A FIELD TRIAL – USING A HEAT TRAP, INSULATION AND HEAT SINKS WITH A 1.8m PARABOLIC SOLAR CONCENTRATOR TO ATTEMPT THE PIZZA OVEN CHALLENGE AT LATITUDE 32S

Andrew Wilson BAppSc

Private Project in Perth, WA, Australia
moguls3@westnet.com.au

With expert guidance from Dr Celestino Ruivo, Instituto Superior de Engenharia, Universidade do Algarve, Faro, Portugal and Dave Oxford, SLiCK Solar Stove, UK

cruivo@ualg.pt daveoxford@metronet.co.uk

Abstract: ‘Domestic’-scale (2- 3sqm area) **Parabolic** reflectors can caramelize (brown) or even burn most food. With this capacity, they are mostly used without heat traps. Larger collectors such as the 10sqm Scheffler mirror employed by the Tamera community [1] can cook community-scale quantities of foods, including those requiring higher temperatures such as flatbreads.

Cooking large (16” / 400mm) **pizzas** challenges parabolic cookers of a domestic scale as pizzas require quite high temperatures to be sustained and distributed over an area of 0.126 sqm, which requires a container with a yet larger surface area, which re-radiates more energy and shades more of the collector.

This study describes the iterative development of the initial design of an oven intended to extend the usefulness of a domestic-scale (1.8m diameter) **parabolic** cooker by the use of a heat trap, **insulation** and thermal mass. Like the Tamera oven it employed a beam focused through an **aperture** into a **cavity.** Its thermal mass comprised its internal framing, steel cladding and 10 mm steel cooking plates. It was intended to be pre-heated. It used glass as a heat trap and (in its first iteration) the sun-facing oven door. The vertical dimension of the oven was to be relatively shallow to limit shadowing of the mirror. The oven was designed with the rear wall sloping towards the mirror at 45 degrees so that the effectiveness of the mirror would optimize during spring, and the front sun-facing door sloped likewise. The challenge set was to cook three 400mm **pizzas** simultaneously in less than 40 minutes (not counting the pre-heat) with the noon sun remaining below 45 degrees. The project began with a re-purposed mirrored 1.8m-dia radio dish. The oven did not meet all the success criteria simultaneously but did sufficiently well to claim “Proof-of-Concept”.

Keywords: Parabolic, pizzas, aperture, cavity, insulation

Ref: [1] https://www.tamera.org/solar-kitchen/

1. **INTRODUCTION**

1.1 Preamble

Mirror-box and funnel-type cookers are simple cheap devices that have the capacity to cook meals for a few individuals. They require the use of transparent heat traps and dark containers. Parabolic trough cookers using vacuum tubes can reach high enough temperatures to burn food but their overall power remains limited by the size of their reflectors. Larger parabolic mirrors like the 1.8m diameter (2.54 square metre aperture) mirror used in this study can reach sufficient temperature to burn food, and can easily cook wet foods in 4 or 5 litre pots without heat traps. The mirror used in this trial had previously cooked from frozen two 'mini-pizzas' (approx 150mm) to a burned condition inside such a lidded black pot. However standard-sized pizzas require quite high (200-250 C) temperatures sustained over much larger areas. Larger containers tend to lose more heat through re-radiation and cast a correspondingly larger shadow over the mirror.

1.2 Extended use

The 1.8m mirror employed in this study would be at the limit of convenient size for many users. The "Pizza Oven Challenge" was set to determine if the use of a heat trap with a single mirror of this size would increase its power sufficiently to cook pizza.

2. METHOD

2.1 Design considerations

The oven needed horizontal dimensions sufficient to contain a 400mm pizza. The vertical dimension needed to be able to accommodate three cooking plates with pizzas on them with a small gap; however the heat trap available at that time was a 330mm washing machine window and it was actually the need to accommodate this that set the minimum dimension of the mirror-facing wall. This reinforced the decision to slope the mirror-facing end to keep vertical height low and to best collect the light reflecting off the mirror. The 45 degrees chosen for technical simplicity roughly optimised the oven for the spring & autumn. The shadowing of the mirror by the oven was considered and the sun-facing door was to be glass to admit some of the light incident on the oven and double-glazed retain its heat. Another design strategy was to use a forward-sloping mirror on the top of the oven to direct into the oven some of the light that would otherwise be lost to shadow.

2.2 Construction

The parabolic mirror available for this trial was 1.8m diameter radio dish covered in mirror tiles. It was bolted to a light carriage and suspended on a swivel at the effective focal point of the mirror. The main frame was relatively heavy, anticipating the need to support a heavy oven. The oven was constructed with a frame of small square section and clad on 5 sides by 1mm sheet steel. This was initially riveted in place. A swinging door was constructed with a light steel frame and with two layers of 6mm glass separated from the metal and each other by standard fiberglass oven insulation tape. The air gap with the door clamped up was estimated at 2+ mm. The edges of the box were seam welded to reduce the escape of heated air. The welding caused some buckling of the metal walls. The washing machine lid was padded on the edges with insulating tape and clamped in place. The sides of the box were insulated with 10mm “Insulfrax” compressed mineral fibre insulation board clad further with 0.3mm aluminium sheet. The steel of the rear wall within the heat trap was initially left intact.

Figure 1. Initial set-up

2.3 First Trial 22/09/2019

The first trial was conducted on 22/09/19, clear sky with maximum ambient temperature 21C. The door appeared to seal reasonably well but the glass and metal of the door were naked as were the support tubes that passed through the sides of the oven. Oven temperature was measured by means of a thermocouple-type probe. The maximum temperature reached was 106 C at time 3:48pm, clearly not hot enough for cooking pizza. The spot temperature at the inside of the back of the oven was measured at 325C. It was difficult to get a repeatable measurement of the surface temperature of the door glass but it was much too hot touch firmly and would evaporate spittle in seconds. The oven suspension bars were very hot near the oven and along with the glass door were judged to be major sources of heat loss. A subsidiary trial with otherwise identical conditions except for the addition of a long mirror suspended as to direct light through the front oven door added only 10C to this peak temperature. The size of the shadow of the box on the mirror was then measured at 700 x 500mm or about 15% of the area of the mirror. The use of a secondary mirror was not repeated.

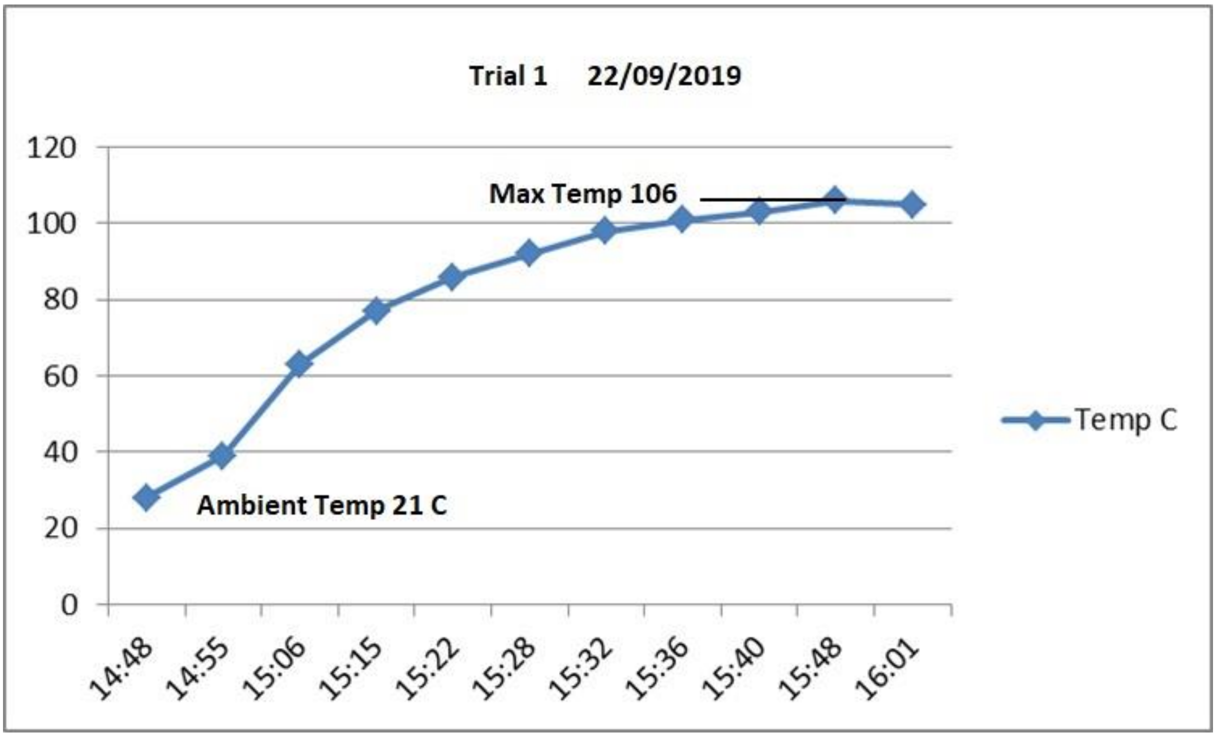

Figure 2. Time-Temperature 22/09/2019

2.4 Second Trial 27/09/2019

The suspension bars were insulated with toweling and the glass door was replaced by a single piece of insulation board. The ambient temperature was 21C. The maximum oven temperature of 128 C was reached at 3pm at which time three pizzas were inserted. The food was removed at 3:30 pm and the oven closed. The temperature fluctuated but reached 122 at 4:06 at which time measurement was abandoned. The external temperature of the glass heat trap was recorded as 167C at time 3:25 and it seems that it too was a significant source of heat loss. The pizzas were cooked through with cheese melted and meat cooked and pastry not starchy. While quite palatable at least to the hungry they were neither browned nor crisp on the surface and they were considered unlikely to be acceptable to a chef. A pertinent side note is that the open oven was left facing the sun as the sun went down but the mirror caused a smoldering fire which destroyed a towel wrapped around one suspension bar and another towel left on the roof of the oven. The oven itself appeared to be intact.

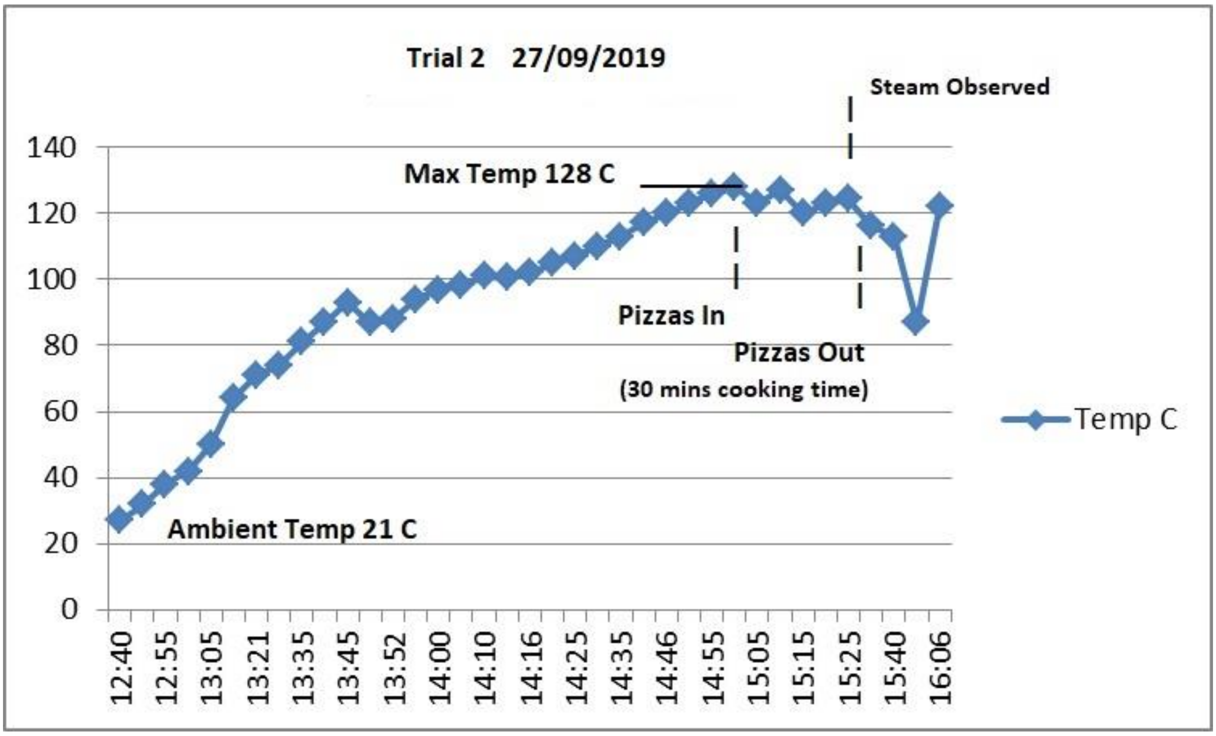

Figure 3. Time-Temperature 27/09/2019

2.5 Third Trial 28/09/2019

For this trial the steel back wall of the oven had a 150mm aperture cut out to suit the size of the smaller glass bowl that was to be used later; however the washing machine lid was still used. The light from the mirror could shine directly into the interior of the cavity instead of just heating the back wall. The ambient temperature was 21 C and the skies were clear but there was a gusty breeze. The highest temperature reached was 145.8C at time 3:45pm. Instability of the temperature became noticeable at higher temperatures. This is likely because the small aperture is sensitive to relative movement of the sun. Other possible causes are variable amounts of direct or reflected light impacting the probe, and with the oven 'door' at this time being a relatively porous piece of unprotected board the variable ambient breeze may blow some air through the insulation.

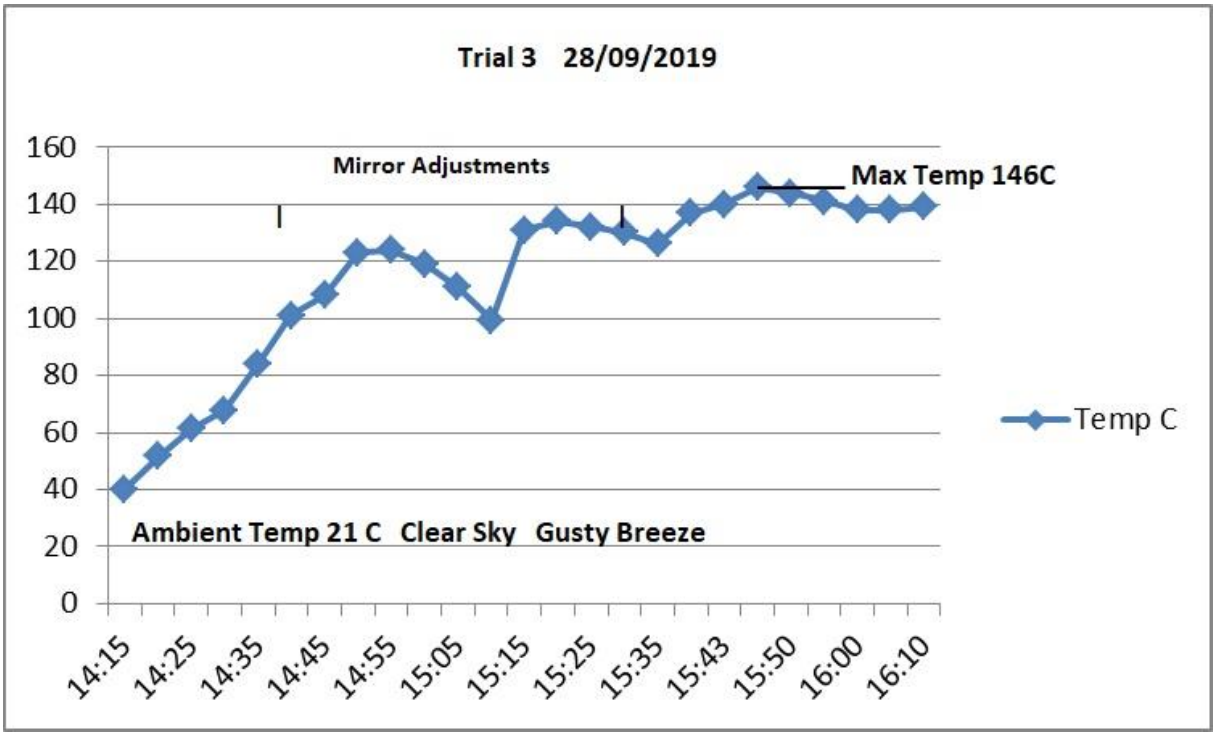

Fig 4 Time- Temp Chart 28/09/2019

2.6 Fourth Trial 19/10/2019

The ambient temperature on this day was 26 C. A smaller glass bowl (18cm diameter) was used as the heat trap. The rear-wall insulation had accordingly been replaced to fit. The shingle sheet of insulation was still being used as the oven door. Three pizzas were used but they were 12” (300mm) due to lack of availability of the larger size. It was noted that the top of the oven became very hot to touch during the trial and it was concluded that there had been some damage to the insulation on the top due to the previous fire and possibly the ingress of moisture from rain. The max temperature reached was 173 C just after midday. The temperature dropped probably due to malalignment with the sun, and the pizzas were inserted at 12:51with the oven at 153 C. The temperature fluctuated following insertion of the food but did not exceed 153 again. This temperature is low for cooking pizza however when removed at 13:28 (37 minutes of cooking time) two of the pizzas were browned on the edge nearest the oven aperture, were otherwise cooked through and the pizza was certainly quite palatable.

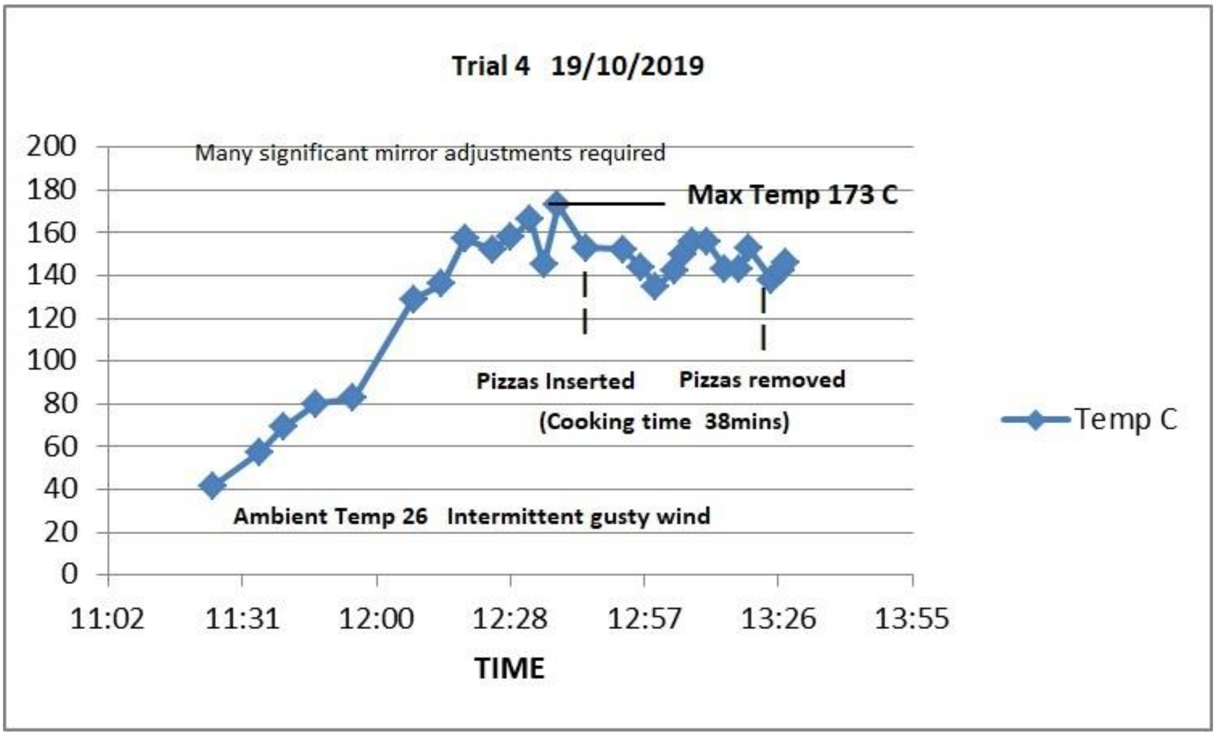

Figure 5 Time-Temperature 19/10/2019

2.7 Fifth Trial 08/11/2019

The ambient temperature was 28 C with an expected maximum of 32 C. The small glass bowl was retained. The insulation on the top had been replaced and a second layer had been added to the top. Air gaps had been filled with mineral fibre and the aluminium cladding had been sealed around with tape. The suspension bars had been re-wrapped tightly with toweling both inside the oven and out, and within the oven had been further wrapped with aluminium foil to reflect radiant heat. The insides of the suspension bars had been stuffed with mineral fibre to prevent heat loss from the inside of the bars. There had not been the opportunity to convert the design to one which was supported from below rather than using through-bars. This was an unplanned, opportunistic trial conducted at an earlier, more advantageous time but was begun without the thermal mass trays. The temperature reached 222 (photographed at 221 C) at which time it was decided to add the thermal mass and run a cooking trial. After the opening of the oven to add the thermal mass (at 11:25) the temperature fluctuated but reached 196 C again at time 11:45, 20 minutes after the trays were inserted. Between 11:47 and 11:49 the single available pizza was inserted with some ice still on it into the middle slot. The temperature recorded at 12:15 was 188 C at which time the pizza was removed, rotated 180 degrees and returned to the oven. The temperature peaked again at 191 C at 12:20 and at 12:25 and reading 187 C the food was removed. This was a cooking time of 36 minutes. The pizza was browned well on one side, browned less well on the other and was perhaps a little dry and overcooked overall. At this point it appears that the problem is becoming one of cooking style (it should probably have been turned sooner and removed earlier) as much as achieving sufficient temperature.

Figure 6. Small Heat Trap

Figure 7. 221C

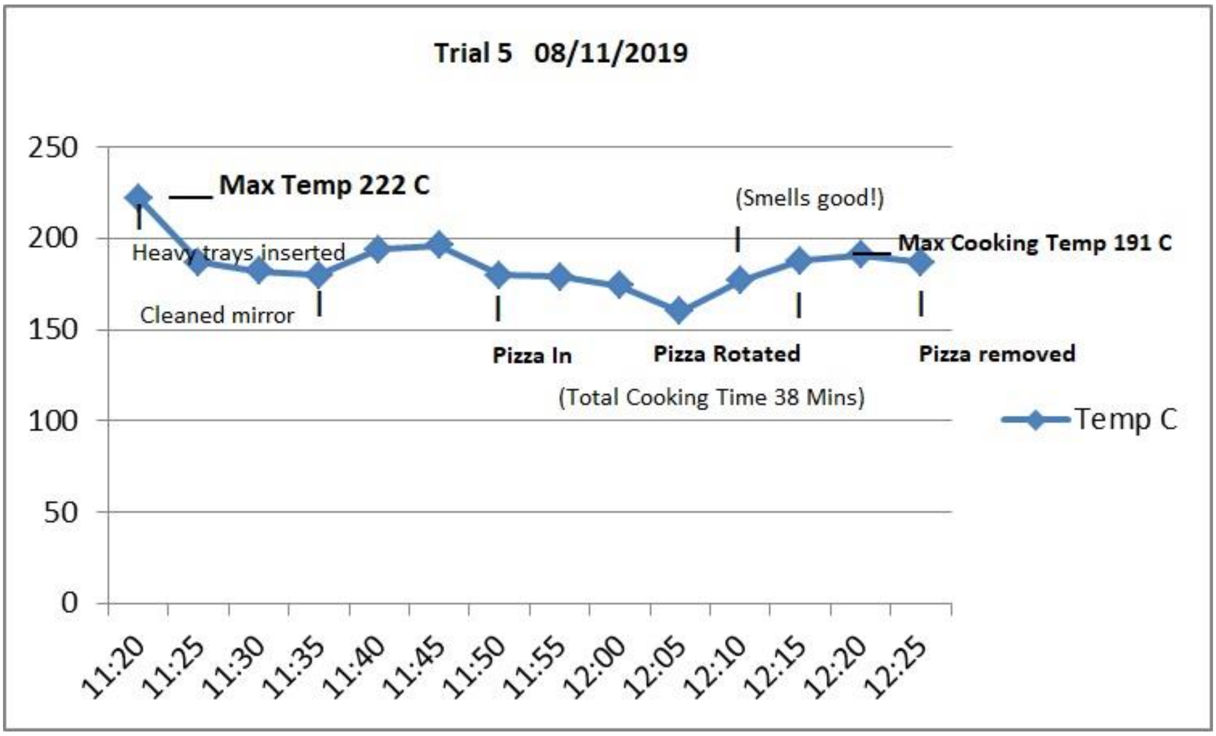

Figure 8. Time- Temperature 08/11/2019

Figure 9. Cooked Pizza

3 DISCUSSION

3.1 Design Features in Retrospect

Size was a primary design consideration. Surface area appears to be a critical determinant of performance. The frozen food market in Perth appears to have deleted the 16” pizza range, perhaps because smaller pizzas better fit microwave ovens. It is suspected that making the pizza oven just a little smaller would have made achieving a suitable cooking temperature disproportionately easier.

The sloping shape of the oven probably allowed a greater collection of energy but increased the surface area somewhat. A future oven design might change the collection point from the rear of the oven to below the oven which would then permit a more vertical, possibly more cylindrical (octagonal?) orientation with a smaller surface area. The chosen shape is also only marginally stable about a transverse axis and for safety requires stabilizing brackets.

The design feature of hanging the box from cross-bars that passed through the interior of the oven is considered a major error. It would have taken little more trouble at the construction stage to have the oven sitting on a cradle with no penetration of the box.

Seam-welding the edges of the metal box was another bad idea. It buckled the metal walls which made close-fitting the sheet insulation difficult. Air leaks would have been sufficiently contained by the insulation itself. The double-glazed window was a major disappointment. The air gap was likely too small and glass is an imperfect insulator. Observation windows might be best made small and probably covered by insulation during operation. The heat trap window needs to be as small as possible. Comparing single- with double-glazing the heat trap window might be an interesting future trial.

Gains were made with cutting the hole in the back of the oven to allow light entry rather than having the light simply heat up the back wall. Shrinking the area of glass to a minimum and fastidiously improving the insulation were significantly helpful in increasing the oven temperatures. The senior engineering advisor (C.R.) suggested that a removable light-diffusing baffle be made for the oven for some uses. This good advice was not acted upon for reasons of the constraints of time.

The concept of collecting light that would otherwise be lost to shadow was tested in a crude way, produced a further 10 C and no doubt could be refined but it added a layer of complexity and size that was judged to be impractical.

3.2 Operational considerations.

With the aperture cut and the smaller heat trap higher temperatures were achieved but thermal stability was reduced. Cutting the aperture allowed more heat into the apparatus but it had the effect of removing the visual bright spot, the main visual aiming clue. A number of techniques were tried including getting an evenly distributed bright ring around the aperture but oddly this proved rather ineffective. Shifting the mirror to obtain the brightest light on the visible rear of the middle tray worked better than the ‘bright ring’ technique; as did simply shifting the mirror in alternate directions and going with the direction that increased the temperature. An idea that was considered but not yet implemented was to place cross-hairs across the aperture. This could be done in conjunction with the radiation diffuser suggested earlier. With higher temperatures the chilling effect of wind gusts also seemed to increase and this was probably exacerbated by the porous nature of the ‘door’. Attending in detail to improving this temporary door may well yield the same benefits that attentive insulation provided elsewhere on the apparatus.

3.3 Alteration of cooking behaviour.

The solar pizza cook might alter the cooking behaviour to suit the equipment, eg choosing thicker pasties, toppings that do better with lower temperatures and even using surface coatings that caramelise at lower temperatures. Other uses for the oven might include cooking turkey which will not fit inside a saucepan and which will cook at a lower temperature than pizza. However while cooking techniques should indeed perhaps adapt to the methods available, that was not the point of the current trial.

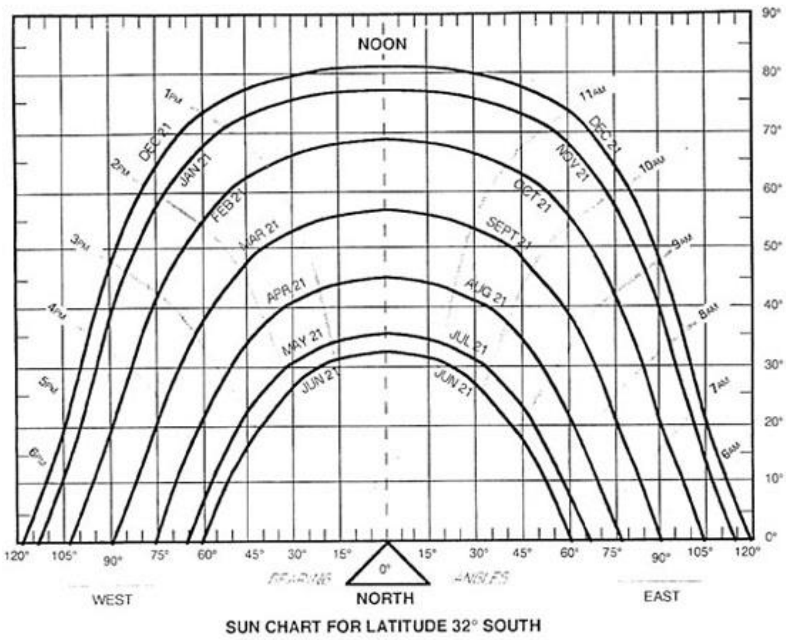

Figure 4 Sun chart for Perth [2]

5. REFERENCES

[1] https://www.tamera.org/solar-kitchen/

[2] Credit- Murdoch University Western Australia
http://www.see.murdoch.edu.au/resources/info/Tech/house/index.html

6. CONCLUSION

The specific determinants of success set for this project were to cook three 400mm pizzas simultaneously in less than 40 minutes (not counting the pre-heat) with the noon sun remaining below 45 degrees. That corresponds with a date of about 21 August which date was missed, although the first three trials were conducted through the mid-afternoon by which time the sun was below 45 degrees anyway. The later trials used pizza that was less in size or quantity than specified. While arbitrary, the objectives set remain as reasonable benchmarks in establishing the practicality of cooking family/small group quantities of pizza. They were not met simultaneously but with the achievement of empty-oven temperatures in excess of 200C and with the cooking including browning of pizza with this apparatus within the official spring, the author claims proof-of-concept. (In Australia spring is regarded as being from 1st September to 30th November) The oven in its most recent iteration has demonstrated that adequately cooking a number of large pizzas is possible around midday on clear days with a reflector of this size, but it has certainly not demonstrated that it is easy. Truly practical cooking of larger quantities of pizzas and other flatbreads remains the province of mirrors larger than the 1.8m reflector used in this trial.