problem. To effect the change from wood fuel to solar however is a transition that is challenging. The issues range from making the technical package work in the field and to making it affordable for adoption amongst those who can afford little. The technical package must also be compatible with the social and human context of cooking. The preparation and sharing of food is a very deep seated aspect of every society so any change to what has been a very long-standing arrangement will be difficult to introduce. The business model also needs to support independence, jobs and self sufficiency. The paradigm shift required to change the practise of wood-based cooking will be more acceptable if it can foster community development rather than social inequality and dependency. This means seeking community engagement in the transition including the building of as much of the new infrastructure as possible locally such as the eCook stoves.

1.3 The lead organisation of this project is Sustainable OneWorld Technology CIC. The organisation is a community interest company which generates sustainable technical solutions to development challenges that are ecologically sustainable and to implement these in a way that is equitable and in non-exploitative partnerships with low income communities.

Aims of the project

1.4 The aim of this project is to make cooking with solar energy derived from photovoltaic panels something which can replace cooking on 3-stone open fires.

Objectives of the project

1.5 The first objective was to undertake a study of the target user group's cooking habits, preferences and practices to input into a user-centred design process. This included an understanding of the current cooking and eating habits on 3-stone fires, knowledge of what food are cooked and eaten and when it is needed. The broader social and peer group behaviour issues are also relevant when seeking to change behaviour.

1.6 The aim of the project is only achievable with an affordable product which is also accepted by those who currently cook on 3-stone fires. We seek to design a product which is not imported as a finished product. The objective is to develop a product which is can be assembled locally and which uses the minimum amount of imported components.

2. Methodology

Outline of the concept

2.1 The concept behind the methods used in the project were to establish, by demonstration, the possibility that an eCook stove could be made which uses local materials for manufacture and that it is possible to build and then trial such a device.

2.2 The concept is that solar energy can be used to provide the heat required to cook food. However often the time when the cooking is required is not when the sun is shining. A method of storing the energy until it is required is needed.

2.3 The use of batteries to store electrical energy, such as lead acid, lithium ion or salt batteries was considered and rejected on the basis of cost, availability and environmental impacts. Innovations in this field may change this analysis in the future.

2.4 The concept of thermal storage is a long-standing approach in the western world in appliances such as the “AGA” range cooker and thermal storage is in use as part of home heating systems, eg night storage heaters.

2.5 Phase change materials (PCM) have been shown to be an option for thermal storage eg Sunamp heat batteries.

Research undertaken

2.6 There were a number of research methods during the project.

2.6.1 Desk and internet research was undertaken to establish the extent of the use of eCooking in Africa to date.

2.6.2 A review was undertaken into forms of thermal energy storage available. This was used to make an informed choice as to the most appropriate storage to pursue.

2.6.3 Desk and internet research was used to inform about PCM. This led to exchange of information and ideas with Pete Schwartz and his team at California Polytechnic State University (Cal Poly).

2.6.4 Laboratory research was used to test and trial various methods of producing a low cost heating element that could be easily manufactured in Malawi.

2.6.5 An email survey was undertaken with Angus Gaisford of Aquaid Lifeline in Malawi into the cooking habits of the low income families he is familiar with.

2.6.6 Field research was undertaken as part of the user-centred design process. This was preceded by a consultation with an experienced product anthropologist with professional background in product development. This consultation gave additional insights which were subsequently used. On the field trip to Malawi local people were observed cooking on wood fires and face to face interviews were conducted. The trip also included meeting people who could aid the manufacture process in Malawi.

2.7 This research was used to inform and influence our design of the eCook stove.

2.8 The designs were shared with our Malawi partners prior to the building of a prototype eCook stove to be used for cooking trials in the UK.

3. Implementation

The work conducted

3.1 Initial desk research was performed to see the current state of eCook stoves worldwide but focussing on Africa to ensure that the project was not duplicating work already done. The report can be found in Appendix 1.

3.2 The types of thermal storage solutions were discussed internally and with our specialist consultants. A key operational ambition of our proposal was to find a way to store thermal energy over the course of a day and to make it available to use as needed without the use of batteries for the storing of electricity. Energy storage as electricity is currently too expensive to meet for our ambition of eCook for low income communities. Initial ideas centred around using a solid thermal storage unit such as metal or concrete but calculations showed that the size of the thermal storage needed was too large to be practical and there were also logistical and monetary problems. The MECS team introduced us to the work of Prof. Pete Schwartz of California Polytechnic State University (Cal Poly) who were investigating the use of phase change material (PCM) as a thermal heat store for cooking purposes. Contact was established with the team and there has been a significant exchange of information and ideas. This led to switching our design approach from simply energy storage via thermal mass, such as that found in an AGA cooker, to energy storage in PCM. The existence of PCM was previously known to our team but the range of chemical options and the price points of the materials were not. A review was undertaken and Erythritol was chosen as the PCM to take forward in the prototype. More information is given in Appendix 2.

3.3 A field trip was included as part of the user-centred design process. The trip involved face to face interviews with ladies in rural villages to find out how and when they cooked their meals and what they cooked. The basic concept of the eCook stoves were discussed with them and they were asked for their views on what they would like and what they would be prepared to use. The report of the field trip is given in Appendix 3.

3.4 The main findings from the field trip were:

- wood was becoming more scarce and more expensive and they were therefore receptive to using solar power to cook with even if they had to buy the eCook stove initially.
- meals were cooked up to 3 times a day, early morning, lunchtime and evening, with the main meal in the evening.
- stirring the pot is an important part of the cooking.
- having a phone charger incorporated would be an incentive for buying the eCook stove.
- security of the solar panel was raised as a concern.
- A two-ring cooking capability would be desirable to enable two elements of the meal to be cooked concurrently.

Design of the e cook stove

3.5 The next stage in the project was that of designing the cooker. Details are given in Appendix 4.

3.6 The decision had been made to use PCM. Basic design criteria had then to be chosen. Energy calculations were undertaken to match the engineering of the solar panel to the cooking requirements and the design of the cooker itself (see Appendix 5). One outcome from these calculations was the decision to base the procurement on the output of the solar panel. This panel may generate more power than is needed for a single cooker, but it was established from the user-centred design work, that two cooking stations in one home, two rings in a western context, would be a desirable outcome. Such an arrangement would bring the advantage of being able to cook and prepare two elements of the meal concurrently. For example, the beans/relish can be cooked at the same time as the Nsima. At present only one item is cooked at a time on the fires.

3.7 Samples of Erythritol were procured and some limited heating and cooling/cooking assessments were undertaken.

3.8 There are two methods for converting electrical energy to heat which have been used in prior work for the heating of PV or electrically powered cookers; diodes and resistive wire. After a review of these two options the resistive wire approach was determined to be our preference. There were a number of factors which led to this decision, but the primary reason was cost when units are being built at scale. See Appendix 6.

3.9 The resistive wire approach needs an electrical controller to undertake a number of functions; to deliver the correct voltage of electrical power, to be able to control the heat input and cut it off when it reaches a preset temperature. This is to ensure that the heating element does not overheat and burn out and that the PCM is not overheated. An electrical controller also gives us the option to build in a 5v supply for the charging of phones; a feature which is considered highly desirable by the target market. We have coined the term Power Optimisation Device (POD) for this controller. See Appendix 5 for details of the POD.

3.10 Electrical power calculations have been done based on the performance of a degraded PV panel. Power output will drop with time due to the age of a PV unit. In dusty conditions the output is also compromised. These factors have been taken in consideration before determining the power required. The power required to melt the PCM has been estimated but this is subject to the insulation performance of the whole structure.

3.11 The shape and size of eCook stove was reviewed. One particular balance considered at length has been the compromise between the bulk and weight of the insulated lid against the user requirements for ease of handling. Whilst a two plate cooker is ultimately considered the most desirable design it was felt to be better to concentrate on a single unit until the engineering system has been proven to work.

3.12 The functional requirements of the eCook stove were continually reviewed. These requirements included:

- The location of eCook stove either inside or outside the house.

- The security issues of having a solar panel outside.
- The types and sizes of pans regularly available and used by households.
- The type of food and the volume of food cooked by a typical sized household.
- The desire for phone charging.

3.13 There were also theoretical calculations and decisions that had to be made to answer such questions as:

- Which PCM was the most desirable to use?
- How much heat is needed and therefore how much PCM is required to produce that heat?
- What is the temperature of the heat released during the phase change cycle?
- How big does the structure need to be?
- How much power can be obtained from a standard PV panel of which size?
- What output is need for the heater to convert PV to heat?
- How long can the PCM hold the heat for?

When finding the solutions to these questions the situation of the final end user had to be taken into account at all times. The solution had to be practical for use by people living in rural Africa. Details of these decisions and the reasons for making them are given in Appendix 4.

3.14 Once the basic design had been agreed by the UK team construction level drawings for the components of the system were sent to our partners in Malawi. We wished to ensure that supported local manufacture was a realistic option. For example, we reviewed the solar panels which are available in Malawi to ensure we incorporate a panel which is comparable into our prototype design.

Prototype building

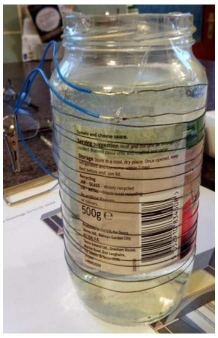
3.15 Once the basic plans had been approved by our Malawian partners the components of a prototype eCook stove were built and tested.

3.16 As we had elected to use resistive wires as the form of heating we needed to build a device which could optimise and control the power drawn from the PV panel. This is needed to match the power taken with the fluctuating power generated by the differing light conditions. This device also needs to be able to prevent the unit from overheating. A prototype electrical controller was designed and built. The unit was tested with a solar panel. This controller was constructed on prototype board for testing. The initial testing was successful. See Appendix 5. Companies were then

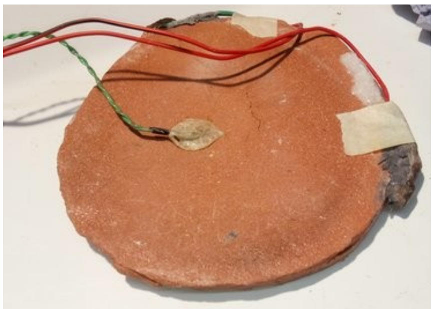
approached to see the viability of producing the board in volume on printed circuit boards. The quotes were at a favourable price. A small number of boards were procured for testing purposes. A solar panel simulator was built to continue with testing due to the lack of solar energy available in the UK at this time of year. The testing of the electrical controller has been successful and it was able to switch the heat input off and on. It has also been possible to include the transformers and a USB socket needed to provide phone charging capability.

3.17 The heater was the next component to be built. The energy from the solar panel needs to be transferred into the eCook stove where it can heat the PCM to melt it. The heater had to fulfil a number of criteria. It had to be robust to survive immersion in the PCM but it also had to be simple enough to be manufactured by non specialists in locally available materials in Malawi. A number of options were trialled. Deatils are given in Appendix 6.

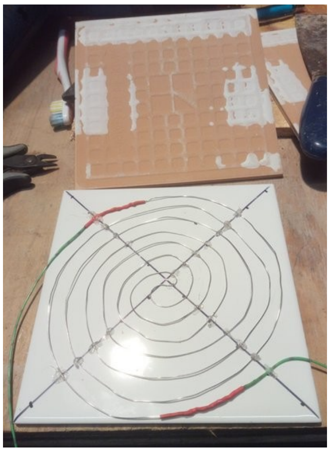
3.18 The first prototype was based on a metal can (to act as thermal transfer) but it was found to be unreliable and encouraged the short circuiting of the resistive wire. See Appendix 6.2.



3.19 The second prototype was based on a glass jar and this has proved effective. These prototypes were able to bring water in the jar to 90°C from 13°C in around 16 mins. We established that used glass jam jars are available in Malawi waste streams. See Appendix 6.3.



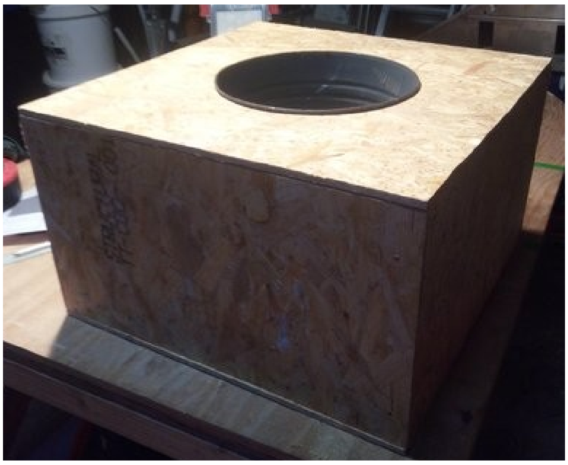
3.20 A third prototype was built by embedding the resistive wires in a clay disc with thermistor for connection to the electrical controller. This was then fired at a local pottery to simulate the available materials and conditions in Malawi. Unfortunately when the disc was fired the clay shrank exposing the bare wires which were burnt in the firing process. An alternative approach was to make a thicker clay disc with preformed grooves which is fired before the wires are laid in the grooves. This is then covered with a second disc before refiring. See Appendix 6.4B.



3.21 A fourth prototype was made using shop bought ceramic tiles in place of the clay discs. Before trying this approach our Malawian partner confirmed that these tiles were available in Malawi at a realistic cost. The heating wires were cemented between two tiles using fire resistant mortar. This prototype has proved to be the most promising design. See Appendix 6.4A.

3.22 One important aspect of the design was the requirement to insulate the vessel containing the PCM. During the day energy will be put into the PCM from the solar panel causing the PCM to melt. This needs to be kept in the liquid phase until it is required for cooking when the change from liquid to solid will release the heat to be used for cooking. The PCM vessel therefore needs to be insulated to retain all the heat. The thermal insulation properties of various materials were researched. The best insulation materials are polyurethane based but these are not practical for an eCook stove designed for building and use in Africa. The thermal insulation properties of a material is also proportional to the amount used. The thicker the insulating layer the more it will insulate However there are practical implications to this as the cook stove cannot be so bulky that it is difficult to reach the cooking surface and any pans on it.

3.23 The prototype eCook stove was fabricated as a hollow wooden box of dimensions 60 x 60 x 35 cm. Having checked that aluminium cooking foil is available in Malawi, the inside of the box was foil lined to reflect the heat back into the box. The inside of the box can then be packed with locally available materials. Options that have been discussed with our Malawian partners include rice husks and maize wastes. These materials are not readily available in the UK so the prototype has been packed with loft insulating material. See Appendix 4 for details.



3.24 The container for the PCM needs to be robust to withstand the constant heating and cooling down and also water tight. In Malawi it is expected that these will be made by local metal workers who are experienced in making cooking pans. For the UK prototype we are using a manufactured metal waste paper bin as the container for the PCM vessel as it is our cheapest and most readily available option.

3.25 Another important part of the eCook stove is the design of the hotplate that will be used for cooking on. There were a number of issues that needed to be overcome. The first one was the material that the hotplate would be made of. It needed to be able to transfer the heat efficiently to the cooking pot and therefore a metal plate has been chosen as the best conductor. In the prototype an old frying pan is being used for this purpose. However, we have also experimented with metal and sand as a metal pan to metal hotplate only works well if both are flat. In trials if they were not both flat then a layer of sand on the hotplate improved heat transfer significantly.

3.26 Another key technical challenge to be overcome was how to transfer the heat from the PCM to the hotplate. When the PCM melts and solidifies it expands and contracts in volume and therefore having the hotplate "floating" in the PCM is not viable. However leaving an air space creates an insulating layer between the PCM and the hotplate. The PCM can also be self insulating when the temperature drops and the PCM solidifies. This will always be the surface nearest to the hotplate when the cooking pan is drawing heat out. The cooling will be from the top layer of PCM leading to this top layer solidify first in much the same way as ice forms on the top of a pond. There is therefore a need to build a structure which can transfer heat from all layers of the PCM to the hotplate. See Appendix 4 for more details.

3.27 Metal bolts were added to PCM and whilst they did transfer heat from one area of the PCM to another, they appeared to have little impact on the overall heat distribution.

3.28 A second trial was the addition of stones into the PCM to conduct the heat through the material. In the first trial the addition did seem to improve the heat distribution but in the second trial the results were more ambiguous.

3.29 In a third trial sand was added as a heat conductor. Whilst the mixture did work, the overall amount of sand which was incorporated was too high in proportion to the amount of PCM to be a realistic option for both heat transfer and hotplate. The mix was approximately 5 parts sand to 1 part PCM.

3.30 A "tower" of ceramic tiles was built above the ceramic tile heater. The tiles were spot cemented together using fire resistant mortar. This allowed the PCM to flow between the tiles improving the heat flow but the top of the tower was above the PCM and the air space between the tiles acted as an insulator. This idea has not been pursued further at the current time but it has not been discarded completely.

3.31 The best material for the heat transfer is a metal. The metal used has to be readily available in Malawi. Empty food tins were used to build towers between the heating plate and the cooking hotplate. The tins had holes punched into them to allow the PCM to flow into and out of them. However the structure was unstable as the tins did not sit flat and were slightly different in height to each other.

3.32 The next prototype for the support of the hotplate and the transfer of heat was a combination of ideas. Three pillars were made using empty food tins at the base. These had three copper pipes placed in each tin and the tubes held in place by gravel. The hotplate was then placed onto the copper tubes. The tins were perforated to allow the PCM to flow into them. This method has shown heat being conducted to the hotplate over many hours. However we consider that this aspect of the design can be significantly improved.

3.33 Another limitation of the hotplate approach is that most cooking pans do not have flat bottoms. They warp with use especially when used on wood fires. For the most efficient heat transfer from the cooking hotplate to the cooking pan the greatest area of metal must be touching metal. The use of sand as a heat transfer medium may be an option going forward.

Prototype heating trials

3.34 The first trials undertaken were to establish that the prototype cook stove could heat the hotplate to a temperature suitable for cooking on. The prototype was built but only partially filled with PCM. The solar panel simulator was used to provide the initial energy. This was fed into the POD. Indicator lights showed that the current was flowing and a second indicator

light showed that there was power to the USB port. The USB port was used to charge a mobile phone.

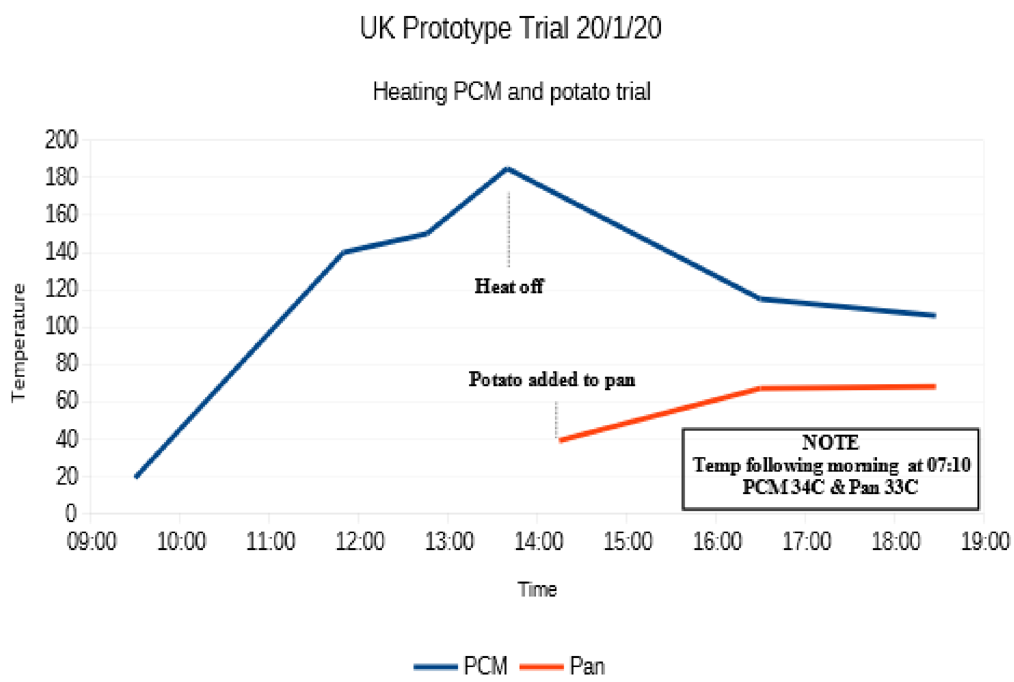
3.35 The clay disc was used as the heater as it had an embedded thermistor connected to the POD. This meant that the heating could be controlled. The POD is built so that at a set temperature the energy flow is reduced and eventually turns off the heater to prevent the PCM overheating and "boiling off".

3.36 The power supplied to the heater was sufficient to fully melt the PCM. The heat successfully transferred to the hotplate. The heater was turned off and 3 hours later the hotplate was at 97°C and the temperature of the PCM was 117°C. The cook stove was left in an unheated workshop overnight and after 19 hours the temperature of the hotplate was still higher that 70°C.

3.37 There is a temperature difference between the melted PCM and the hotplate. We expect this to be overcome by the addition of more PCM and a better heat transfer device between the PCM and the hotplate.

3.38 There had to be a rethink in the design as a failure of the heater showed up a flaw in the design. With the heater unable to operate it could not melt the PCM and we had difficulty in retrieving it from the solid PCM. We therefore looked at ways of putting the heater outside of the PCM vessel and have been using the heater in an oil bath which surrounds the PCM vessel.

3.39 The eCook stove was trialled using potatoes in a pan. There was a failure of the heater plate during the trial but the temperature achieved before the failure was sufficient to cook the potatoes overnight.



3.40 A trial was also done using maize flour. Although the temperature obtained in the pan was insufficient to boil the water flour mix it was hot enough to denature the flour and produce a solid food stuff similar to Malawian nsima.

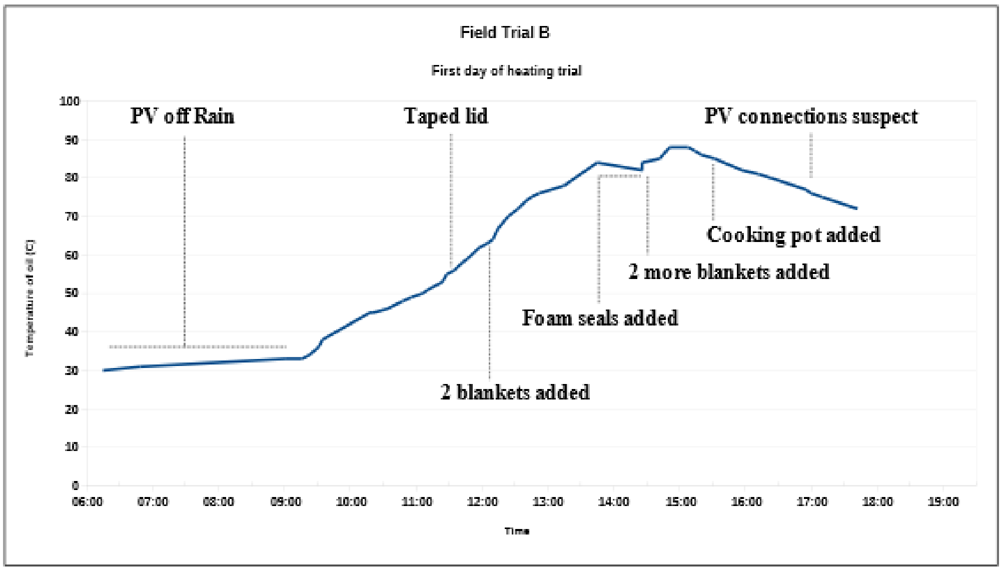
3.41 We were able to do a heating trial using a clay heater plate connected directly to a solar panel. The trial took place outside on a cold but sunny February afternoon. We were able to heat up water from 4°C to 60°C in 50 mins. At that point the sun went in and we were unable to continue the trial.

Malawi prototype trials

3.42 Production drawings of the eCook stove components had been previously sent to our partners in Malawi and they had arranged for them to be made locally. John Mullett went out to Malawi in February 2020 to train on the assembly of the eCook stove and to trial it. The details of his visit are given in Appendix 7.

3.43 At the time of the visit it was the rainy season in Malawi and most days were overcast with little or no sun. The prototype was assembled and the functionality of the components tested. The temperature of the oil bath reached 73°C but the weather conditions prevented any further temperature rise.

3.44 Full trials were commenced on the second day. It was shown that the insulation was inadequate as there was considerable heat loss from the stove. Further insulation in the form of blankets and foam tape was procured and this improved the heating potential. A mix of water and maize flour was placed in the pan on the eCook stove. There was some thickening of the maize flour achieved.



3.45 It was found that there was a large temperature differential between the oil temperature and the cooking pot temperature and it was concluded that the PCM was acting as an insulating layer. The decision was taken to transpose the oil and the PCM so that the oil was in direct contact with the heat transfer rods. This did achieve a thickened nsima paste but over too long a time to be acceptable. It also showed that the insulation was still insufficient.

3.46 Trials were performed using the heater as a hotplate outside of the insulated cook stove. Water was heated and when at a suitable temperature a local lady used the solar powered hot plate to cook nsima porridge.

3.47 Time was also spent, when in Malawi, explaining to local people about the concept of the eCook stove and how it could be built and how it worked. See Appendix 8 – Dissemination for more details.

The project findings

3.48 The findings of the project have been divided into three sections: local buildability, local cooking interest and technical developments.

Local buildability

3.49 A key objective of the project was to devise an eCook Stove that could be built by a local business with minimal imports. This has been successful. The main components of a prototype eCook stove were built by local people in Malawi. It was then assembled by the local people under the guidance of John Mullett who supplied the POD and heater plates.

3.50 The POD and heater plates were supplied by SOWTech because of the time restraints of the field trip visit. As explained below and in Appendix 5 the POD has been developed so that it can be assembled locally. The heater plates have also been developed, in collaboration with our Malawian partners, with components that can be readily sourced in Malawi enabling the heaters to to built locally.

Local cooking interest

3.51 There has been a lot of local interest in the eCook stove. We were able to use the hotplate connected to the PV panel to cook maize flour to produce Nsima porridge. We were also able to cook Nsima using the slow cook approach but the length of time this took was too long for practical use at present due to the lack of sunshine.

3.52 The use of the hotplate, without the heat storage PCM element, can be a way to use the eCook stove in the presence of sunshine. There was also interest in using this approach to heat oil to cook street food such as mandasi. Mandasi are produced by local sole traders to sell in markets. They cook on 3 stone fires using wood as the fuel at present..

3.53 There is also a lot of interest in the eCook stove development by those organisations that prepare meals on a larger scale to feed school children. Being able to use solar power rather than wood would save both in cost and deforestation and potentially allow more meals to be provided.

Technical developments

3.54 We have been able to demonstrate that the PCM, Erythritol, can be melted using the power from a solar panel. This PCM can retain the heat over a number of hours and be used to cook food. The temperature differential between the temperature of the PCM and the temperature of the hot plate has shown that the eCook stove can be used to "slow cook" food. This will allow food to be cooked over a longer period of time and disconnect the cooking time from the presence of sunshine.

3.55 One major technical development was the design and production of the Power Optimisation Device (POD). We have developed a device that will regulate the power from the solar panel that is low cost and which is fabricated so that it could be made, and repaired, locally using readily available tools with minimal training.

3.56 Overall our findings are that there is much interest in the eCook stove and that, although there are still some technical problems to overcome, we have made good progress and have developed a product with potential to become an eCook stove that can be used in rural Africa to alleviate some of the issues caused by the use of wood as a cooking fuel.

Limitations of the innovation/approach/design/system

3.57 The limitations of our work on this project can be summarised as follows:

3.58 The use of solar power to capture heat energy only works well during periods of strong sunshine. An alternative of secondary cooking capability will still be required. Undertaking our field testing during the wet season highlighted this challenge.

3.59 The food eaten by the those with the lowest income is cooked using high intensity heat (fire). The cooking procedures and recipes are based on this type of heat. Whilst our PCM stored heat was released at 118°C we were not able to transfer this temperature to the cooking pan in the work undertaken to date. The cooking pan in the eCook stove did not achieve boiling temperatures and as this is part of the "usual" way of cooking this is a limitation. Further work on the choice of PCM and the hotplate design should overcome these limitations.

3.60 We were able to demonstrate heat sufficient to slow cook most foods but this form of cooking will require new recipes/approaches to cooking.

3.61 Achieving a paradigm shift in wood fuel use may be easier to achieve by provision of an alternative or supplementary fuel for cooking enterprises that feed many. These enterprises know they have a problem with wood fuel and are prepared to work towards alternatives. However achieving this may not be considered the best approach to effecting alternative cooking for the vast majority. Having said that, home cooking is not how around a third of all Malawi children get their hot meal.

3.62 The stored heat battery using PCM materials will be easier to demonstrate for cooking porridge in bulk cooking.

3.63 One of the limitations of the trials work undertaken is that direct heating and hotplates were only considered towards the end of the project. These approaches show promise and the limited work on these ideas was a limitation.

3.64 The use of a PCM has been shown to work. A limitation is the local availability of the material. The materials are however mass produced and there is no technical reason why local production of PCM could not be supported if demand was demonstrated. However it is a challenge for early trials.

3.65 Whilst local production of the electrical heaters and POD's is possible, there is a need to invest in training and capacity building.

4. Practical applications of the concept to the national cooking energy system (including costs)

4.1 A number of practical applications have come to light as a consequence of our work on this project. They are not outcomes that we would have been expected before we undertook the study and especially the fieldwork in Malawi. The applications fall into two categories, those which do involve heat storage and those which do not.

Direct heating

4.2 One of the outcomes is the concept of the PV powered hotplate. This would be a flat, probably metal hotplate with a resistive heater attached and a PV panel which powers the hotplate via our POD. This product could be made now given the expertise developed to date.

4.3 The application for the hotplate would be as a unit which could boil water in direct sunlight. This is a challenging task for stored heat at this time, but simple enough if undertaken with direct sunlight. African beans are a key protein source for our target beneficiaries but they require boiling to denature the toxins. The boiling time required is limited, so passing beans onto a “slow cooker” for the balance of cooking would be realistic.

4.4 A second direct heating option which would be quick to develop would be a direct PV powered deep fat fryer. Frying food such as mandasi (donuts) is a way in which some entrepreneurs make a living. Many street food vendors also use frying as a means to cook their offerings.

4.5 To produce such a unit would require a few small changes to the apparatus already developed so that the oil could be taken to 190°C. The system would comprise a PV panel, POD and a heater. The cooker itself could be manufactured from steel or concrete.

4.6 The use of a deep fat fryer would never be mainstream cooking for the poor, but it could be a useful demonstration unit to introduce and familiarise the community to the concept of PV cooking. There is however a real market for this style of cooking of value added products. Given that such cooking is undertaken by those who generate cash it could mean that they would have the resources to buy such a cooker. Obviously if the weather did not support PV cooking then the traditional stove could be used as an alternative at these times.

Cooking with stored heat

4.7 The challenge of cooking the food consumed by the poorest using stored heat is difficult when boiling the food is the norm. Slow cooking and stews are not available to the low income on a regular basis. However the research did indicate a possible approach that could have merit for large scale cooking for the poor. As discussed elsewhere in this report, there are charities who give thousands of children the only hot meal they get. Mary’s Meals is one such organisation. This organisation has a daily challenge to find the wood necessary to cook these meals. Their ladies start the cooking process at around 3am so that the porridge is ready for the children before they start school. The charity used to supply the wood fuel for cooking in most locations but due to the challenge of supplying the wood, the local population now has to supply their own wood. Only in urban areas does the charity provide some fuel in the form of bamboo briquettes but the supply is erratic and not available at scale. The scale of the cooking undertaken by this organisation is very significant. They feed over 860,000 children in Malawi every school day. This equates to over 2,000 pots of food which is more than 250,000 litres of porridge and this is for only 30% of primary school aged children.

4.8 The way in which we could see the eCook stove work being applied is to use the technology we have developed to provide hot water to cook with. It would involve a solar powered heat store or battery, filled with PCM, which is charged during the day. The heat battery is insulated and retains its heat overnight. Hot water is provided from the heat battery at the commencement of cooking. The firewood consumption would be dramatically reduced as the water heating would be from approx 90°C to 100°C rather than 20°C to 100°C. This would save raising the temperature of the liquids by 70°C. Although this would not replace the wood based cooking it would reduce it considerably and provide other benefits such as reduced cooking time. The organisation would be capable of rolling out any new technology across multiple locations as they have a centralised and standardised system.

4.9 The same provision of hot water to prime the cooking process could be relevant also to other cooking applications too.

4.10 The other heat storage application is the slow cook oven. Much has been learnt from this project regarding the design and layout of the unit. Further reviews of higher temperature phase change materials could make it easier to get higher hotplate temperatures. Improvement to the insulating materials available is needed and further work on hotplate heat transfer is also required. It is going to take a significant evolution in cooking behaviour to move away from the intense hot cooking processes used when heating with wood/charcoal. This process of change from using hot temperature fuels to longer cooking at lower temperatures will not occur until a suitable cooker is available to the poor. Without it the transition will not even begin.

Costs

4.11 An eCook stove will only be acceptable to people if it is affordable and they can see a cost benefit to having one. Feedback from the user-centred designed process indicated that people were willing to pay for the stove. They could see that the cost could be offset against the price of buying wood and that the price of wood was increasing and availability was decreasing.

4.12 The main cost of the eCook stove is the solar panel. The panel in Malawi cost about 80,000MK (£85). The Malawian government has recently removed taxes from all renewable energy products. The trend is for the cost of such solar panels to reduce.

4.13 The POD was designed so that it did not use modern manufacturing methods requiring complex factory based equipment. It is a double sided printed circuit board which would probably be manufactured in China but the device could be assembled locally.

The component cost of a single POD for the prototype was around £5. When ordered in quantity the cost will reduce to pennies rather than pounds.

4.14 The ceramic tile heater components cost around 50p and the clay heater plates were considerably less than this.

4.15 All other components of the eCook stove including the outer casing and the inner metals vessels were built in country and this experience has shown us that it can be further value engineered with more cost effective raw materials sought.

4.16 We would expect, with economies of scale, that the eCook stove could be manufactured at a cost acceptable to local people whilst giving employment to those fabricating it in country.

5. Next steps

5.1 The project has brought insights into options for moving forward with PV powered cooking. A brief comment will be made on some of these. These are not placed in any particular order of significance.

5.2 **A PV powered hotplate for boiling during the day** - The technology we have developed in the project means that we can build a hotplate for boiling liquids which can be used during sunshine. This would make it possible now to make Nsima or to render African beans safe. These are necessary “boiling” tasks and ones that are currently difficult using the PCM stored heat.

5.3 Develop a micro-enterprise deep fat fryer - Using the technology we already have to produce a deep fat fryer which would work in full sunshine and enable “value added” products such as Mandasi to be made and sold. This unit would require a small change in the temperature regulation sensors to enable the oil to reach deep fat cooking temperatures (c 190°C). However, as the food goes straight into the hot oil temperature transfer to the food is not a problem.

5.4 Both of the above projects are low hanging fruit but have limited scale and reach potential,. However they would represent a good demonstration or “show what can be done” potential.

5.5 **Develop a heat store for the provision of hot water for cooking using PCM** - Mary’s Meals, a charity based in Scotland, provides a cooked meal every day for over 30% of all the children in Malawi. The meal comprises of maize and soya porridge locally referred to as likuni phala, fortified with essential vitamins and minerals. The porridge mix and the methods of cooking are standardised throughout the programme. To make the porridge water is heated from ambient (18°C) to around boiling by burning unsustainable wood fuel. If the cooking was started with the water already at approx. 85°C, this would mean a major reduction in the wood fuel requirement. We consider that the PCM heat storage approach could be designed and scaled to provide hot water for cooking without requiring a major change in tools or methods of cooking.

5.6 The project would be to use the PCM heat store to capture sunshine through PV during the day, hold the heat in insulated structures and then, when hot water is required, pass cold water through the heat store to generate hot water for cooking. Hot water would not be stored but simply piped to the cooking pot as and when needed. Using hot water would mean far less wood burned to bring water up to the required temperature and thus effecting an immediate and dramatic wood fuel saving. The production of the meals is standardised and the same approach is also used in 18 other countries so there is the potential to repeat in multiple locations once the technology is proven.

5.7 Evolution of “slow cook” options for low income communities - The existing eCook stove we have built needs further refinement to improve heat transfer into the cooking vessels. We would like to pursue such improvements, perhaps in partnership with other organisations such as Cal Poly. We would like to explore other food groups that might be suited to slow cooking without boiling. The transition away from intense wood heat cooking will probably requires the introduction of slow cook options to these communities. We would like to continue to work towards this objective.

Dissemination Plan

5.8 We have begun to disseminate information about our project to interested parties. See Appendix 8 for further details. SOWTech has a newsletter that is sent to our supporters on an irregular basis. These supporters include personnel from some of the major international charities and NGO's eg Senior Officer for Water, Sanitation, and Hygiene promotion in emergency response in the International Federation of Red Cross and Red Crescent Societies, people we have worked with in the past and other similar minded people. We have sent out two newsletters about the project (they are also on our website sowtech.com/lynns_letters.html). A number of people have responded directly to the newsletter with positive comments.

5.9 We have also shared the plans with our Malawian partners to ensure that the work we are doing in the UK can be easily replicated in Malawi. They have given us feedback as to what materials are available at an affordable cost and what isn't.

5.10 On the field trip to Malawi we discussed the concept and preliminary plans for the eCook stove with the potential customers and users of the stove. The results of the discussions were positive and are reported on elsewhere in this report.

5.11 During the field trip we also had the opportunity to take part in a debate with secondary school children on the impact of new technology. The main focus was on mobile phones and internet as that was the technology they knew about. However the debate was opened up as we introduced the idea of a solar powered eCook stove to them. The concept was well received as they were very aware of the problems of using wood as a fuel both to the environment and to health as well as the supply and cost issues.

5.12 We have been sharing our knowledge and experimental results with the team at Cal Poly under Prof. Pete Schwartz as they are working on a similar project and hope to continue with the collaboration.

5.13 We have also been discussing the concepts of the project with an entrepreneurial company working in Zimbabwe looking towards future expansion of the project.

5.14 We have produced a series of appendices for this report that will be converted into standalone reports on aspects of the project which will be published on our website.

5.15 We are looking to produce of videos suitable for uploading onto YouTube to show the work relating to the eCook stove project.

5.16 Further articles will be written in "Lynn's Letter" to share the information about the project with our distribution list.

5.17 We intend to continue with our talks with organisations such as Aquaid Lifeline and Mary's Meals to pursue the development of suitable eCook stoves with them and disseminate the information about it to them.

6. Conclusion

6.1 The aim of our project was to make cooking with solar energy derived from photovoltaic panels something which can replace cooking on 3-stone open fires.

6.2 Our first objective was to undertake a study of the target user group's cooking habits, preferences and practices to input into a user-centred design process. The results of this study was that there was an appetite for something that could replace wood based fuel as this was becoming more scarce and as a consequence more expensive. The staple food stuff cooked by the poor in rural locations in Malawi has remained unchanged for generations and as such is ideally suited for cooking on an intense heat source. Meals are usually nsima porridge for the children in the morning and then nsima with red beans and relish in the evening.

6.3 Local ladies had input into the user-centred design for the project. They were keen to try an eCook stove. They would like it to have more than one cooking area, not use wood fuel and have the ability to charge a mobile phone. Stirring the pot was an important part of the cooking process but this was not continuous. They wanted the time taken to cook a meal, from first building the fire to serving, to be no longer that it takes now.

6.4 The second objective of the project was to design a product which is not imported as a finished product but which is could be assembled locally and which uses the minimum amount of imported components. This has been a key design criterion throughout the project.

6.5 At all stages of the project we have been in communication with our Malawian partners to ensure that the materials we were planning to use were available in country at an affordable price.

6.6 We have developed an eCook stove that has been shown to be able to be fabricated in Malawi. On the second field trip to Malawi the structural components of an eCook stove were made by the locals and the solar panels bought locally. The Power Optimisation Device, which is required to optimise and control the power drawn from the PV panels, was produced as part of the UK prototype but was designed so that it could be assembled (and be repaired) locally by trained technicians. The heater plate was brought from the UK due to time constraints but it was agreed that they could easily be made locally in country.

6.7 On the field trip to Malawi the eCook stove was assembled and trialled. The local people were enthusiastic about it and keen to learn about it. Some of the local ladies were able to try cooking using it and they made their local staple food, nsima porridge.

6.8 In conclusion we have achieved our objectives of the user centred design process and of working with our Malawian partners to produce an eCook stove that can be built locally with minimum imports. There is still development work to be done to produce a viable product for rural households but there are a number of avenues that we are exploring where the eCook stove so far developed can be used to reduce the amount of fire wood used.

7. Appendix

7.1 We have produced a number of appendices as separate documents that give a more in depth explanation of the work done for this project including photographs and diagrams.

Appendix 1 – Review of ecooking in Sub-Saharan Africa

A review looking at the current methods of cooking in Sub-Saharan Africa with emphasis on the situation in Malawi. The types of eCook stoves that are available at present including those in development as well as those that have been trailed in the field and are in production.

Appendix 2 - Simplified Guide and Review of Phase Change Material

A guide to what Phase Change Materials (PCM) are, how they work, applications of PCM and the reasons for our choice of PCM.

Appendix 3 - Report of initial user-centred design visit to Blantyre area of Malawi, 9-16 October 2019

Report of the visit was made to the Blantyre area of Malawi from 9-16 October 2019 by Lynn McGoff of SOWTech C.I.C. as the initial consultation in the user-centred design process for the developing of an eCook stove using solar pv as the stoves energy source.

Appendix 4 - Design and Construction of the SOWTech UK Prototype eCook Stove

The Appendix gives an account of the design and fabrication of the UK prototype of the eCook stove excluding the heater and the Power Optimisation Device. It includes pictures and diagrams explaining what has been undertaken but the technical text has been kept to a minimum. The account seeks to convey the areas where things have not gone according to plan as well as those that we are pleased to report.

Appendix 5 - Power control, thermodynamics and PV panels SOWTech eCook stove

This appendix covers three topics regarding the cooking power topics relating to the project. There are three discreet topics covering the development and use of a Power Optimisation Device to control and optimise the PV power derived from the PV panel, the thermodynamic calculations which formed the basis of the power requirement, and a brief account of the PV panel specification issues options identified during the procurement of PV in Malawi.

Appendix 6 - Development of PV powered heaters for the eCook stove

The development of the eCook stove required heaters to be developed which would be powered by photovoltaic cells. One of the requirements was that they should be suitable for local manufacture. This appendix summarises the steps taken which led to the development of two types of heater. Both types of heater can be made locally to the end user as they are simple to make and require the minimum of bought in components.

Appendix 7 - Technical Report of the Field Trials of the Malawi Prototype

This appendix gives an account of work undertaken to build a prototype eCook stove in conjunction with partners Aquaid Lifeline, at the children's village at Namisu, near Blantyre, Malawi. The work was undertaken on 10-14 February 2020.