Appendix 6

Development of

PV powered heaters

for the eCook stove

Contents

Preface

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.

The aim to make these short accounts discreet so that they are easier to cross reference and to make it as easy as possible for easier for the reader to follow the evolution of the project.

Abstract

This appendix gives an account of the evolution of the heaters used in this project. Each iteration of development is described as a Step. Later in the project two different paths for heater fabrication were developed in parallel.

The development of a heater which could be fabricated within the low income community was a key part of our overall objectives. Simple tools, low cost and locally available materials (as far as possible) were considered essential.

Step 1: Evaluation of prior work

Introduction

Prior work led by Prof Pete Schwartz at California Polytechnic State University (Cal Poly) had demonstrated that heaters could be made using diodes. The alternative option for generating heat was the use of heater wire. A review of both approaches was required.

Work undertaken

The consultants to our project, Dr Euan Smith and Dr Paul Routley, considered both options and also had communication with the Cal Poly team.

The following exchange is a sample of the communications we have had but it illustrates the nature of this collaboration.

To Pete, Matt,(Cal Poly)

Euan here, I've been helping Paul and John in some of the discussions.

Have you looked at the reliability of the diode chain? I would have suspected that the failure mode of a diode would be open circuit, as I would think that a failure of one of the connections (wire bond to the semiconductor, solder joint, etc) would be more likely than degradation to the semiconductor itself, and unless they are well sealed then moisture could accelerate the corrosion of such joints. A single diode chain represents a lot of such contacts in series and would be susceptible to a single point of failure.

Euan. (SOWTech team)

To Euan, Paul, (SOWTech)

Euan: Exactly what we are dealing with. Moisture is infiltrating the area surrounding the diode chain, and allowing corrosion on either the first connection (copper wire to tin coated copper diode lead) or the last (same as above).

Paul: How are you able to get a PWM for $4? Sounds awesome. Is this something you are buying, or building? Thanks for the well organized diagram. This makes resistive heaters more attractive, but there is still the issue of ease of construction/manufacturing. I also am confused: the goal of the PWM is to extract maximum power from the panel AND to provide maximum power to the heater. Are you providing maximum power to the heater? What kind of losses do you expect? I have a personal solar system, and pwm charge controller by Renogy that claims 99% efficiency in drawing power from the panel and 98% conversion efficiency, for example.

…......................I applaud you for heading that direction and suggest you keep going.

Matt

This collaborative discussion and exchange has continued through the project.

Conclusions

The outcome of the review was that our technical consultants understood that the hot diode approach was workable, but on balance we decided to pursue the resistive wire approach. The reasons for this included:

- *Lower unit cost at scale*
- *More resilient to corrosion issues*
- *More operational and control flexibility*

Step 2: Tin can heaters

Introduction

The tins in which canned food is sold are available in household waste in Malawi. The first heaters we made used these cans.

Work undertaken

Resistive wire (Constantin Ni Cu) was measured to an appropriate length to give a resistance of approximately 10 ohms. This was wrapped around a can and then held in place using fire cement. The expectation was that the metal can would provide a radiant heat source. The wire has an insulating layer so it requires that layer to be stripped to make the connections. A transformer and rectifier were assembled to provide a power supply which would mimic, as far as possible, a PV panel supply.

The trial failed as the heater wire burnt off the insulation on the wire and the metal can then shorted the circuit.

The following photo illustrates the heater.

Conclusion

The can being conductive was not suitable as a heater element. A glass bottle might make an alternative which would not be electrically conductive, but which would be capable of withstanding heat, and be readily available in low income communities.

Step 3: Using Glass food bottles as heaters

Work undertaken

Using pasta sauce bottles, various heaters were made and tested. The resistive wire is difficult to hold in place with fire cement due to it's "spring" so glue gun and heat resistive self adhesive tape were used. The wrap around a bottle was easy to make once the ends were secured to the bottle.

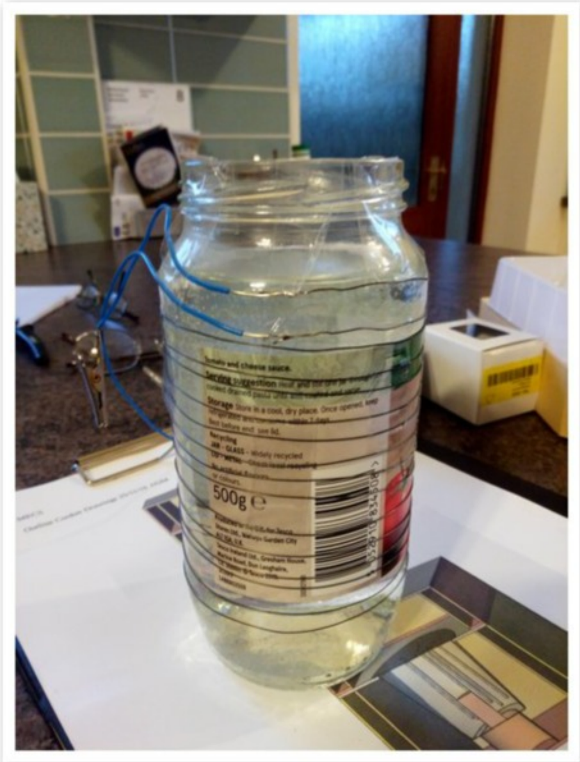
The following photographs illustrate the approach:

Conclusions

Whilst a bottle worked well as a support it was felt that we should develop a more robust heater structure.

Photo illustrations

#1 Heater wire being wound onto jar



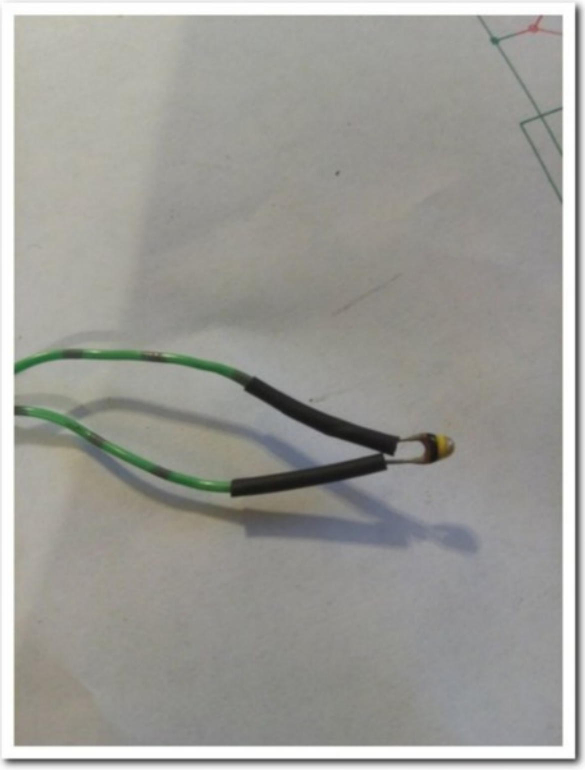
#2 Heater wires soldered to power wires

#3 Heat resistant tape being used to hold wires

#4 Wire encased with fire cement

Photo illustrations cont

#5 Fire cement being cured on stove



#6 Thermistor used on bottle to control max temperature

#7 Heat resistant tape holding thermistor

#8 Jar heater under test - note thermometer

Step 4A: Development of ceramic tile heaters

Introduction

A flat heater was felt to be the most flexible shape which was likely to be the most robust. The heater project followed two different strands of development.

One approach was to use ceramic tiles as the heat-conducting support structure. We established through our partners that ceramic tiles are readily available and in Malawi.

The second approach was to make heaters in clay. Clay bricks are manufactured within the low income communities for house building. To seek to mimic this situation, we joined a pottery workshop in Cambridge. These two initiatives ran concurrently. The ceramic tile approach will be described first in this report.

Work undertaken

White ceramic tiles, 150mm by 150mm were used to make the heaters. The method used to make the heaters evolved so this report briefly outline this process.

The first heaters were made using NiCu wire. The wire was cut to length and then wound in a double spiral on the surface of one tile. Various methods of holding the wire in place were tried, but a dab of hot glue gun worked well. Once the wires were held in place fire cement was used to make a sandwich with a second tile.

Initially the fire cement was used to just hold the two tiles together, but once we started using oil as a heat exchange material, the exposed heating wire boiled the oil. It was therefore necessary to fully enclose the heater wire.

We had some failures with the point of connection between the heater wire and the wire delivering power to the heater. Various methods such as push connectors, solder and shrink tube were used. Eventually the method found to be the most satisfactory was “chocolate block” connectors with the plastic stripped off. The used of a hot blade rope cutters worked for this task.

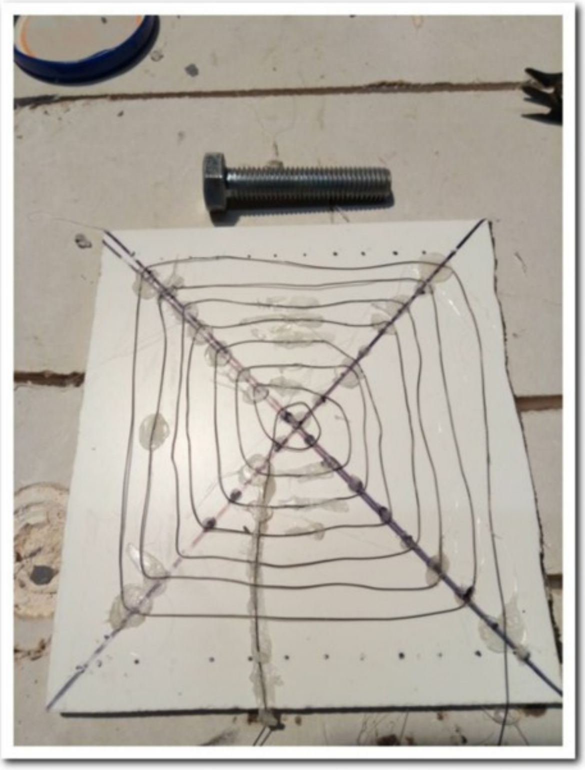
Later in the project we used cement to create thicker tiles. The cement stuck best to the smooth ceramic surface rather than the clay back. We consider this to be a result of the porous and weak surface texture of the tile. This however, will be useful if trying to mould concrete only heaters without retaining a tile.

If the concrete is not oven heated to dry out the heater fails when put to use. This is a result of the vaporisation of the moisture by the heater. This vapour is unable to escape and the resulting pressure causes the cement to blow apart. One of the other options is to “condition” the heater in oil. By putting the heater in oil, the temperature rise is controlled as the oil dissipates the heat, and the moisture vapour is released into the oil slowly and the resultant void filled with oil. This approach seems promising and worth testing further.

A small framework helped to shape the tile heater. Once we started fully encasing the heater wire in cement, the second tile was left off to allow for drying and vapour release.

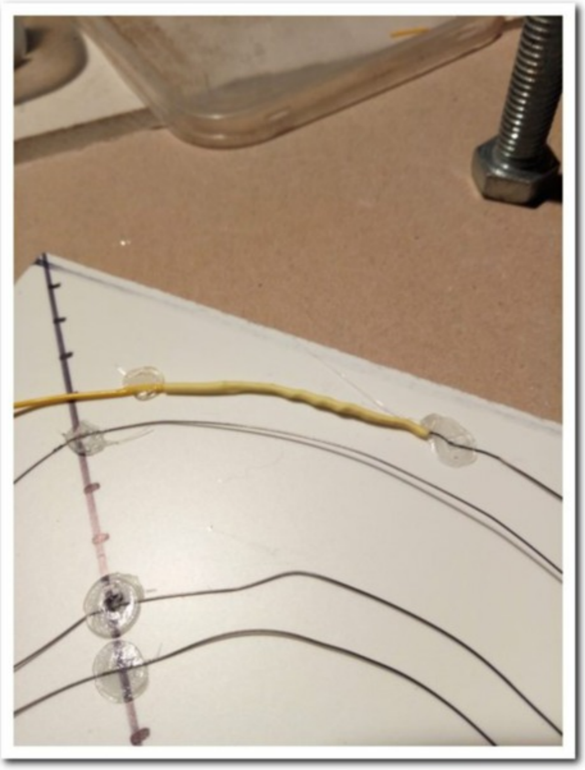
The following photographs illustrate the processes described above.

Photographs illustrating the development of the tile heaters



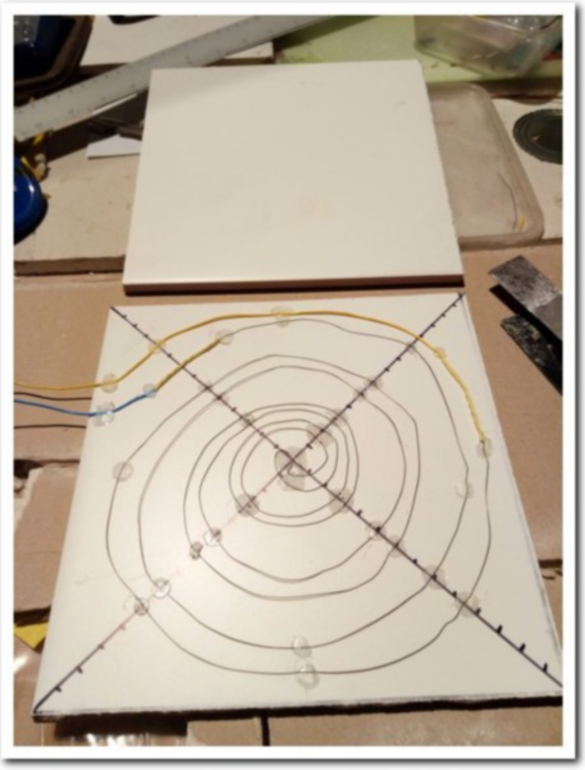
#1 First tile heater - overlapping wires

#2 Double coil wire layout - Bolts and glue gun



#3 Shrink wrap joining heating wire to power wire

#4 Fire cement used to join tiles



#5 Fabrication - Lay down the heat wire

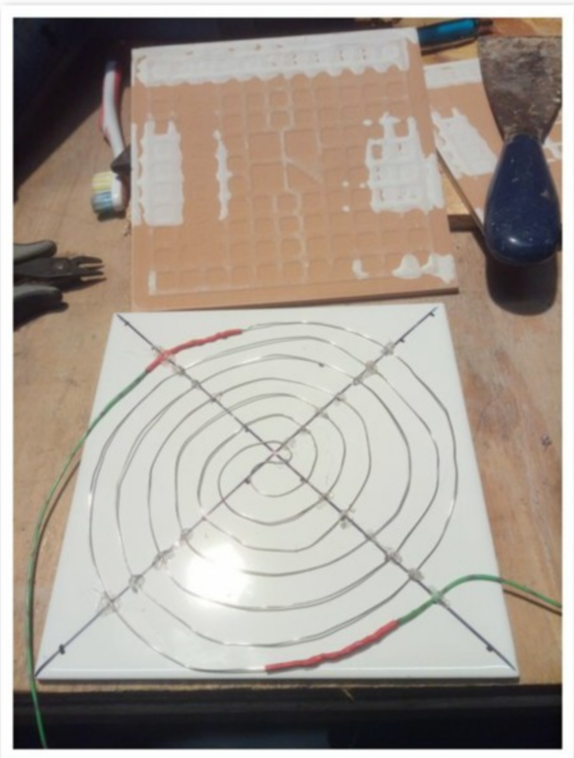
#6 Fabrication - Apply fire cement

#7 Fabrication - Spread fire cement avoiding

#8 Fabrication - Apply fire cement to second tile and apply to the first tile

#9 Start of cement/mortar trials

#10 Dabs of cement/mortar used as per wall tiling

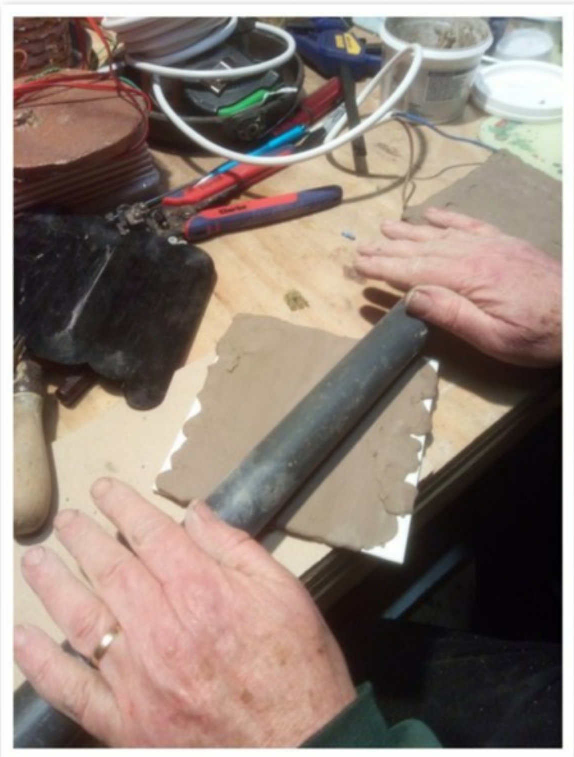


#11 Heating wire changed to Nichrome wire

#12 After fabrication always test the wires

#13 Use of 3D printed profile to mark wire path in a clay

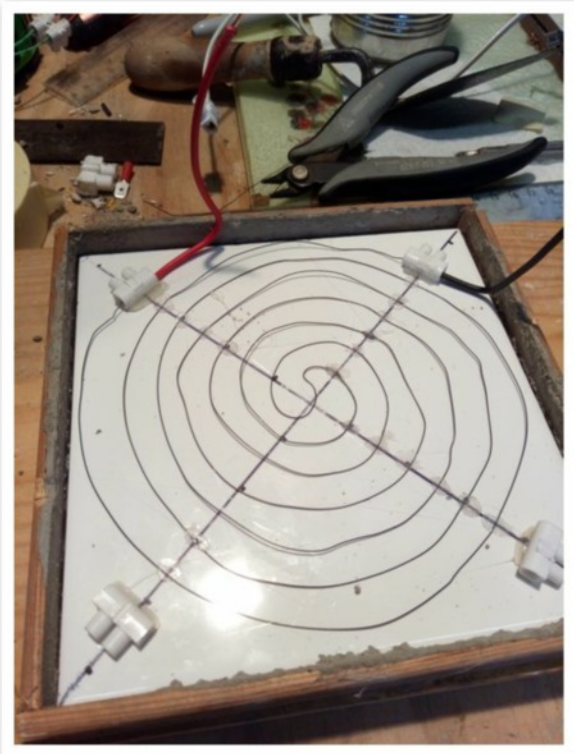
#14 Wire squeezed into clay to hold wire in place



#15 Top sheet of clay rolled out

#16 Top sheet applied to wired clay

#17 Dried clay shrunk after drying. Tile weak and unserviceable due to exposed wires



#18 Wooden frame used to hold cement and experimentation with choc block connectors

#19 Heating wire being held together using masking tape

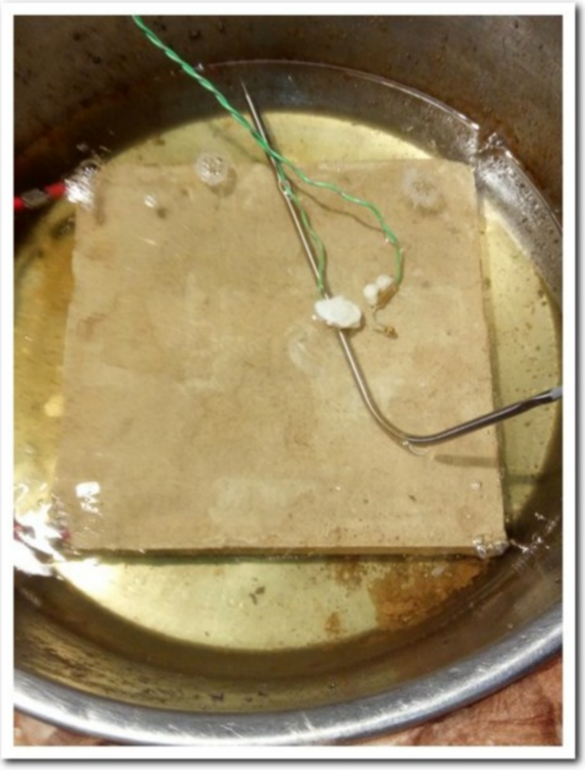
#20 Mould filled with cement. Channel being grooved for cables

#21 External choc block as connector

#22 Push fit connector being encased in cement

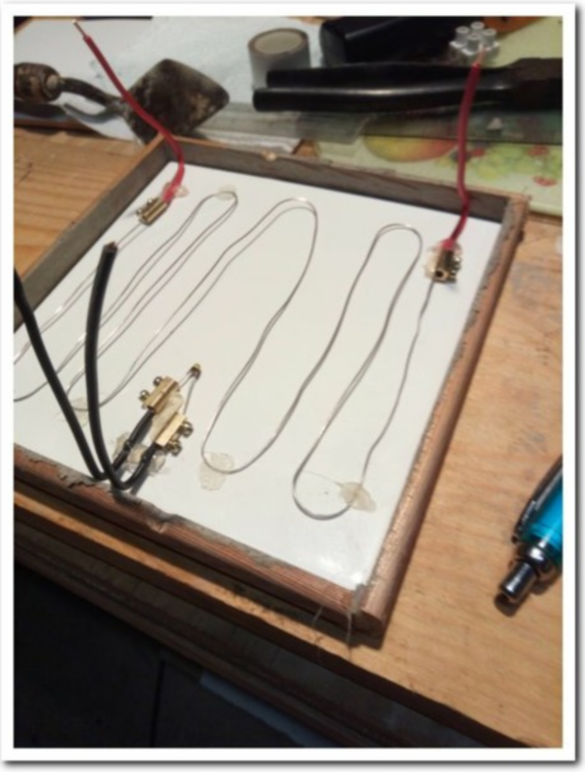
#23 Cement tile blown by heating with retained moisture - A

#24 Cement tile blown by heating with retained moisture - B



#25 Oil bath being used to condition cement

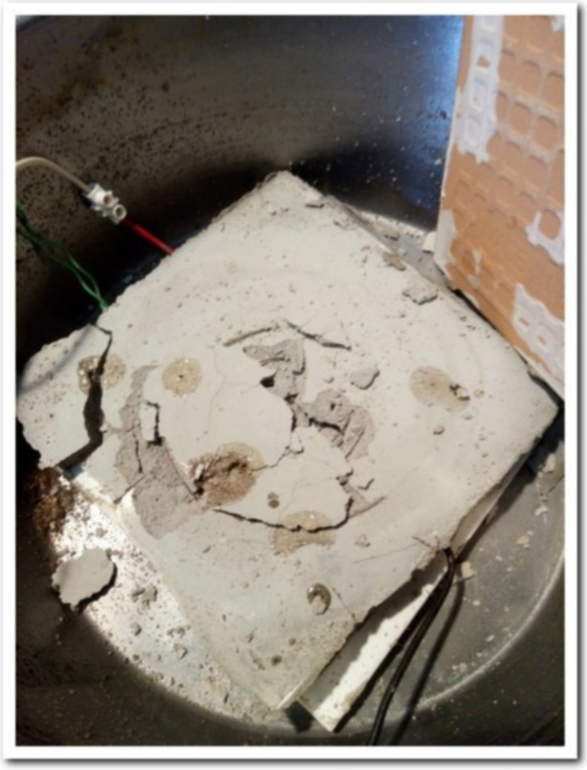
#26 Revised wire-shaping framework with shorter distances



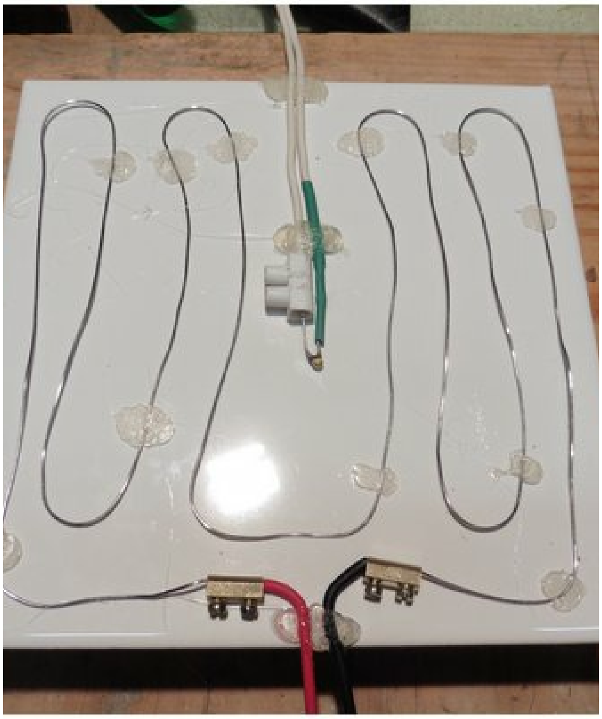
#27 First version of mould showing wires coming out in the vertical plane

#28 Revised mould to allow wires to protrude in a horizontal plane

#29 Stripped choc block shown as internal connection to power/sensor wire



#30 Thermistor connection using a choc block to provide tension support once in cement



#31 Wire arrangement to allow for horizontal emergence

#32 Clamps being used to hold tiles whilst setting

Step 4B: Development of clay tile heaters

Introduction

The use of clay to make bricks is a familiar process to most rural economies in low income areas. To make heater tiles using clay is a good fit with our objective of developing a locally manufactured eCook stove. In order to explore this option we joined a workshop in Cambridge which offers facilities for pottery making. (https://www.kilncambridge.com/)

Dr Paul Routley, our technical consultant undertook this experimental work and he was given assistance from Dr Bilgin Soylu, one of the owners of the facility.

Work undertaken

The first trials with the clay was undertaken using Constantin (Ni Cu) heating wire. The wire was pressed into the clay in the shape of a double loop. This clay was then dried and fired. The shrinkage of the clay during firing of the clay was enough to cause the heater wire to become exposed. The temperature of the kiln was hot enough to cause the heater wire to fail. Photos are included below to illustrate this issue.

The conclusion from this work was that a more robust heater wire should be used. The Constantin wire has a melting temperature of 1200°C and this was subsequently changed to Nichrome wire which melts at 1500°C

Further tiles were made with the new heater wire. The method of assembly was changed.

A wire path template was developed and printed on a 3D printer in plastic. This template was then used to press a depression into the clay tile which corresponded to the predrawn path of the heater wire. Once the wire was in place, a second disk of clay was applied onto the first disk of clay, thus encapsulating the heater wire.

The heater wire was left exposed during firing so that the power supply wires could be attached later. During firing, the clay did shrink and in some instances the clay cracked. The heater wire circuits were not broken so some cement paste was used to fill the cracks.

As the Malawi field trial arrangements progressed, the resistance of the heater wire was changed from around 8 ohms to 3 ohms, to accommodate the type of PV panel which was to be used.

There were instances during the trial where the point of connection between the power supply wires and the heater wires was vulnerable. As exposed heater wire became a source of boiling oil in the later trials it was necessary to further cover the heater wire on the tiles after firing with cement paste.

Conclusions

The clay tiles worked well and were very robust. They remain a workable proposition for local fabrication, but refinement of the process is needed to overcome identified weaknesses. One downside for the clay tile was that it is not easy to creating a smooth surface which can act as a hotplate for cooking.

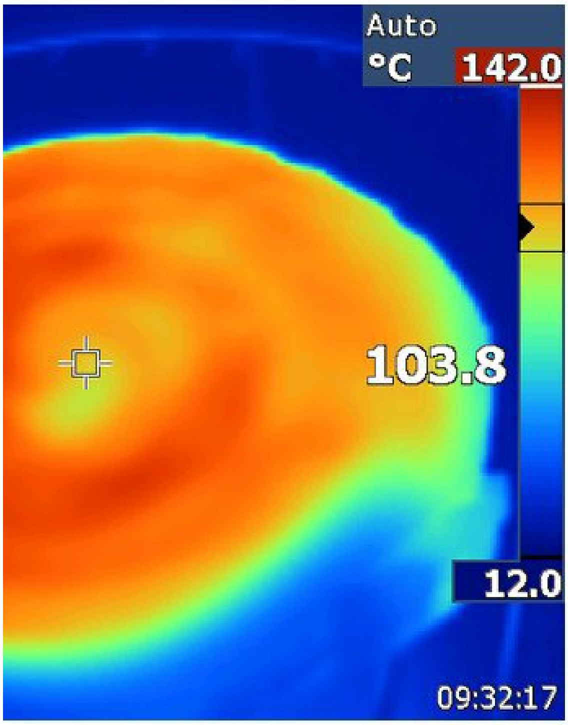
Photographs to illustrate the development of the clay heater tiles

#1 First attempt at clay heaters. Burnt out wire shown as brown flecks

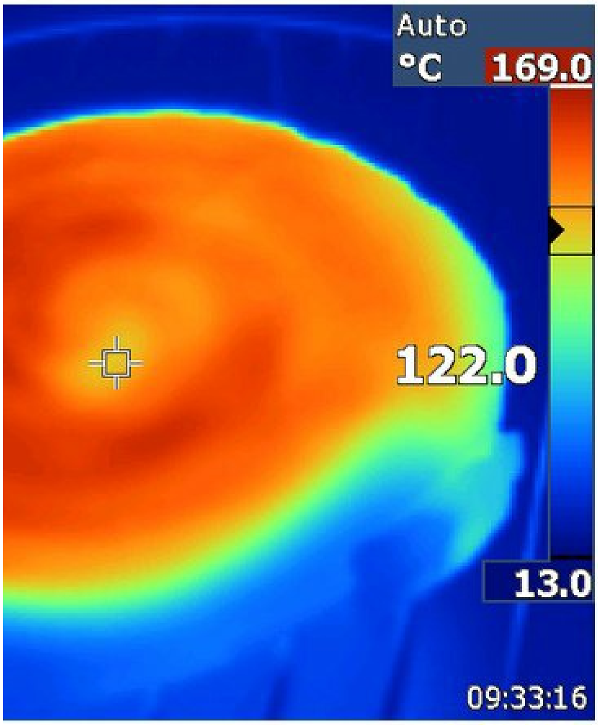
#2 Close-up of damaged heater wire

#3 Version of clay tile under heating load. Infra red photos of this tile below.

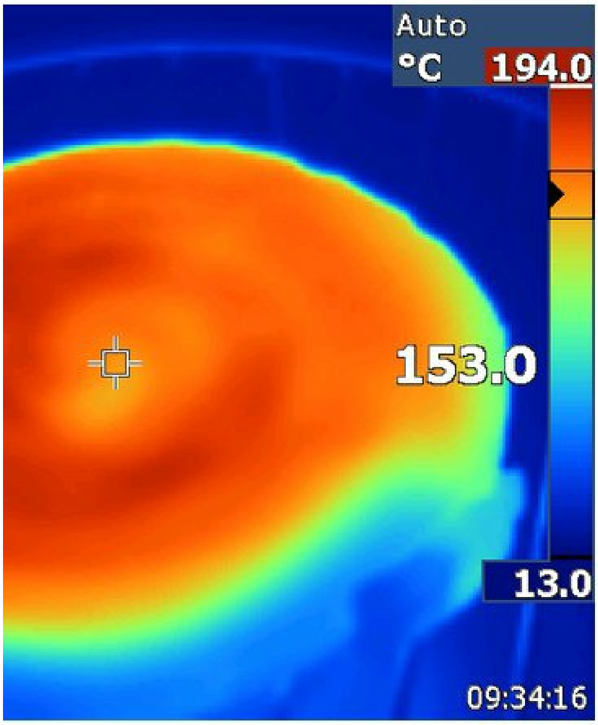
 # 4 Clay tile having been used in PCM. Reinforcements of cable showing on right



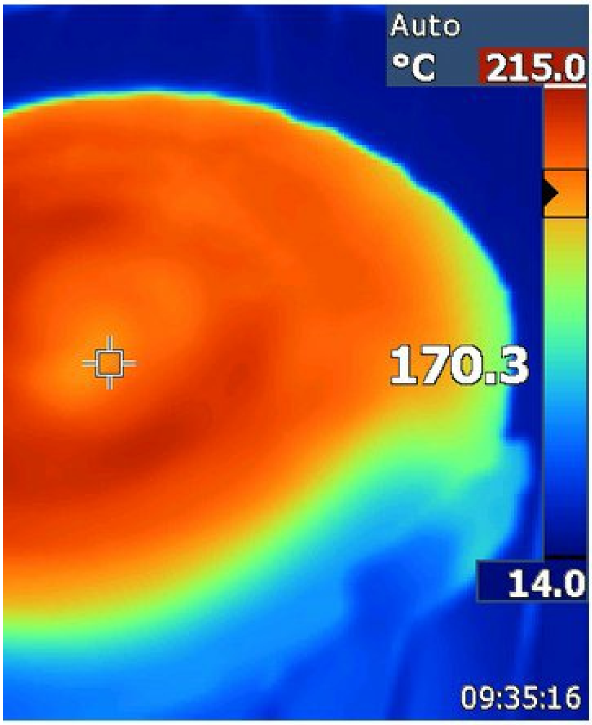
#1 Series of Infra red photos of heater plate trial. Max temp shown at top right.



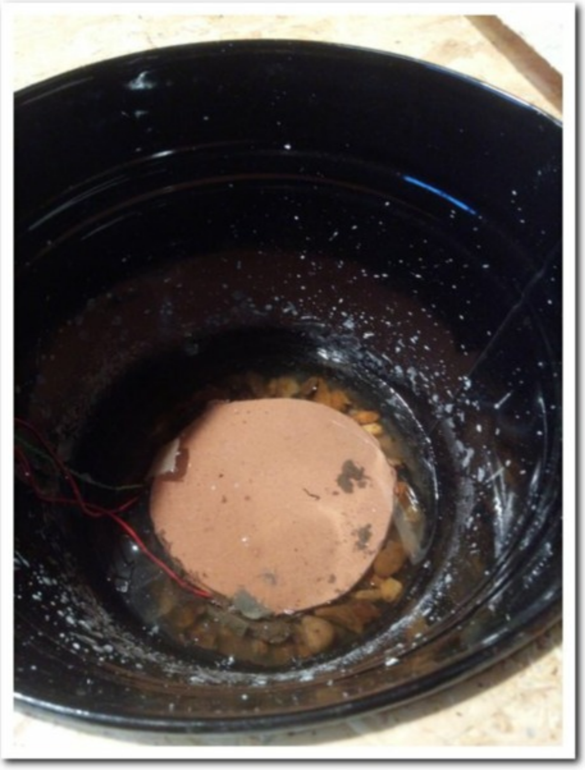
#2



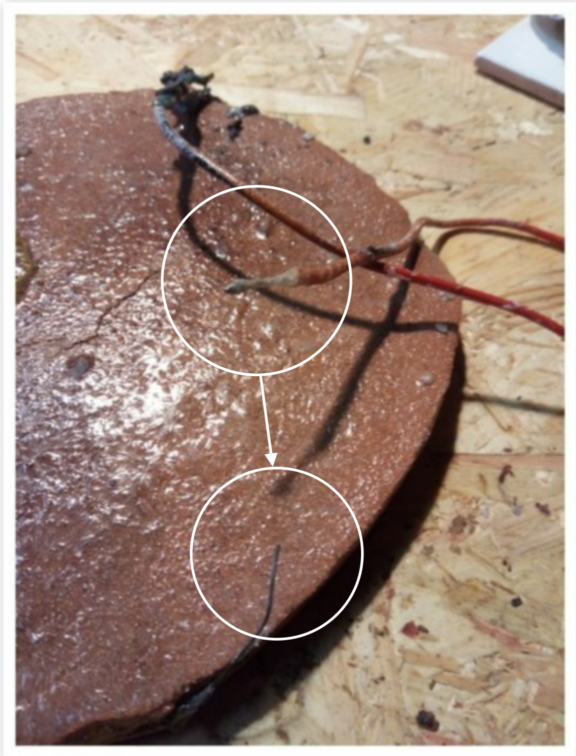
#3



#4 Max temperature shown as 215 C



Clay heater in molten PCM. Gravel used to raise the heater above the base of the bucket



Power cable to heater cable failure. This failure resulted in heater being frozen in PCM

3D printed template for heater wire in clay heater plate

Hotplate trial showing pan on top of clay tile.