SOLAR COOKING IN THE UK

Quantifying UK domestic energy saved using a solar box cooker.

London 2012 & 2013

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Appendices

1.0.0 SUMMARY

A solar cooking exercise was carried out during 2012 and 2013 within an urban context in the south east of the United Kingdom. The exercise set out to assess and quantify possible energy savings from the domestic use of a commercially available solar box cooker during suitable weather conditions.

It was shown that the process of solar cooking during the course of this exercise provided cooked food which would have used 40 units (2012) and 33 units (2013) of electricity if cooked conventionally.

The exercise has indicated a total energy saving of 73 units of electrical power over the two year study period using a solar box cooker in a domestic, residential environment and this would save a total of £5.82 per year.

A guiding principle for this unprecedented exercise is to stimulate further interest in a neglected area of potential domestic energy saving and hydrocarbon use reduction.

2.0.0 INTRODUCTION - PURPOSE OF STUDY

The purpose of this research is to establish if energy savings are available using solar cooking equipment in a UK domestic context. In the absence of research or data in this area an empirical approach has been selected. The study will present a practical data logging methodology to ensure that where energy savings might exist that these savings can be reasonably quantified.

The premise of the study is to solar cook a standard measure of food during a single day and to benchmark the results against the power required to do this using electricity.

The benchmark is the amount of food that could be cooked using one unit of electricity (i.e.1kWh). Chickpeas were chosen for the benchmarking test, as they are cheap, store well, soften when cooked, and can form the nucleus of a family meal. On assessment it was found that one unit of electrical energy will cook 100g dry weight of chickpeas

Where a solar cooking session succeeded in cooking the same weight of chick peas, it would be recorded as a 'one unit' day. This label was chosen because it implies that the solar energy captured and deployed for cooking was equivalent to 'one unit' of electricity.

The food item selected for this exercise was the preparation of approximately 250g of rehydrated, cooked chickpeas from 100g dry weight using 450ml salted water.

2.2.0 SOLAR COOKING EQUIPMENT AVAILABLE 2012-2013

Broadly there are two types of solar cooking device:
2.2.1 Solar box cooker
2.2.2 Parabolic or panel reflector cookers.
(Other hybrid and experimental systems exist and might one day form the subject of future local research)

Domestic knowledge and perceptions of solar cooking devices vary across the developed world from very little to non-existent. Some ‘early adopter’ domestic knowledge exists in the USA from where the two main commercially available units originate. Market penetration in the USA includes sales to enthusiasts and the emergency preparedness market. Transport costs of these bulky items take a large percentage of purchase cost, making export from continental USA expensive.

2.2.1 SOLAR BOX COOKER

The two units available to the USA market during the study period were the Sports Solar unit and the more recently developed (with apparently broader uptake) Global Sun Oven (GSO) unit which has recently been rebranded as the ‘All American Sun Oven’ in acknowledgment of its main customer base.

Solar box cookers available commercially exist around the globe (e.g. Australia and India). In addition to commercial units a broad body of information exists on DIY construction techniques for units of varied longevity and efficiency standards.

A Global Sun Oven (GSO) unit was used in this exercise (See appendix B). This consists of a solar box cooker with integrated two dimensional vertical angle adjustment (to adjust for sun angle).

Figure 1 Global Sun Oven - Solar Box Oven

The GSO consists of a black finished aluminium interior with ‘self-leveling’ plate, rock-wool insulation and vacuum formed plastic exterior. A laminate wood fascia houses a silicon seal onto which a heat tempered glass cover is attached via chromed hinges.

A folding set of hard anodized aluminium sheets is fixed to the GSO unit by a single linear hinge and forms a reflector area of approx 0.7m2. This erects and folds away quickly and logically. These panels are set at around 60deg from the plane of the glass so the area of reflected light matches the glass top when ideally positioned. At other times when the unit isn't perfectly tracking the sun, some repeated internal reflection capture is possible.

2.2.2 PARABOLIC & PANEL REFLECTOR COOKER

Parabolic solar cookers rely upon concentrated solar energy being focused on a cooking vessel. Extremely high temperatures can be generated in short time periods and a parabolic solar cooker will be regularly ‘refocused’ to maintain the solar input.

Panel cookers use flat reflective panels to capture solar input relying more on multiple internal reflection within a funneled area to focus light onto a suitable cooking vessel. These can be of low cost and use simple materials.

The above solar cooking formats might form the basis of further UK study but were not selected for this exercise.

2.2.3 COOKING VESSELS

There is no standard pot/cooking vessel designed specifically for solar cooking use. Important design criteria are: that the vessel must be of dark finish, that it must have a close fitting lid (to contain heat) and be of thin metal material (to facilitate heat transfer to the cooked product).

An assumption was made that a transparent lining material or cover to the dark cooking vessel would give a better retention of heat and subsequent temperature gain than if left uncovered. This might be critical in the high UK latitudes. A study by Dr. Roger Bernhard using a parabolic cooker in the cloudy tropics indicates that adding a transparent lining to a cooking vessel can harvest more solar energy than not lining it (seehttp://solarcooking.wikia.com/wiki/HotPot).

Our study used a 1.0L black aluminium pot and lid. During 2012 this pot was contained within oven roasting bags of polymer material (Appendix C). These one use bags were found to be flimsy in repeated use becoming opaque and friable.

During 2013 the pot/lid set was housed within a microwaveable pot, which had a double skin lining and resisted heat (Appendix C). Over the study period this lining became opaque during use, with some pitting damage and fissure cracking.

2.3.0 UK CONTEXT

Weather reporting is a universal pastime in the UK, embedded in the national psyche. Consideration of the practical uses of sunshine might be met with a response along the lines of 'there isn't any to use'.

The British Isles are subject to a temperate maritime climate, with varying precipitation and insolation ranges. Atlantic storms can be seasonally dominant. Sometimes in summer extended high pressure systems can settle for long periods.

Indirect use of solar energy using solar thermal and photovoltaic generation methods during recent years have indicated payback periods confirming their viability in this climate. These fixed systems are regularly deployed in 'off grid' situations where enhanced benefits are available.

There is no UK tradition of direct sun use for cooking, food preparation, pasteurization or sterilizing. Sunshine is sometimes used for proving bread dough.

2.3.1 DOMESTIC ENVIRONMENT

The purpose of this two year project is to acquire usage data for a solar box cooker in a domestic, developed world family setting in south east, urban UK.

It has been a naturalistic rather than a strictly controlled laboratory study that has been designed to test real time, domestic conditions of use. These are conditions under which a more widespread practice of solar cooking might reasonably occur.

The study has been driven by a practical approach with limited resources and is presented as a starting point in the absence of historical studies within this area.

3.0.0 METHODOLOGY

3.1.0 POSITIONING OF SOLAR BOX COOKER

It is critical to position a solar box cooker with a good aspect to global and direct sunlight, especially during the middle section of the day. The two positions used in this study benefitted from this and had an elevated southern aspect over an urban townscape. Both positions were partially restricted at earlier or later parts of the day. The effect this had was to reduce insolation periods. The general area was hard surfaced, built environment with low albedo. Ambient temperature would be high due to the greater thermal storage locally (e.g. brick walls, hard surfaces) in comparison to soft landscaped features such as lawn grass.

The location was approximately 30m above sea level at GMT/0degW longitude and 51'30N latitude.

3.2.0 SOLAR BOX COOKER USAGE FACTORS

The exercise would be influenced by factors effecting the use of this cooking format such as holidays; family activities; weekends away; ease of use (these factors are expanded upon in 4.3.0).

The cooker selected was of a type that is quickly and easily deployed so as to leave sufficient time for other domestic and vocational duties. The unit requires minimal attention throughout the day and does not need to be re-focused regularly.

The standard set up for assessing a 'one unit day' (see 3.3 below) would be as follows: A measure of chickpeas and water is placed into a black metal vessel and a lid placed on. This would then be placed within the transparent cover (oven bag or plastic steamer). Then this is carefully placed at the centre of the light absorbent plate within the GSO. The glass lid would be closed and latched tight. The angle of the oven glass would be set at right angles to the incoming sun or as close as possible and the oven axis set slightly ahead of the suns position. During a standard day the oven might be repositioned to track the sun on average twice.

Where left unattended at early morning set up the GSO would be pointed directly south.

The glass would occasionally be wiped clean if steam or desiccated salts had produced stain marks over time. From time to time the GSO interior would be cleaned of residues if spills, steaming or boiling over had occurred.

3.3.0 CHOICE OF CONTROL PRODUCT

The premise of this study is to solar cook a standard measure of food during a single day, and to benchmark the result against the power required to do this using electricity.

The basic unit for a 1kW day ('one unit day') equivalence is the production of 250g of rehydrated, cooked chickpeas from 100g dry weight. The amount of slightly salted water added was 450ml.This was the minimum weight of cooked, rehydrated chickpeas successfully prepared on any one unit day.

Many of the one unit days listed provided larger weights with more complex and varied cooked food types since it has been possible to cook the chickpea control with other pots of food within the solar cooker. This would still be recorded as a one unit day. In reality this might provide 'multiple unit days' due to the strength of the insolation available.

The reasons for the use of chickpeas in this research are as follows:

A. Chickpeas are very cheap at approximately £1.5/kg dry weight. Spoilage (on promising but ultimately cloudy days) is therefore a negligible cost. This food source is easy and quick to prepare and set up within the solar box cooker first thing in the morning whilst completing normal domestic tasks

B. A 250g tin of cooked chickpeas in brine (400g total) would cost £0.40-60p. Unsoaked solar cooked chickpeas might cost £0.15p for this amount.

C. The household like chickpeas, they can be converted into hummus which is a popular spread, and they can be stored once cooked (in the event of a period of sunny weather providing a cooked chickpea 'surge'). Many other recipe possibilities exist for this versatile pulse.

D. Conventional cooking of dry chickpeas is not straightforward. They must be soaked overnight. One must boil them in a lot of water. For over 10 minutes they must be boiled and then they must be simmered for well over an hour. The last part can result in burnt pans/wasted food & time. The kitchen can smell, and there are clear hazards associated with unattended simmering in a domestic setting (see below).

E. There are different types and sizes of chickpea. Similar to many food items it's not a homogenous product.The cheaper dried pulse was selected for the exercise, which is usually produced in Canada and sold in local shops at around £3.00/ 2Kg.

3.4.0 1 KW EQUIVALENCE– 'THE ONE UNIT DAY'

The 1kW electrical unit was evaluated as an appropriate benchmark in this study using the following process:

3.4.1 CONVENTIONAL COOKING BENCHMARK

100g weight of chickpeas was cooked using an electrical hob connected to standard electrical point power meter giving the following results for electricity used. Two test exercises where carried out:

3.4.2 BENCHMARK TEST 1. 15/12/12 AMBIENT TEMP – 19C.

This test attempts to correspond as much as possible with the conditions of the solar cooked product (e.g. same size pan/un-soaked chickpeas/ minimum quantity of water)

100g dried (un-soaked) chickpeas were cooked in a light metal pan, with 450ml of water. A Czech made twin hob electric unit with three power settings (model 'Criterion') was used (the smaller of the 2 hobs). A plug in energy monitor ('Model 200MU') was connected at the power outlet, displaying kWh consumed in use and watts/amperes in real time. A wall clock was used and readings of use taken every 10minutes until the chickpeas were cooked enough to use/eat.

22:10. Start: 785W/3.11amps/0kwh
22:20. Boiling: 747W/3.10amp/0.15kwh
22:30. Turned down to min. setting: 190W/0.83amp/0.26kwh
22:40. 178W/0.75amp/0.29kwh
22:50. Water level too low , added 300ml, returned to max setting:760W/3.15amp/0.36kwh
23:00. Turned down to middle setting: 279W/1.15amp/0.45Kwh (*)
23:10. 269W/1.12amp/0.50kwh
23:20. 270W/1.15amp/0.55kwh
23:30. 265/W1.10amp/0.58kwh
23:40. 270W/1.16amp/0.64Kwh

23:50. Water level too low, stopping hydration. Added further 300ml water and turned up hob to max. setting : 765/3.05/0.68kwh
24:00. 780W/3.10/0.79kwh
00:10. 765W/3.12/0.92kwh
00:20. Finished. 748W/3.06amps/1.05kwh

250g drained weight chickpeas were cooked, mostly soft throughout, and used the following day in a roast, just warmed up with gravy.

(*) At this point my partner was vacuuming in the kitchen under the electric hob set up. I mentioned to watch out for scalding water, they said ‘I’ll be out your way in a minute’. This partially illustrates a common hazard in hob cooking for extended periods, not present in solar cooking.

3.4.3 BENCHMARK TEST 2. 18-12-2012 AMBIENT TEMP 20C

The chickpea cooking recipe from 'Mrs Beetons Cookery and Household Management Book' 1980 (First Published 1860), was used to test a more domestic example of cooking chickpeas.

One is advised to soak the chickpeas for 6-12 hours in cold water, preferably changing the water once during this time to prevent the chickpeas from fermenting.

To cook: Drain and cover with fresh cold water. Season; add a chopped onion and parsley stalks. Bring the water to the boil and cook for about 2-2 ½hours or until the peas are tender.

A larger pan with lid was used, due to the soaked size of the chickpeas. Using the above equipment for test 1.1litre of water with 100g chickpeas was used (no onions or parsley). The large hob ring was used due to the greater volume of water.

20:00 Start 338W/1.42a/0kwh
20:10 339W/1.41a/0.05kwh
20:20 1126W/4.76a/0.11kwh
Turned up to max setting or will be here all night.
20:30 327W/1.37a/0.29kwh
Back down to middle setting as good rolling boil
20:40 334W/1.42a/0.34kwh
20:50 331W/1.39a/0.40kwh
Low boil
21:00 332W/1.41a/0.46kwh
21:10 335W/1.41a/0.51kwh
21:20 333/W/1.31a/0.56kwh
21:30 1148W/4.81/0.63kwh
Turned up because not boiling
21:40 1142W/4.73a/0.89kwh
21:50 11313/4.73a/0.89qkwh
Added 300ml water to keep chickpeas covered
22:00 330/1.39/1.10kwh
22:10 343/1.44/1.15kwh
22:20 Finish 337/1.41/1.20kwh

Nicely cooked and soft, 275g drained weight. Used in oven baked chorizo/tomato dish the next day.

3.4.4 BENCHMARK TEST RESULTS & CONCLUSIONS

1. Both tests cooked 250g rehydrated weight of chickpeas using over 1Kwh of grid connected electrical power.
2. Both tests took in excess of 2 hours to cook 100gs of Chickpeas satisfactorily.
3. Both tests required low level supervision input over the cooking period to ensure the pan didn't boil dry and spoil the chickpeas.
4. Test 1 highlighted a hazard associated with cooking over a long period in a domestic setting.
5. Higher than normal levels of humidity occurred within the kitchen area during cooking.
6. Higher than normal temperatures occurred within the kitchen during cooking.

It was concluded from two test exercises that a minimum of 1Kw of electrical power is necessary for the preparation of 250g cooked chickpeas using an electric hob in a domestic setting.

4.1.0 RESULTS

4.1.0 1KW EQUIVALENCE DAYS – ONE UNIT DAYS

The Global Sun Oven solar cooker was used on the following days in 2012 & 2013 resulting in 1Kw of electrical power (1 Unit Day) equivalence using the methodology outlined in item 3.0 –3.4

2012		**2013**	
27 March	1 Unit Day	06 April	1 Unit Day
28 March	1 Unit Day	07 April	1 Unit Day
29 March	1 Unit Day	05 May	1 Unit Day
30 March	1 Unit Day	06 May	1 Unit Day
13 April	1 Unit Day	06 June	1 Unit Day
21 April	1 Unit Day	08 June	1 Unit Day
12 May	1 Unit Day	25 June	1 Unit Day
22 May	1 Unit Day	28 June	1 Unit Day
23 May	1 Unit Day	29 June	1 Unit Day
24 May	1 Unit Day	30 June	1 Unit Day
25 May	1 Unit Day	5 July	1 Unit Day
26 May	1 Unit Day	6 July	1 Unit Day
27 May	1 Unit Day	7 July	1 Unit Day
28 May	1 Unit Day	8 July	1 Unit Day
29 May	1 Unit Day	9 July	1 Unit Day
30 May	1 Unit Day	10 July	1 Unit Day
13 June	1 Unit Day	11 July	1 Unit Day
21 June	1 Unit Day	12 July	1 Unit Day
25 June	1 Unit Day	13 July	1 Unit Day
21 July	1 Unit Day	14 July	1 Unit Day
22 July	1 Unit Day	15 July	1 Unit Day
23 July	1 Unit Day	16 July	1 Unit Day
24 July	1 Unit Day	17 July	1 Unit Day
25 July	1 Unit Day	18 July	1 Unit Day
26 July	1 Unit Day	19 July	1 Unit Day
03 September	1 Unit Day	21 July	1 Unit Day
04 September	1 Unit Day	22 July	1 Unit Day
05 September	1 Unit Day	27 July	1 Unit Day

06 September	1 Unit Day	01 August	1 Unit Day
07 September	1 Unit Day	30 August	1 Unit Day
08 September	1 Unit Day	31 August	1 Unit Day
09 September	1 Unit Day	06 October	1 Unit Day
15 September	1 Unit Day	07 October	1 Unit Day
19 September	1 Unit Day		
22 September	1 Unit Day		
06 October	1 Unit Day		
07 October	1 Unit Day		
10 October	1 Unit Day		
13 October	1 Unit Day		
11 November	1 Unit Day		
TOTAL 2012	**40 x 1 UNIT DAYS**	**TOTAL 2013**	**33 x 1 UNIT DAYS**
Polymer oven bag and anodized aluminum pot (App B)		**Plastic steamer and anodized aluminum pot (App B)**	

During 2012 in the UK a total of 40 Days were recorded as effectively providing and equaling the use of 1kWh of electrical cooking power.

During 2013 in the UK a total of 33 days were recorded as effectively providing and equaling the use of 1kWh of electrical cooking power.

The exercise provided the equivalent of 73 regular tin size portions of cooked chickpeas in brine on the one unit days indicated.

4.2.0 WEATHER AND PV COMPARISON FOR 2012/13

4.2.1 WEATHER DATA

Met office data for 2012 & 2013 can be found at
http://www.metoffice.gov.uk/climate/uk/2012/
http://www.metoffice.gov.uk/climate/uk/2013/
The area in question would be South East/South Central, London area E8 .

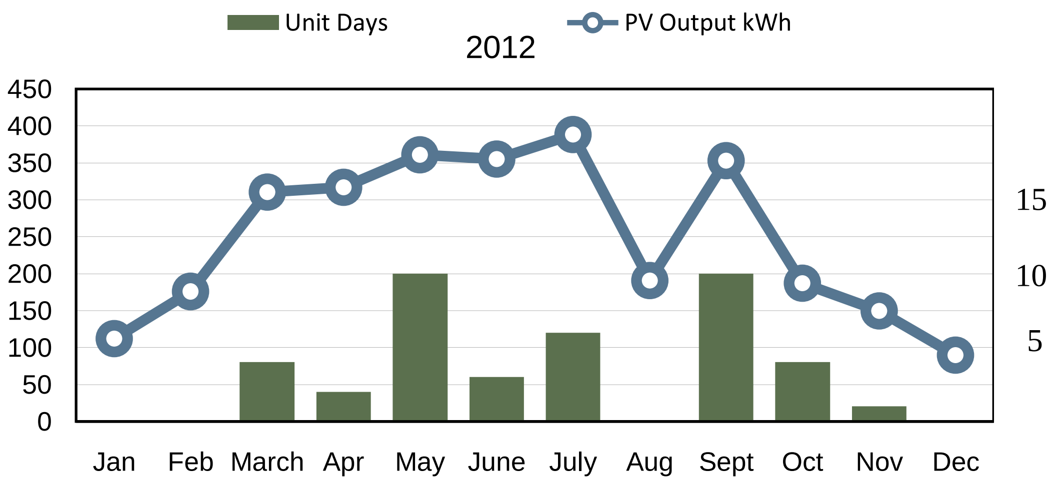
This data was taken between 1971 and 2000 at the nearest national weather station in Greenwich; around 7 miles (11.3 km) south of the study location:

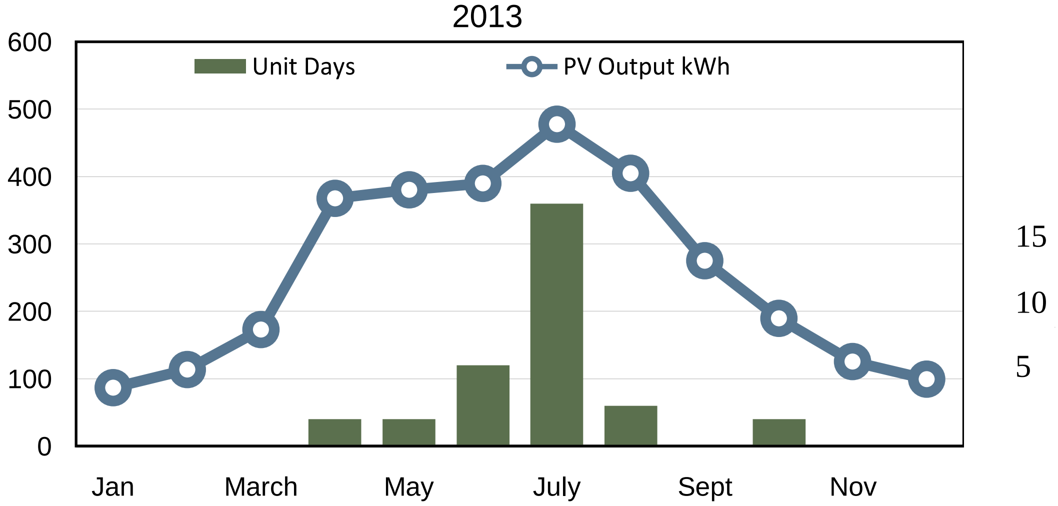
Climate data for London (Greenwich)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	14.0 (57.2)	19.7 (67.5)	21.0 (69.8)	26.9 (80.4)	31.0 (87.8)	35.0 (95)	35.5 (95.9)	37.5 (99.5)	30.0 (86)	28.8 (83.8)	19.9 (67.8)	15.0 (59)	37.5 (99.5)
Average high °C (°F)	8.3 (46.9)	8.5 (47.3)	11.4 (52.5)	14.2 (57.6)	17.7 (63.9)	20.7 (69.3)	23.2 (73.8)	22.9 (73.2)	20.1 (68.2)	15.6 (60.1)	11.4 (52.5)	8.6 (47.5)	15.2 (59.4)
Average low °C (°F)	2.6 (36.7)	2.4 (36.3)	4.1 (39.4)	5.4 (41.7)	8.4 (47.1)	11.5 (52.7)	13.9 (57)	13.7 (56.7)	11.2 (52.2)	8.3 (46.9)	5.1 (41.2)	2.8 (37)	7.5 (45.5)
Record low °C (°F)	−10.0 (14)	−9.0 (15.8)	−8.0 (17.6)	−2.0 (28.4)	−1.0 (30.2)	5.0 (41)	7.0 (44.6)	6.0 (42.8)	3.0 (37.4)	−4.0 (24.8)	−5.0 (23)	−7.0 (19.4)	−10.0 (14)
Precipitation mm (inches)	51.6 (2.031)	38.2 (1.504)	40.5 (1.594)	45.0 (1.772)	46.5 (1.831)	47.3 (1.862)	41.1 (1.618)	51.6 (2.031)	50.4 (1.984)	68.8 (2.709)	58.0 (2.283)	53.0 (2.087)	591.8 (23.299)
Avg. rainy days (≥ 1.0 mm)	10.8	8.5	9.6	9.4	9.0	8.3	8.0	7.6	8.5	10.7	10.1	9.9	110.4
Avg. snowy days	4	4	3	1	0	0	0	0	0	0	1	3	16
% humidity	91	89	91	90	92	92	93	95	96	95	93	91	92.3
Mean monthly sunshine hours	49.9	71.4	107.1	159.8	181.2	181.0	192.1	195.1	138.9	108.1	58.5	37.4	1,480.5

4.2.2 PV OUTPUT COMPARISON

Monthly PV output data from a domestic SSW facing 3kWp FITS installation in Rainham, Kent, UK (ME8 postcode, 10 miles from study site) has been used in a graphic comparison with the monthly unit days recorded in our study. Notably the monthly PV data shares a corresponding graphic shape with the monthly unit day breakdown recorded in this study. It must be noted that a PV installation is a permanent fixture whereas the solar cooking unit was used spasmodically during the study
http://solar-panels-review.321web.co.uk/monthly-pv-solar-panel-generation.php





PV output to Unit days 2013 and 2014 at East London locations

4.3.0 DOMESTIC USAGE FACTORS & OBSERVATIONS

The setting for this solar cooking study is a standard domestic family home within a UK (developed world) context.

The family consists of two adults and two mid-age school children with adults both working 4 days per week each with some work from home. This could be a typical UK family unit within an urban environment. The following factors should be noted:

1. Holidays. Family holidays around August school holidays meant this peak solar cooking period was under used if used at all.

2. Moving House (18/06/12) in same street to a house with a reduced south aspect (adjacent house restricted insolation from 3pm). Previously the morning insolation was restricted before 9-10.am. A reversal of early/late cooking patterns was noted. This interrupted use around this period, but did not greatly affect the level of insolation received at the either cooking location.

Experience of solar box oven set up and use over a number of seasons meant that the primary operative was experienced in performance and integration into their daily pattern. At times other family members would use the unit, or at least point it at the sun if required. The children knew the safety issues due to the heat and strong foci - the unit presents an inaccessible appearance due to the reflectors creating a side buffer zone.

Wind is a major issue in an elevated, exposed sunny spot and the unit would be clipped back to a fixed point, preventing tumbling. Any concerns about wind load and damage to the reflectors have not yet been realised.

The unit was always used when the primary operative was at home on a sunny day. If they weren't home during a cloudy day which cleared, then that would be a potential one unit day that would remain unrecorded.

Using the GSO has meant that the primary operative would regularly check short range weather forecasts and prepare for sun in advance. Sometimes unpredictable weather this would result in a spoilage of chickpeas due to cloud/ low grade heat, but due to experience this was rare.

4.4.0 EQUIPMENT CONDITION

The GSO solar box cooker was first used in 2008 and has had extensive, domestic summer use since. Its condition at the beginning of the first test year was good, however the wooden fascia was showing signs of warping and the wood fixing points had been repaired. The plastic base had also partially detached from the timber fascia, allowing some hot air escape from the enclosed insulation layer. The gaps also allow rain to enter the absorbent fibre insulation.

At the close of the year the lower hinge fixing had torn away from the timber fascia and had to be user repaired to ensure glass retention. The timber fixing area appeared to be subject to degradation due to water damage, possibly due to high humidity of cooking, and expansion/ contraction of metal fixings set into a porous material.

One could expect lifetime use from the GSO unit, but it is clear that it will require some regular maintenance and attention to achieve this.

Maintenance interventions to the solar box cooker used to date have been of insignificant cost/time input.

Figure 1 pan and microwaveable steamer laid out

The metal cooking pots used have not changed or been altered by heat or use. The polymer roasting bags used in 2012 suffered swift degeneration under repeated use. On average they might be used 3-4 times before tearing or even blowing away.

The microwaveable steamer could be used again for one more season, but is appearing a bit worn, the plastic has degenerated and this use is likely to be at the edge of its capabilities. The opaque sheen to the plastic may be preventing full heating potential for the cooking pot within.

Figure 2 microwaveable pot with pan inside

5.0.0 CONCLUSION

5.1.0 SUMMARY OF RESULTS

A preliminary exercise demonstrates that the preparation of a standard 250g weight and retail can size unit of Chickpeas would require 1kWh of electrical power which we have called 'one unit'.

Our premise is to use a market obtained solar box cooker to prepare a standard unit of chickpeas during a single day period and where successful this has been recorded as a 'one unit day' having successfully offset one unit of electricity (1kWh).

The solar cooking part of this food preparation exercise was accomplished using only Global Horizontal Irradiance (GHI) as energy input, within an irregular domestic usage pattern. Years 2012 and 2013 yielded 40 and 33 one unit days respectively with a biennial total of 73 one unit days.

The results of this exercise in solar box cooker use in a UK domestic environment indicate a potential saving during a two year period of 73kWh of grid delivered electrical power.

That offset could provide a reduction in grid connected power costs to the end user in similar circumstances of £5.82 per year at £0.16p/kWh (NEP figures for average electrical costs (http://www.nottenergy.com/energy_cost_comparison/).

Averaged to each year the exercise has created 36.5 portions of solar cooked food for £5.47p per year which if bought in equivalent single portions would cost on average £18.25 per year (assuming £0.50p for a 400g tin of cooked chickpeas in brine).

5.2.0 PAYBACK PERIOD/CO2/WATER USE

The savings recorded might deliver a modest payback against a solar cooker purchase. This would be factored against any 'on costs' that may be incurred (e.g. maintenance of equipment/damages/winter storage).

The (GSO) Solar Oven type used will require additional maintenance for medium term use in a UK climate. This was not assessed but appeared to be of negligible cost.

The electrical power displaced by solar cooker use might result in a reduction in primary energy use, CO2 emissions and pollutants at the point of centralized electricity production.

The offset might result in a reduction in water use at point of centralized electrical generation (according to the U.S. Geological Survey, thermoelectric power generation accounts for 3.3% of net freshwater consumption).

A wider use of solar cooking during the peak 9:00-17:00 time period might result in utility base load shaving, where modest reductions in demand during peak period translates into less requirement for generation at source.

The electricity (or gas) load displaced by solar cooker use is that associated with the cooking of an evening meal. Using solar energy for cooking in the middle of the day can displace late afternoon / early evening cooking fuel used to cook the evening meal quickly. This time period historically aligns with the domestic peak demand for cooking fuel.

5.2.1 BILLSAVERS COMPARISON

During 1992-93 The Lothian & Edinburgh Environment Partnership (LEEP) carried out a study of energy use in domestic appliances ('Billsavers– Counting the Cost'). It was found that the mean annual consumption of an electrical cooker is 639Kwh.

Using this dated study as a base annual standard our study indicates that 6.2% (2012) and 5.1% (2013) of annual electrical cooking energy might be displaced by using a solar box cooker in a domestic environment.

5.3.0 DISCUSSION

FURTHER STUDY

The author is not aware of the existence or otherwise of solar cooking data logging exercises carried out within a UK context and in addition has been unable to locate any exercise which attempts to log use of a solar cooking device within an irregular domestic setting.

The data recorded here represents minimum savings available during the period of study. Many holiday periods (e.g. all of August 2012) and mid week sunny days went unrecorded so the savings estimated are conservative.
It is almost certain there were more one unit days than recorded here.

It is not unreasonable to suggest that the energy savings identified using a solar box cooker as outlined in this study might invite further consideration and research.

This could take the form of standardised data logging exercises, across a range of UK locations using a larger and more statistically valid group.
In addition a more controlled study might seek to optimise performance across a range of samples within an annual cooking period.

Payback periods against unit purchase would need to be assessed using current economic data to give a fuller indication of potential savings in a UK setting. A market test of solar cooking devices in the UK might be a function of this study since the interest generated would serve to pump prime and habituate usage along with kick starting the economics of solar cooking in the UK.

Maintenance requirements for units over time would need to be assessed and modeled in parallel with data logging exercises to validate any payback assumptions

OFF GRID AND EMERGENCY PREPARDNESS POTENTIAL

This exercise indicates a modest cost benefit to using a solar box cooker in a grid connected environment. The use of a solar box cooker for off grid use e.g. summer caravan, waterways boat or camping trips might reveal cost savings far in excess of grid connected savings. Costs for propane or charcoal cooking can be far in excess of grid connected costs.

Our data logging exercise has not set out to measure these potential uses and logic would suggest that recording and quantifying off grid energy and cost savings might be a next step. The human scale of a domestic solar cooker might even encourage participants to integrate their use in normal off grid activities such as camping or sunny day alfresco picnics.

A solar box cooker could be of use for emergency preparedness in the event of a power cut or other rapid system breakdown scenario. Solar cooking methods could be used for water or equipment sterilisation during an emergency, easily achieving the temperatures required in the right weather conditions.

Therefore an exercise might be carried out to assess possibilities for UK disaster relief and this might attract the attention of large utilities and other bodies tasked with providing assistance during times of trouble.

INTEGRATED COOKING

Solar cooking is a key component of 'integrated cooking'. This system for cooking integrates the use of manufactured rocket cook-stoves, alongside solar cooking units and retained heat cooking systems. Integrated cooking allows seamless, low impact, low fuel use cooking around the clock given the right conditions.

http://solarcooking.wikia.com/wiki/Integrated_Cooking

This methodology is proposed for developing world situations suffering economics of scarcity. There is of course no reason why integrated cooking would not at times be favorable in the UK and this might be the focus of further study in support of this.

SOCIO-ECONOMIC FACTORS

Hand in hand with any further study would be a consideration of the socio-economic factors that might govern uptake or broadening of domestic use in the UK . Developing world exercises indicate a lack of uptake amongst target groups despite fuel poverty and for many reasons not always clear. Often the reasons given conflate with a general resistance to change common amongst low income subsistence farmers. Developed world populations do not have these attitudes and are more accustomed to change.

Figure 2 Nicaraguan group Solar Women of Totagalpa prepare baked goods for sale

This is a broad area for study and given its history of innovation the UK might actually lead the way under the right circumstances in uptake, energy conservation and the more latent gourmet potential of cooking using the sun.

GOURMET POTENTIAL

Slow cooking using lower temperatures imparts its own unique taste and textural qualities to food. For example cuts of tough meat cooked in a solar box cooker will soften well whilst retaining essential moisture. Sous Vide steam cooking or slow cooking techniques benefit from dedicated users with master chef experts in relatively new cooking areas.

Solar cooking has potential to generate its own UK master chefs, experts in a whole new field.

This exercise has not considered the ‘foodie’ appeal of solar cooking and further study of this in the UK might appeal to the ‘less scientifically rigorous’ researcher.

SOLAR BOX COOKER – MADE IN THE UK

Perhaps a design of Solar Cooking Unit, optimised for the UK climate might be targeted for study. This is unknown territory and where this method of cooking passes the disbelief stage in the UK a specific cooker designed to pull the most from our climate using locally focused engineering expertise might go from strength to strength. A powerful, robust and reliable UK unit might one day provide options alongside other less renewable outdoor cooking types such as gas or disposable BBQs on hot summer days.

SOLAR COOKING IN THE UK

Solar cooking will never compete head to head with the ease and convenience of primary hydrocarbon (gas/oil) or secondary (electricity) cooking systems. This study does not set out to consider fossil fuel use in financial or environmental terms or to discuss limits to growth in their use.

The data and savings recorded here serve to highlight a practical use of our most abundant renewable energy source and to encourage further discussion and study in a UK setting.

Solar cooking on a camping holiday in Provence, France 2011

5.4.0 CASE STUDIES 1 & 2

5.4.1 CASE STUDY 1

22nd September 2013. This was an ‘indian summer’ day with the air temperature reaching over 23degC. Food was ‘doubled up’ in the GSO using the control chickpeas on top of a baking pan with a chocolate cake inside (with a borosilicate glass lid between the two)

You can see the cake in completed form (cream and jam added afterwards). The chickpeas were perfectly cooked. It would not have been a day for switching on the oven to bake a cake as it was too hot. This was definitely a one unit day and appears to have exceeded that.

5.4.2 CASE STUDY 2

8th December 2013 Sunny morning with temperature approx 4degC at 9:00am. 100g chickpeas were placed in the GSO to see if it was possible to cook them through. At 12:30pm the indicative temperature gauge had reached 46degC at about 10 degC air temp (possibly due to a little cloud cover developing). Sun is now low and moving fast, GSO at maximum tilt. Chickpeas not really cooked at all, warmed, but heat loss is rapid when no sun. There doesn’t seem to be any heat available in the sunshine.
This marked the end of that solar cooking year with the author not wishing to waste chickpeas further. This was not recorded as a‘one unit day’.

6.0.0 ACKNOWLEDGEMENTS

I would like to acknowledge the following people and institutions for their contribution in assisting, providing reference or kind words in support of what might appear to be a pointless exercise carried out under bleak, northern smog.

Dave Oxford is a UK based scientist and solar cooking enthusiast based in sunny Cornwall, UK. Dave is one of the few serious solar cooking empiricists’ I’ve met here and is a fellow alumni of the University of East London’s AEES MSc course. Dave has helped me to focus the study and to expurgate any serious clangers, his support has been invaluable.

Id’ like to thank Natalia Blackburn, a Mechanical Engineer based in California, US. Natalia’s study ’Quantifying Energy Savings of Thermal Solar Cookers In US Households’ was carried out in 2012 and has just been released. I‘ve had the privilege of corresponding with Nathalie during this time and her knowledgeable comments have helped me to condense and bring logic to the structure of the study.

I would also like to thank Mike Thompson, course leader for MSc Sustainability: Faculty of Science & Technology, Anglia Ruskin University, Cambridge. Mike showered some logic onto the study in 2013 by suggesting the ‘1 unit day’ instead of the less palatable ‘1kWh day’.

The Solar Cooking Yahoo Group has been invaluable over the past decade in generating a community of interest in the subject. With contributors from all over the world it is the main forum for discussion of the solar cooking topic. I’d like to thank the contributors and moderators for their ongoing work on the subject.

I’d like to thank the originators of the http://solar-panels-review.321web.co.uk/ website based down at Rainham, East London (approx. 10 miles south east of the study location) for allowing me to use their real time PV data to compare against solar cooking unit days.

A further web based resource is the Solar Cookers International Network
http://solarcooking.wikia.com/wiki/Solar_Cookers_International_Network_(Home)
This is the largest solar cooking resource available and has provided reference and great reading.

Finally I would like to thank my family for their guinea pig role in this study and for putting up with odd, shiny devices set up in prominent locations. They have also been great at dealing with ‘chick pea surges’ when these have arrived and I have never had to chuck out hummus, falafels or (my favourite) chana masala. My kids are perhaps the only children in the UK to see solar cooking as a regular way to cook food.

APPENDIX A

PRINCIPALS OF SOLAR BOX COOKING

The basic purpose of a solar box cooker is to cook food, purify water or sterilize cooking equipment using energy from sunlight which heats the interior of the box.

THE GLOBAL SUN OVEN (see Appendix B)

Sunlight incident upon a surface is categorized as follows:
Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground and includes DNI and DHI (see below).

DNI (Direct Normal Irradiance) is the solar radiation that goes in a straight line from the direction of the sun at its current position.

DHI (Diffuse and Horizontal Irradiance) is the solar radiation that does not arrive on a direct path from the sun and has been scattered by molecules and particles in the atmosphere and comes equally from all directions.

On a clear day most of the solar radiation received by a horizontal surface will be DNI, on a cloudy day DHI.

Sunlight, both DHI and DHI enters the solar box through a transparent top. It turns to longer wave heat energy when it is absorbed by a dark absorber plate and cooking pots within. This energy cannot escape by re radiation through the transparent top and causes the temperature inside the solar box cooker to rise until heat loss is equal to the solar heat gain. Temperatures sufficient for cooking food (typically 110-150degC air temp) and pasteurizing water (around 65degC) are easily achieved in the right UK weather conditions.

If two boxes have the same heat retention capabilities, the one that has more gain, from stronger sunlight or additional sunlight via a reflector, will be hotter inside.

If two boxes have equal heat gain, the one that has more heat retention capabilities from better insulated walls will achieve a higher interior temperature.

We will explore the following principles: heat gain; heat loss and heat storage

HEAT GAIN *How do foods heat up in a solar box cooker*

The heating of an enclosed space into which the sun shines through a transparent material such as glass on a greenhouse results in heat gain. Short wave visible light and some infrared light easily pass through glass and is absorbed and reflected by materials within the enclosed space. Darker materials absorb more light, which is stored or re-emitted as longer wave heat energy. Because it is of a longer wavelength this radiant energy cannot easily pass back out through the glass and is therefore trapped within the enclosed space.

In a solar box cooker light energy is absorbed by dark pots and absorber plates underneath the pots. This partially converts into longer wavelength heat energy and radiates from the interior materials. The reflected light is either absorbed by other materials within the space or does not change wavelength and passes back out through the glass.

Critical to solar cooker performance, the heat that is collected by the dark metal absorber plate and pots is conducted through those materials to heat and cook food contained therein.

Glass orientation
The more directly the glass faces the sun, the greater the solar heat gain. During a normal solar cooking day user adjustment will be required to ensure the glass or focus ‘tracks the sun’to achieve optimum solar heat gain.

Reflectors, additional gain
Single or multiple reflectors bounce additional sunlight through the glass, into the solar box. This additional input of solar energy results in higher cooker temperatures.

HEAT LOSS *How is heat lost in a solar box cooker?*

The Second Law of Thermodynamics states that heat always travels from high to low energy. Heat within a solar box cooker is lost in three ways: conduction, radiation and convection.

Conduction
The handle of a metal pan on a stove becomes hot through the transfer of heat from the stove through the materials of the pan to the materials of the handle. In the same way heat within a solar box cooker is lost when it travels through the molecules of glass, metal, air and insulation to the air outside of the box.

The solar heated absorber plate conducts heat to the bottom of the pots. To prevent loss of this heat (via conduction through the bottom of the cooker) the absorber plate is best raised from the bottom using insulating spacers, or suspended.

Radiation
Things that are warm or hot - pots and food - within a solar box cooker give off heat energy by radiation to their surroundings. This heat energy is radiated from warm objects through air or space. Most of the radiant heat given off by the warm pots within a solar box is reflected from the inner lining of the box and the glass window back to the pots and absorber plate. Although the transparent glazing will trap much of the radiant heat some escapes directly through the glazing.

Convection
Molecules of air move in and out of the solar box cooker through cracks and this is called convection. Heated air molecules within a solar box escape, primarily through the cracks around the top lid or side "oven door" openings. Construction imperfections will also allow hot air to escape. Cooler air from outside the box will enter through these openings to replace convected air..

HEAT STORAGE *How is heat stored in a solar box cooker?*

As the density and weight of the materials within the insulated shell of a solar box cooker increase, the capacity of the box to hold heat also increases. The interior of a box including heavy materials such as rocks, bricks, heavy pans, water, or heavy foods will take longer to heat up because of this additional heat storage capacity. The incoming energy is stored as heat in these dense materials. This will slow the heating of air in the box.

Dense materials charged with heat will radiate that heat within the box, keeping it warm for longer periods when sunlight is no longer incident on the box cooker.

APPENDIX B
THE GLOBAL SUN OVEN

Directions for using your
GLOBAL SUN OVEN®

Using your ***SUN OVEN***® is easier than you may think. The best way to learn is to start cooking. After a few meals you will feel like an expert. Don't be afraid to experiment. Nothing will burn and you will find your ***SUN OVEN***® much more forgiving than a conventional gas or electric oven.

Placement

Put your ***SUN OVEN***® in a sunny place which is unobstructed by shadows from trees, buildings, etc. Remember that areas not currently shadowed may be affected later by trees or buildings as the sun moves across the sky.

Setup

Unsnap the webbing strap that holds the reflectors in place. Lift and unfold the reflectors (which are hinged to the top of the ***SUN OVEN***®) and slide the slot on the bottom section of the reflectors over the thumb screw in the wooden frame, making sure the thumb screw fits through the slot. Twist the thumb screw one-quarter turn to hold the reflectors in place. **(Note: To protect the reflectors during assembly and shipping a protective film has been applied and must be removed before initial use.)**

Focusing

Aim the front of your ***SUN OVEN***® towards the sun. Stand behind the oven and place it so that the shadows are even on both sides. Tilt the oven enough to eliminate the shadows in the front and back portions of the oven chamber. To adjust height of the rear leg, lift the back of the ***SUN OVEN***®, depress the button, and slide it into the appropriate hole. Check again that the oven is properly aimed towards the sun (there should be minimal shadowing on the sides of the inner chamber) and adjust the leg length as necessary.

As the cooking time progresses, it will be necessary to occasionally adjust the aim of the oven. We recommend a minor adjustment hourly to eliminate shadows in the oven chamber. If you cannot adjust the oven for a long period of time, we suggest that you immediately aim the ***SUN OVEN***® towards where the sun will be during its strongest time (between 10 AM and 2 PM). This will eliminate shadows during the most effective cooking period.

The ***SUN OVEN***® works best on clear, sunny days. Intermittent clouds will slow down (but not stop) the cooking. Probably the most important key to efficient ***SUN OVEN***® cooking is eliminating shadows in the oven chamber.

Preheat

You are now ready to let the ***SUN OVEN***® pre-heat (usually it will reach 300 degrees F in about twenty minutes). The first time you use the oven it is best to leave it in the sun for 60 to 90 minutes, with the glass door closed and latched down, before placing the food in the chamber. After the oven has been pre-heated, let the oven cool and clean the inside of the chamber and the glass door with a non-abrasive cleaning solution. Now you're ready to get cooking.

Cooking Tips

The ***SUN OVEN***® method of cooking is so natural and subtle that much less moisture is required for recipes – cooked in covered pans, that is. The natural, internal juices come into unique play, resulting in a superior, moist taste. Be sure to cut down, by at least one-third, any liquid measurements called for in stews or sauces. This does not apply to bakery products.

Since foods do not burn in the ***SUN OVEN***®, it is not necessary to stir foods after they are placed in the oven. Use a meat thermometer to determine when to remove meats (put the meat thermometer in the meat before placing it in the oven). Opening the oven door unnecessarily will slow the cooking process.

Cooking Pans

With your ***SUN OVEN***®, you can cook in any kind of pan that can fit into its interior. However, maximum results are obtained by using LIGHTWEIGHT, black or dark-colored pans. With anything requiring a lid, you can use either clear or colored Pyrex. Avoid shiny materials such as foil, the reflection reduces the cooking efficiency of the oven.

Maintenance

Maintenance on your ***SUN OVEN***® is very minimal. Using any non-abrasive glass cleaning solution, such as Windex, will keep the reflector material and glass clean. If the reflectors and glass are not kept clean, the oven will not reach its target temperature.

Recipes

You may look at our web site for recipes.

PLEASE NOTE: Glass latches (on the right side of the glass door) are tightened before shipping – you may need to unscrew them ¼ to ½ turn.

SUN OVENS INTERNATIONAL, INC.

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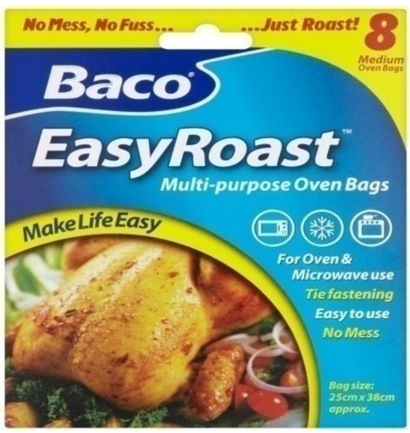
APPENDIX C
EQUIPMENT USED

M&S MICROWAVEABLE POT

1 L EUROHIKE POT



GENERIC OVEN BAGS

APPENDIX D
MONTHLY SOLAR PV OUTPUT IN ENGLAND UK 2012/2013

http://solar-panels-review.321web.co.uk/monthly-pv-solar-panel-generation.php


Monthly Solar PV Panel Output in England UK

This is the data for solar PV electricity produced each month showing how early the panels started generating and how late they finished as well as the maximum peak output during the day. This will be added to each month as the data builds up. You can also view **Month by Month comparison of solar panel electricity produced** for 2011 onwards so it will show how January 2012 compares to Jan 2013 and Jan 2014 for example.

UK Monthly PV Output data

The monthly data shows by month the solar PV electricity output generated and peak output. You can see the difference as the days lengthen and the number of hours generation increases.

Month	Earliest Start Time	Latest End Time	Max Peak Output kW	Total Monthly Output	Total Generation Time (hours)	Min Daily Generation kWh	Max Daily Generation kWh
02/2014	07:15	17:20	2.772	190.048	248	0.808	13.073
01/2014	08:05	16:20	2.400	119.721	222	0.517	8.426
12/2013	08:10	15:50	2.412	100.546	204	0.145	9.015
11/2013	07:20	16:20	2.640	126.815	231	0.256	11.073
10/2013	07:10	18:25	2.760	190.764	293	1.006	12.438
09/2013	06:45	19:25	2.928	275.68	346	2.059	18.073
08/2013	05:55	20:25	2.988	405.324	415	2.831	18.679
07/2013	05:15	21:00	2.880	478.611	460	6.195	20.335
06/2013	05:10	20:55	2.964	390.924	454	5.455	21.632
05/2013	05:25	20:45	2.988	381.87	439	1.39	20.897
04/2013	06:05	20:10	2.988	368.609	383	2.477	21.382
03/2013	06:10	19:15	3.000	173.49	314	0.589	15.502
02/2013	07:25	17:25	2.832	114.644	236	0.228	12.587
01/2013	08:05	16:40	2.460	87.89	197	0.023	9.35
12/2012	08:05	15:45	1.992	90.864	201	0.237	8.324
11/2012	07:15	16:20	2.580	150.373	233	0.469	10.988
10/2012	06:55	18:35	2.832	187.09	292	0.469	14.466
09/2012	06:40	19:40	2.928	353.696	352	1.6	18.149
08/2012	06:40	19:35	2.736	191.792	20	2.911	18.08
07/2012	05:25	21:05	2.952	388.361	458	4.644	20.568
06/2012	05:10	21:00	2.988	355.405	444	1.793	20.412
05/2012	05:25	20:45	2.976	361.963	437	1.637	20.614
04/2012	06:05	20:05	3.012	317.365	380	1.855	19.079
03/2012	06:20	19:20	2.940	310.457	340	1.642	18.74
02/2012	07:10	17:25	2.736	176.98	254	0.542	13.306
01/2012	08:05	16:30	2.388	111.913	224	0.193	9.51
12/2011	08:00	15:55	2.136	103.37	212	0.359	8.542
11/2011	07:15	15:50	2.112	51.508	88	0.979	8.176

Links of interest

Solar Power - immersion heater
Solar Panels - Monthly Outputs
Solar Panel - Bluetooth Monitoring
System Specification
Solar Panel Installation Photos

Solar Panel Output by Day