Viridian Solar – Clearline Solar Thermal Test Report - Average Household Simulation

Prepared for:
Viridian Solar

30 January 2009

Client report number 251175

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Project Title:	Viridian Solar - Clearline Solar Thermal Field Trail
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Acknowledgements

Project Team;

David Forward - BRE

Arron Perry - BRE

Michael Swainson - BRE

Nick Davies – BRE Associate

Stuart Elmes – Viridian Solar

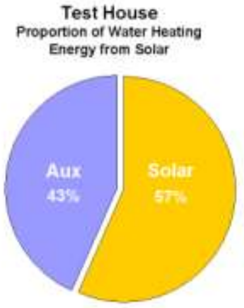
This report was compiled with the help of the entire project team. Therefore all members of the project team should be named as co-authors.

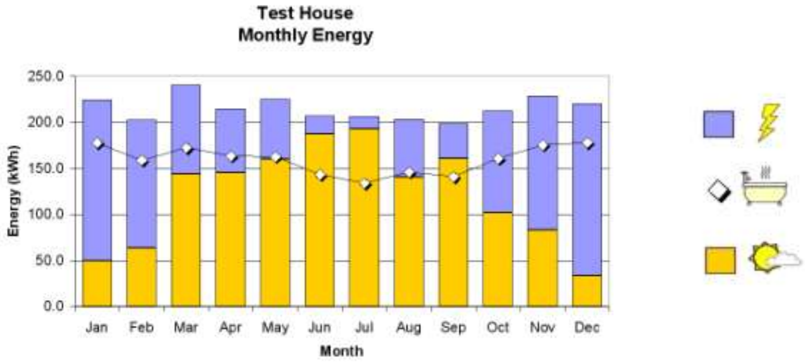
Executive Summary

Building Research Establishment (BRE) was commissioned by Viridian Solar to oversee the experiment and produce an independent report on the energy benefits in use of its Clearline solar water heating system. The objective of the test was to provide credible information on the Clearline solar hot water system.

An automated test facility was produced that used the solar heating system with a pattern of hot water use for the average sized dwelling.

	Location	Orientation	Hot Water Used (litres/day)	Hot Water Used (kWh)	Fuel Energy Saved (kWh)	Solar Fraction
	Cambridge	South	100	1,913	1,850	57%





The system was subjected to a more sophisticated form of testing than previous studies, which simply heated a cylinder of cold water each day having emptied it fully the night before, the Viridian Solar test rig included the effects of the auxiliary heating system (boiler or immersion heater), and took into consideration the pattern of hot water use – that is the timing of hot water removal and an adjustment for temperature of the volume of hot water used.

The results presented are for what could be termed a “disinterested household”, where no attempt is made to optimise the solar energy benefit (for example by switching off the boiler and using a greater volume of lower temperature solar heated water). As such, it could be considered to be more representative of the likely solar energy savings when solar water heating moves into mainstream use.

The 12 month period covered April 2006 – April 2007. The results showed that the solar panels have made a useful contribution to the hot water needs of this average home, providing 57% of the heat energy input to the hot water cylinder, and saving 1,850 kWh per year in fuel compared to a high efficiency gas condensing boiler.

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1 Introduction

Following consultation with the construction industry, Viridian Solar launched what it claims to be an innovative and cost-effective solar water heating system. The system has been designed to dovetail into the conventional building process, with the panel fitted by roofing contractors when covering the roof, and all plumbing connections to be made from inside the building by the solar contractors at the normal time in the build process.

Viridian anticipates that this approach will yield significant cost savings in the installation process, provide developers with a more attractive breakdown of responsibility, and result in an aesthetically superior product.

Typical Properties with Clearline Solar Panels

The goal of the study was to provide better information to developers and consumers about the benefits from solar water heating.

There have been previous studies in solar water heating in the UK, but these have differed from the Viridian testing scheme. These studies include;

"*Side by Side Testing of Eight Solar Water Heating Systems*", DTI/Pub URN 01/1292, 2001.
This was a test-bed analysis of solar water heating output which linked a solar panel to a hot water cylinder and measured the heat energy collected by emptying the cylinder every evening. It bears little resemblance to how solar systems are installed and used in practice; in particular, the effect of an auxiliary heat source (boiler) was ignored.

"*Analysis of Performance Data from Four Active Solar Water Heating Installations*", DTI/Pub URN 01/781, 2001.
This study examined four households put forward for a study by Solar Trade Association members. It did not measure the boiler or immersion heater input to the cylinder and presents the solar fraction as a proportion of hot water energy, ignoring the effect of standing losses in the cylinder. This would greatly over-state the benefit of solar. In addition, this study included households that had spent upwards of £3,000 on a solar heating system and might be considered "enthusiasts" willing to change their behaviour to gain maximum benefit rather than being representative of mainstream users.

Faced with uncertainty about the true benefits provided by solar heating systems, and under pressure to justify a high cost, many solar companies resort to best case scenarios.

“Save up to 70% of your hot water energy”

The aim of this study was to seek to provide information on the realistically achievable benefits of solar water heating using the Viridian Solar Clearline system.

This report can be read in conjunction with a similar study by the BRE and Viridian Solar, “225314 Viridian Solar – Clearline Solar Thermal Field Trial”, 27 May 2008 which covered six households where Clearline solar panels were installed and monitored for a period of 12 months.

It is suggested that the results from the automated test facility is more representative of the likely average benefits across the housing stock and more informative for national policy making, whereas the study of the real households is more informative for its conclusions on the effect of human interaction with the technology.

2 Experimental Design

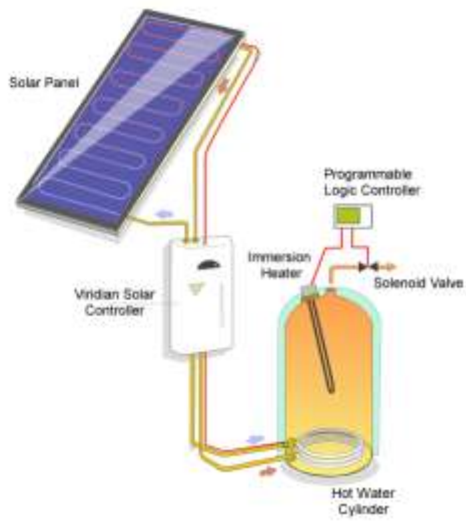
2.1 Description

Viridian Solar built a test facility that put the solar water heating system into a realistic but well-controlled test environment. Previous tests of solar heating systems did not achieve such high levels of realism, for example not taking into account the way that water is removed from the tank throughout the day, and ignoring the effect of an auxiliary heating system.

The facility comprises a Viridian Solar Clearline V30 solar panel, integrated into a south facing roof of conventional construction and inclined at thirty five degrees to horizontal. The location of the test facility was Cambridgeshire, UK.

The Test Facility

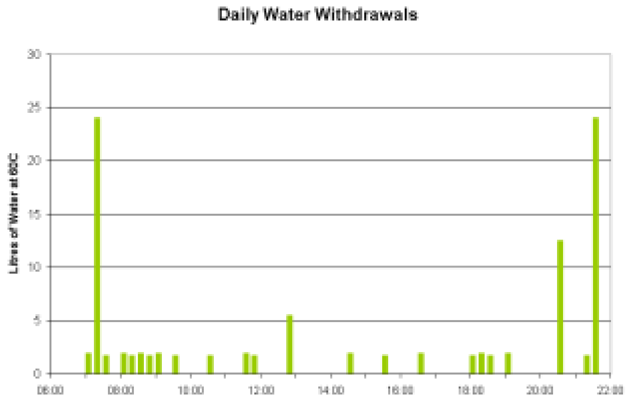
The area beneath the roof was enclosed, insulated, and maintained at room temperature. Inside the structure was a hot water tank, which was indirectly heated by the solar panel. An electric immersion heater on a timer control lifted the temperature of the top half of the tank to 60°C on days when there was insufficient light energy for the solar panel to do so. On days when the solar panel had raised the temperature sufficiently, a thermostat at the top of the cylinder prevented the immersion heater from activating. Appendix 1 gives a detailed description of the materials and methods used in the experimental design.



Schematic of Test Equipment

Under software control, the test house could be configured to withdraw water from the hot water cylinder in a pre-programmed pattern. The water withdrawals were measured in energy terms rather than volume - to simulate real conditions – if the water was cooler, then more was used. Some withdrawals (for example those simulating a shower) do not start counting energy until a certain temperature was achieved.

The system simulated the hot water use of the average European household according to EU M324EN. The equivalent of 100 litres at 60°C was withdrawn throughout the day in the pattern shown in the figure. The water withdrawal pattern is described in more detail in Appendix 1.



Water withdrawal pattern

2.2 Measurement and Data Logging

The metrology equipment was specified, calibrated and the installations inspected by BRE.

Heat meters were fitted at the hot water cylinder to measure the flow of heat in and out. Two were fitted – to measure solar energy input and the energy content of the hot water withdrawn from the cylinder.

In addition, electricity meters were fitted to the immersion heater to measure the auxiliary energy required to heat the cylinder, and to the solar control set to measure the electrical energy consumed by the solar circulation pump and control electronics.

Temperature gauges were placed at the solar flow and return, the cylinder top and bottom, inside the test facility to measure ambient temperature, and in a North facing Stevenson screen to measure outdoor temperature. A pyranometer was located mid-way up the solar panel and inclined at the same angle.

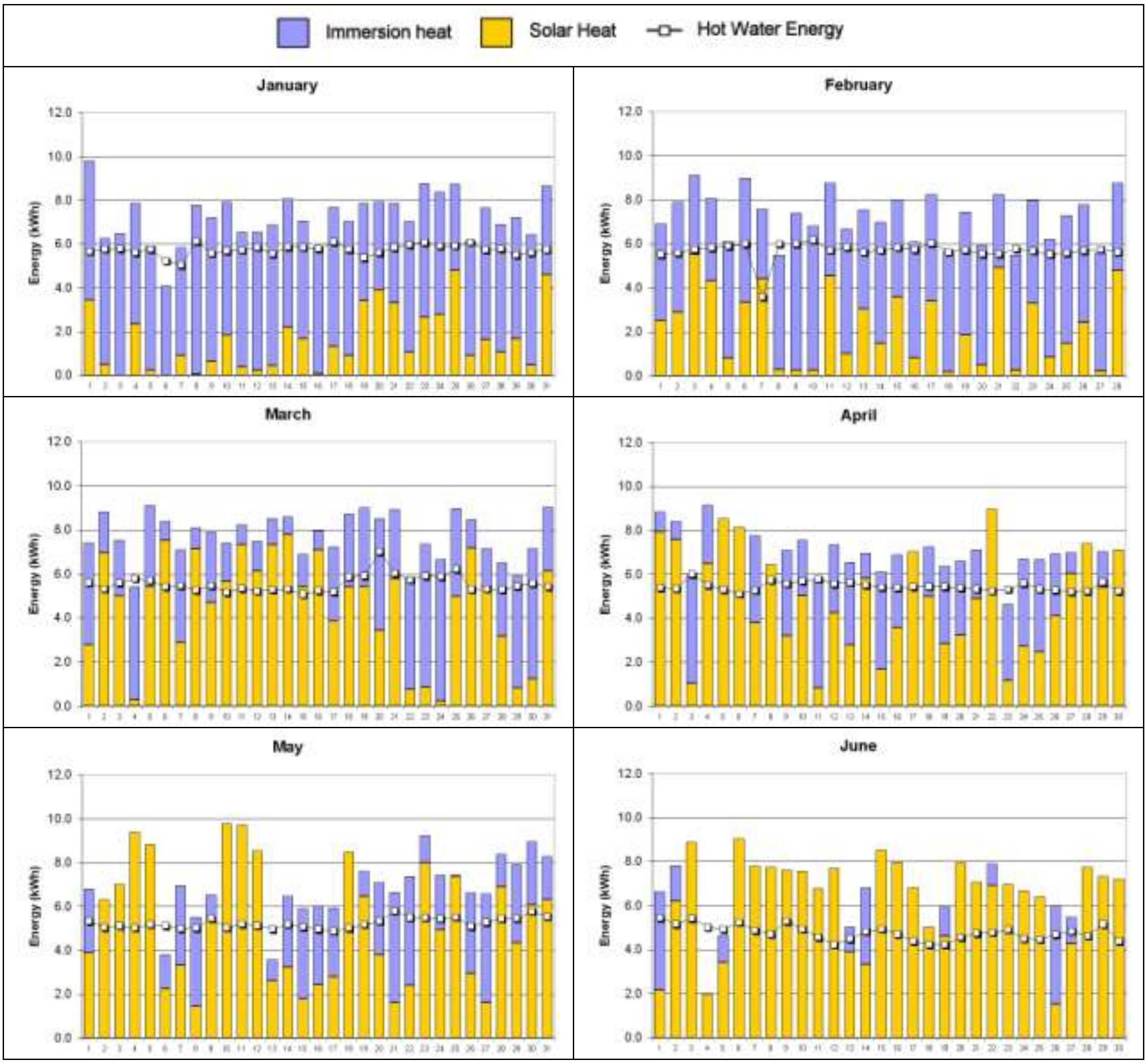
The temperatures, solar irradiation and heat energy pulses were logged every three minutes for a year. Data was remotely downloaded by BRE via GSM modem.

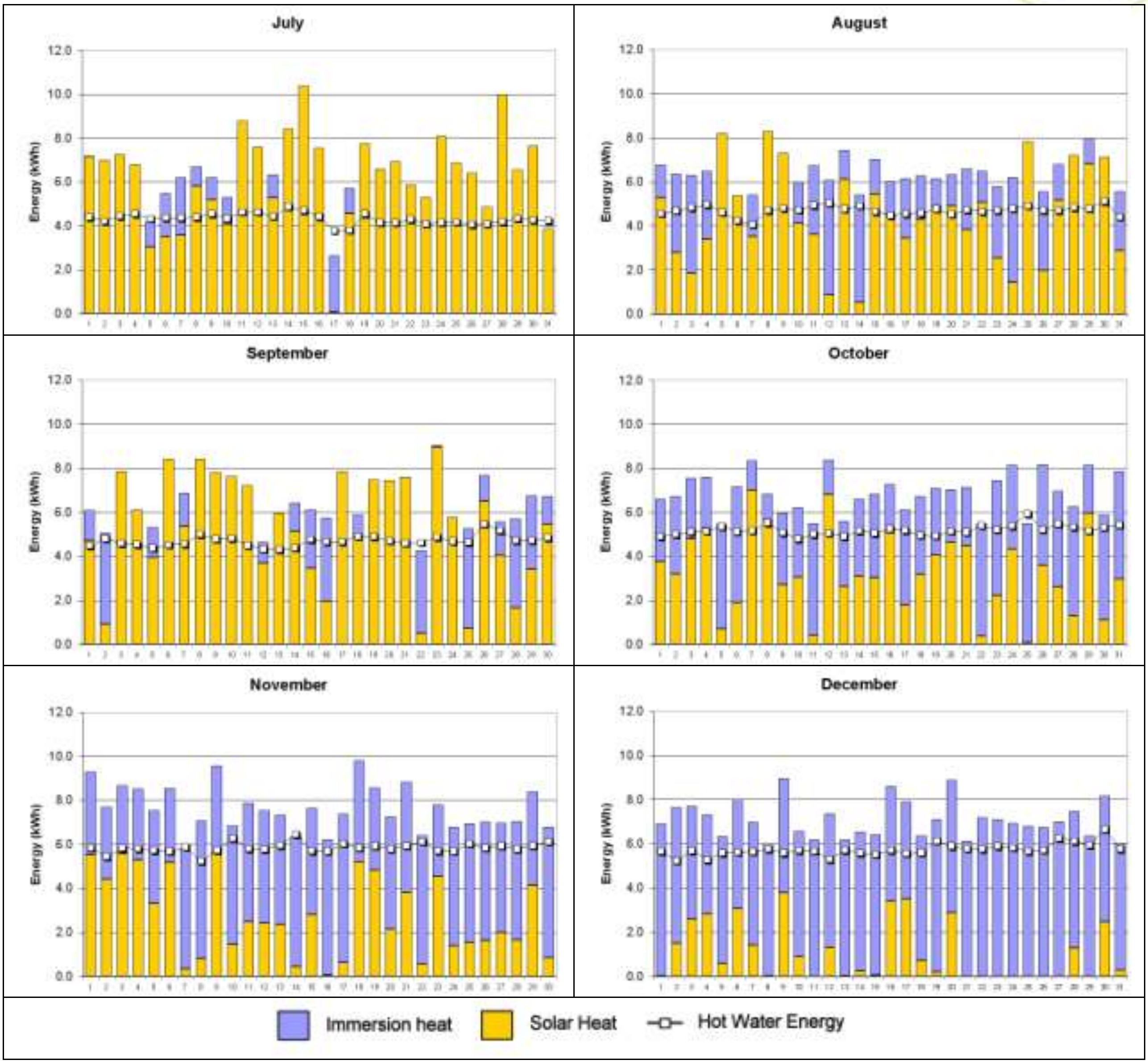
See Appendix 1 for further information on the metrology equipment.

3 Results

3.1 Summary

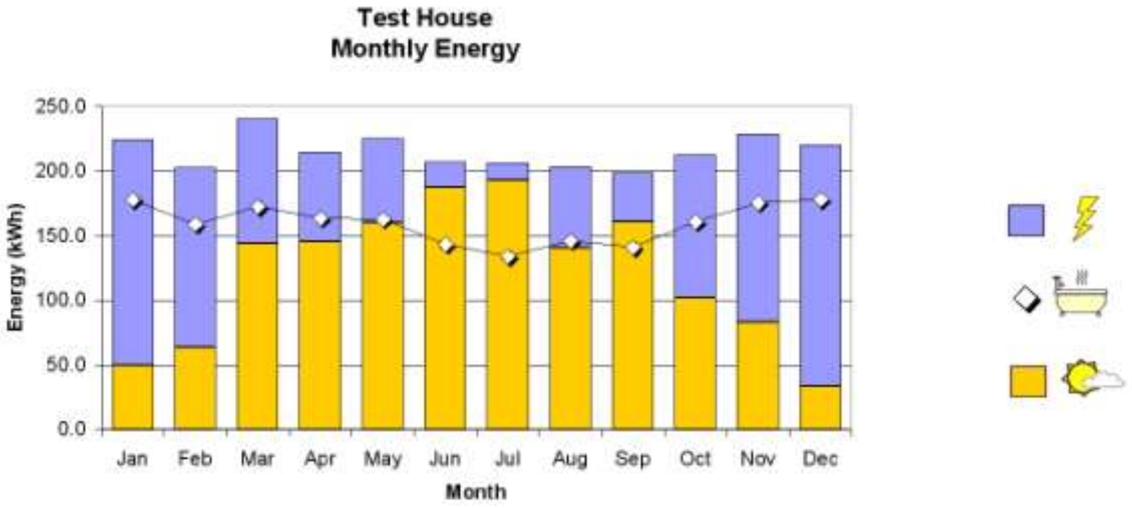
The three minute data from the test house is summed to give daily totals of energy, and these totals are plotted in the graphs below. Small periods of missing data were filled in according to the method outlined in Appendix B, in order to present data representing a full calendar year.





Moving from the shorter, colder days of winter to longer, brighter, warmer days of spring and summer, the preponderance of orange (solar heat input) increases, and the amount of blue (immersion heat) decreases.

The energy values for each month were summed and plotted below:



It can be seen that the solar energy (orange) follows a characteristic solar curve with the solar heating system making most of its contribution to hot water demand during the summer, spring and autumn.

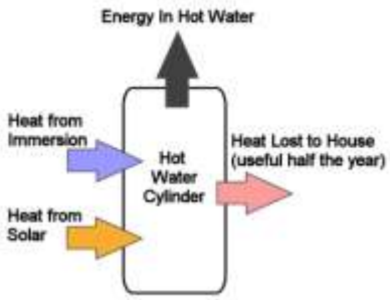
The hot water energy demand drops in the summer months, not because the water use changes (it is kept constant throughout the year), but because the temperature of the incoming water rises, so the energy needed to heat it up to 60C is reduced.

	Immersion Heater (kWh)	Solar Heat (kWh)	Hot Water Use (kWh)	Solar Electricity Consumption (kWh)
Jan	174.9	49.5	177.9	3.4
Feb	139.7	63.3	158.8	3.8
Mar	95.9	144.2	172.4	7.3
Apr	68.8	145.6	163.4	7.5
May	64.8	160.2	162.6	8.3
Jun	19.9	187.2	143.3	8.6
Jul	13.7	192.8	133.9	8.3
Aug	62.5	140.7	145.8	7.7
Sep	37.8	160.9	140.9	7.6
Oct	110.7	101.9	160.7	5.6
Nov	145.3	83.1	175.5	5.0
Dec	186.5	33.3	177.9	2.5
	1,120.3	1,462.8	1,913.1	75.6

3.2 Discussion

3.2.1 Solar Fraction

The solar fraction is the proportion of the energy demand for the hot water met by solar. The energy demand is the sum of the energy used at the tap, including heat losses in the pipes on the way to the taps and heat losses from the hot water cylinder.

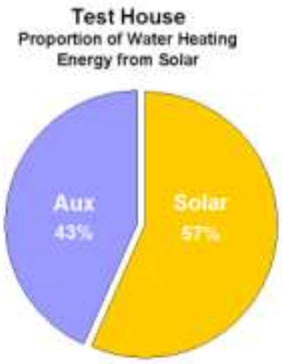


Energy Balance Hot Water Cylinder

In the study, the heat from the immersion heater, the heat from the solar water heating system and the energy removed from the cylinder in hot water were measured.

It is not possible to directly measure the heat lost from the cylinder, but since the heat flows must be in balance, then the solar fraction can be simply expressed as:

Solar Fraction = Heat from Solar / (Heat from Solar + Heat from Immersion)



$$\text{Solar Fraction} = \frac{1463 \text{ kWh}}{1463 \text{ kWh} + 1120 \text{ kWh}}$$

$$= 0.57$$

The solar fraction for the year is calculated to be 57%.

It was noted that the dedicated solar store (Vs) was 55 litres for a collector area of 3.05m^2. The Domestic Heating Compliance Guide[1] calls for a dedicated solar store of 25 litres per square metre of collector. This would result in a solar store of 76 litres. However in the case of the test house the auxiliary heating is done using an immersion heater rather than a boiler. This results in an increase of the dedicated solar volume but also reduces the daily demand volume.

3.2.2 Useful Energy Savings

Not all of the solar heat that is put into the cylinder is of benefit; a solar cylinder may have higher losses than a conventional hot water cylinder due to its larger size, and during summer being at a high temperature for more of the time.

[1] *Domestic Heating Compliance Guide,* (2006) DCLG, NBS, London

Although the simulation house uses an immersion heater for convenience of measurement and installation, most UK households use a carbon based fuel fired boiler system. It was considered to be instructive to convert the measured electricity savings into savings in a boiler-heated household.

Since the boiler has an efficiency of less than 100%, and there are heat losses in the pipes connecting the boiler to the cylinder, the fuel energy saved by the solar heat input will be higher than the measured solar heat added to the cylinder.

The data was corrected for these factors as outlined in Appendix 3, to arrive at an estimate of the useful heat saving from the solar heating system.

	Measured Solar Energy Input (kWh)	Boiler Firings Avoided	Primary Circuit Losses Avoided (kWh)	Excess Cylinder Losses (kWh)	Useful Solar Energy Benefit (kWh)	Fuel Energy Saved (kWh)
Test House	1,463	219	264	60	1,667	1,852

3.2.3 Electricity Consumption

The solar controller and pump use electricity to circulate the heat transfer fluid that transports heat from the solar panel to the hot water cylinder. The electricity consumption of each of the systems was measured and is tabulated below.

Electricity Consumed (kWh)	75
Energy Saved (kWh)	1,850
Electricity as a % of Energy Saved	4%

It can be seen, the electrical energy consumption is a small fraction of the energy saved, being only 4%.

4 Conclusion

This study has shown that solar water heating can make a significant contribution to the energy used to produce domestic hot water.

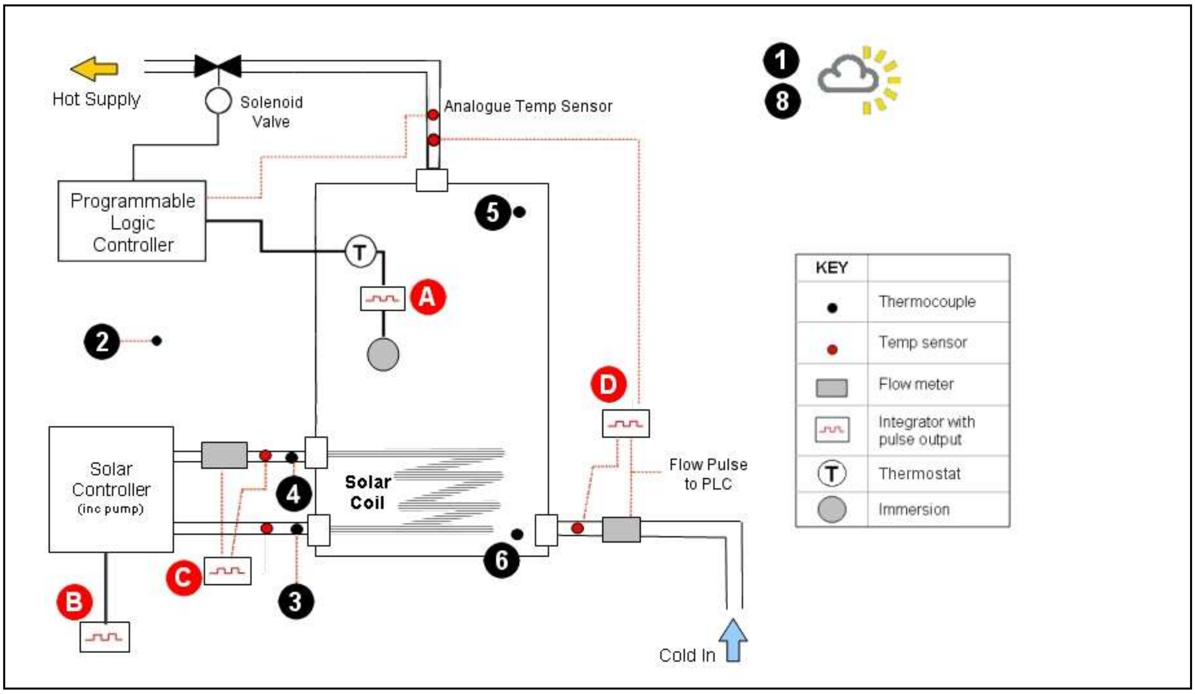
The test house was used to simulate a “disinterested” household taking no steps to adjust their behaviour, or optimise the heating system beyond using a timer controller on the boiler. This report shows that a “disinterested” household would achieve a proportion of hot water energy from the solar system of 57%. For a household with average hot water use, and a modern condensing boiler this would correspond to savings in gas energy of 1,850 kWh per year. Also resulting in the saving of 360kg per year of carbon dioxide emissions against gas heating, and 620kg per year of carbon dioxide emissions against electric heating.

Appendix A - Metrology and Experimental Design

Data-logging Schedule

The schematic shows the domestic hot water system, and the measurements taken at the hot water cylinder.

The domestic hot water (DHW) is provided from a factory insulated twin coil vented copper cylinder of 180 litres. There is a booster pump for the shower, which takes water from a port near the top of the cylinder wall rather than from the cylinder dome.



Channel Number	Identifier	Channel Type	Measurement	Units
1	Outdoor	Thermocouple type K	Outdoor temperature	°C
2	Indoor	Thermocouple type K	Indoor temperature	°C
3	Solar flow (hot)	Thermocouple type K	Solar circuit temperature warm side	°C
4	Solar return (cold)	Thermocouple type K	Solar circuit temperature cool side	°C
5	Cylinder top	Thermocouple type K	Cylinder top temperature	°C
6	Cylinder bottom	Thermocouple type K	Cylinder bottom temperature	
7	Not Used			
8	Solar Irradiation	Thermocouple type K	Pyranometer	
(A) 17	Immersion	Pulse counter	Immersion heater energy	1/100 kWh
(B) 18	Solar power	Pulse counter	Solar controller energy consumption	1/100 kWh
(C) 19	Solar heat	Pulse counter	Solar heat energy charged to cylinder	1/100 kWh
(D) 20	DHW	Pulse counter	Energy content of domestic hot water used	1/100 kWh

The measurements recorded by the data logger are tabulated above. Data was recorded every 3 minutes for 12 months.

Equipment

Temperature measurements were by type K thermocouples, either pipe mounted with jubilee clips, or surface mounted on the cylinder. In all cases, care was taken to insulate well around the thermocouple.

Temperature Inputs			
1	Ambient		Type K thermocouple in Stevenson screen on North facing wall
2	Indoor		Type K thermocouple at mid-tank height and out of fan heater flow
3	Solar loop flow		Type K thermocouple probe, tip in mid-flow
4	Solar loop return		Type K thermocouple probe, tip in mid-flow
5	Tank top Temp		Type K thermocouple probe gauge point G
6	Tank bottom		Type K thermocouple probe gauge point F
7	Not used		
8	Pyranometer	Eplab	WMO class I Precision spectral pyranometer 8.84×10^{-6} $V/(Wm^{-2})$
Pulse Inputs			
A	Immersion Power	Ampy	5916B Energy Meter 100pulses/kWhr
B	Solar Power	Ampy	5916B Energy Meter 100pulses/kWhr
C	Solar Heat flow	DMS	Supercal 531 230v powered two open pulse outputs of energy and flow volume 2mtr Pt500 sensors Energy output 0.01kWhr/pulse. Calibrated for 30% ethylene glycol 440 Superstatic Meter qp1.5, ½ “ screwed unions 2.5m heating cable
D	Draw off Heat	DMS	Supercal 531 ‘D’ Cell Battery powered two open pulse outputs of energy and flow volume 2mtr Pt500 sensors Energy output 0.01kWhr/pulse. Calibrated for water 440 Superstatic Meter qp1.5, ½ “ screwed unions 2.5m heating cable
Datalogging			
	Datalogger	Eltek	Data logger with 8 pulse counting channels and 8 thermocouple temperature inputs (K or T). 250k readings memory. Modem kit with external aerial

Heat Meter Calibration

Heat meters were only available calibrated to 30% Ethylene Glycol solution. The heat transfer fluid used was 30% Propylene Glycol.

	shc J/kgK		ρ kg/m^3		shc.ρ J/m^3 x10^6	
Temp	10C	50C	10C	50C	10C	50C
30% Ethylene	3700	3875	1040	1025	3.84	3.97
30% Propylene	3900	3950	1030	1010	4.02	3.99
Ratio					1.047	1.005

Source:
"Solar Engineering of Thermal Processes" 2nd Ed, *Wiley Interscience,* Duffie and Beckman Appendix E pp. 837-838

Linear extrapolation to 30°C ratio: (1.005 + 1.047)/2 = 1.025

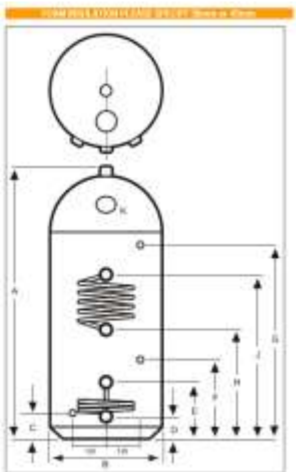
A correction factor of 1.025 is applied to the heat measured as solar input.

Materials and Methods

Hot Water System

1	Cylinder	Albion	Ecocyl 450mm x 1350mm 180 litres
2	Immersion	Screwfix	3KW 27 inch, heating the top 110 litres
3	Thermostat	Horstmann	Tank surface fitting, set to 70C
4	Header tank		2 x 18 litre, in insulated cold space
5	Solar Panel	Viridian Solar	V30 3m2 roof integrated panel
6	Solar Circulator	Viridian Solar	
7	Solar fluid	Viridian Solar	30% Propylene glycol solution

Cylinder details



	DIMENSIONS												
A	HEIGHT	1050	1200	1500	900	1050	1200	1350	1500	1800	1200	1350	1500
B	DIAMETER	400	400	400	450	450	450	450	450	450	500	500	500
	CONNECTORS												
A	HWDO 22mm Compression*	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME
C	COLD FEED 22mm Compression*	100	100	100	100	100	100	100	100	100	100	100	100
D	ECO ELEMENT 22mm Compression	100	100	100	100	100	100	100	100	100	100	100	100
E	ECO ELEMENT 22mm Compression	180	180	180	180	180	180	180	180	180	180	180	180
F	THERMOSTAT 1/2" BSP	200	200	200	200	200	200	200	200	200	200	200	200
G	TEMP GUAGE POINT 1/2" BSP	860	1010	1310	700	840	990	1150	1300	1500	995	1150	1300
H	Primary Coil 1" male c/w Albtec	335	410	455	305	335	400	400	465	530	360	410	435
J	Primary Coil 1" male c/w Albtec	635	710	755	605	605	700	770	765	830	660	710	735
K	Immersion Heater Boss	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME	DOME
	CAPACITIES												
	Upper Coil	80	90	120	80	95	125	125	145	170	140	160	175
	Eco Element	35	45	50	40	45	55	55	65	75	60	70	75
	Total	115	135	170	120	140	175	180	210	245	200	230	250

*28mm on 1800 x 450 and above

Environmental

1	Roomstat	Horstmann	Linked to heater, set on below 20C
2	Heater		1kW fan heater
3	Roomstat	Horstmann	Linked to extractor fan, set on above 25C
4	Fan		Extractor fan at ridge

Control

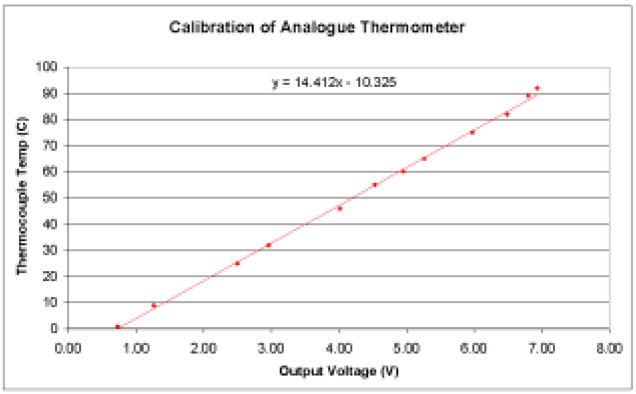
1	Controller	Mitsubishi	Alpha 2 PLC controller AL2-14MR-D
2	Tank Outlet temp	Crouzet	24v DC Analog temperature probe 0-10v 89750153, tip mid flow
3	Tank Outlet valve	Burkert	0290 servo assisted solenoid valve

The analogue temperature probe was calibrated in hot water against a Type K thermocouple to produce the curve (right).

A linear best-fit curve was used to derive the outlet temperature from the input voltage to the PLC.

The PLC control software controls the immersion heater and the solenoid valve.

The solenoid valve is opened to create the programmed water withdrawal pattern (below).



For each draw off, the PLC opens the valve at the required time. The PLC counts watt-hours (Wh) based on an input of pulses of 1/27.5 litres of flow from the superstatic flow meter on the tank inlet and the analogue tank outlet temperature. The energy flow from the tank is based on a notional inlet temperature of 10°C on the grounds that the householder neither knows nor cares what the tank inlet temperature when deciding how much hot water to run.

Draw offs A and D and E count Watt-hours pulses until the counter is full, and then turn off the valve. Draw offs B1, B2, C, and F wait for the draw off temperature to exceed the set point in the compare function before starting to count.

Tapping Cycle

The water withdrawal pattern was chosen to reflect usage in an average-sized dwelling. The withdrawal pattern follows European Standard “Tapping Cycle 2”[2], corresponding to the average household in the EU. The equivalent of 100 litres at 60°C is withdrawn throughout the day in the pattern below.

[2] EU M324EN

		min ΔT (°C)	Start counting (°C)	Energy kWh
1	07:00	15	25	0.105
2	07:15	30	40	1.4
3	07:30	15	25	0.105
4	08:01	15	25	0.105
5	08:15	15	25	0.105
6	08:30	15	25	0.105
7	08:45	15	25	0.105
8	09:00	15	25	0.105
9	09:30	15	25	0.105
10	10:30	0	10	0.105
11	11:30	15	25	0.105
12	11:45	15	25	0.105
13	12:45	0	10	0.315
14	14:30	15	25	0.105
15	15:30	15	25	0.105
16	16:30	15	25	0.105
17	18:00	15	25	0.105
18	18:15	30	40	0.105
19	18:30	30	40	0.105
20	19:00	15	25	0.105
21	20:30	0	10	0.735
22	21:15	15	25	0.105
23	21:30	30	40	1.4
				5.845

The Start Counting column shows the actual temperature which the outlet water must reach before the output counts towards the energy required for that withdrawal.

Appendix B - Data Logging

Data Logging

(a) Coverage

The data logger was contacted monthly via its GSM modem by BRE and the data was downloaded. There were no missing periods of data collection.

(b) Immersion Heater Failure

The immersion heater connection fused during November, and it was a week before it was remedied.

The data for this period of one week presented in the report has been modified as follows:

Hot water draw off energy – copy in readings for the previous unaffected week
Immersion Energy - a day with similar solar energy input was found in the previous two weeks, the immersion energy was adjusted to match this day.
Solar Energy Input – left as measured.
Solar Electricity Consumption – left as measured.

The effect of these changes is minimal.

	Immersion (kWh)	Solar Electricity (kWh)	Draw Off (kWh)	Solar Heat (kWh)
November	114.75	4.95	154.78	83
November adjusted	145.30	4.95	175.45	83
Difference	+30.55	0	+20.67	0
As a percentage of full year energy.	+2.7%	0	+1.1%	0

(c) Noise on Data Logger Inputs.

The data set exhibits infrequent noise. Investigation has pointed to this noise occurring within the data logger, perhaps triggered by the operation of the solenoid valve – the values in the 3 minute period are often far too high to be possible (e.g. equivalent to 200 kW from a 3kW immersion heater), the values are also characterised by being values such as 4, 8, 16, 32, 64, 1024 or simple combinations of these numbers. This strongly suggests bit-setting errors in the data logger. The data logger manufacturer was unable to remedy this.

The nature of the noise was relatively infrequent (1-2 times/day). The data was manually cleaned using the following simple rules:

Noise was identified by filters showing an unusually high value in any one of the pulse inputs
Noise was also identified manually as non-zero values in 3 or more of the four pulse inputs
Noise value in Immersion input was changed to the average of the surrounding three minute periods
Noise value in Solar E column was deleted

Noise value in Draw off column was deleted unless coinciding with a draw-off, in which case it was edited to make that draw off agree with the target draw off for that time.
Noise value in solar column was changed to be the average of surrounding 3 minute periods.

(d) Cross Check with Manual Readings

All of the heat meters and power meters have digital displays showing a running total of energy measured in kWh. It was therefore possible to confirm the accuracy of the data set after cleaning by comparison with readings taken manually at the beginning and end of the logging period.

The table below shows for each measurement, the total presented in the report and the total manually read from the meters. The difference is very small, and gives confidence that the data presented is robust.

	Energy from Immersion (kWh)	Energy from Solar (kWh)	Hot Water Used (kWh)	Controller Energy (kWh)
Total Presented in Report	1,121	1,462	1,924	74
Propylene Glycol Adjustment (see Appendix 1)	1,121	1,426	1,924	74
Immersion Heater Adjustment	1,090	1,426	1,903	74
Manual readings	1,085	1,420	1,867	74
Difference	5	6	36	0
%	0.5%	0.4%	1.9%	0%

Appendix C - Useful Energy Savings

Useful Solar Energy

Not all of the solar energy input to the cylinder is useful. Some makes up for higher heat losses from the cylinder due to the fact of the solar system itself which holds the cylinder at a higher temperature for more of the time in summer months than a conventional heating system would.

Equally, solar energy input to the cylinder that is not used (for example when the household is away on holiday), should not be counted towards energy savings.

The cylinder losses for each month were estimated as the difference between the sum of solar and boiler energy and the energy content of hot water used. To estimate the excess heat losses from the cylinder due to the solar energy input, the summed heat loss for the six months of October, November, December, January, February and March were compared with the summed heat loss during the other six months of the year.

The difference between the two figures was taken as an estimate of excess heat losses from the hot water cylinder due to the higher average cylinder temperatures in summer, and the effect of summer holidays.

Primary Circuit Losses

Although the monitoring system used an immersion heater as the heat input device, most dwellings in the UK use gas or oil boilers. It is therefore useful to estimate the energy saved at the boiler.

By having a solar heating system, the boiler fires less frequently, and when it does so runs for less time to warm the pre-heated solar water. Heat losses from heating the pipe-work connecting the boiler to the cylinder are therefore avoided, and should be added to the energy benefit of having the solar heating system.

The government's SAP calculation estimates the losses in the pipes connecting the boiler to the cylinder (called the primary loop losses) as 610kWh per year for uninsulated pipes between the boiler and the cylinder, or 310 kWh for insulated pipes.

The losses are made up of heat capacity losses (heating up the water in the pipes for them to slowly cool once the pump stops circulating the water to the cylinder), and heat losses during the heating of the cylinder.

It was assumed from this that the difference between the two figures (300kWh) stem from heat losses from the pipes during the cylinder heat up, whereas the figure of 310kWh which is unaffected by insulation is the heat capacity of the water in the pipes.

The number immersion firings were counted. The reduction in primary circuit losses was estimated as follows:

$$\text{Avoided Primary Circuit Losses} = \text{Solar Fraction} \times 300\text{kWh} + \frac{\text{No. immersion firings avoided} \times 310\text{ kWh}}{365 \times 2}$$

Boiler Efficiency

Typical modern boilers achieve efficiencies around 90% on a seasonally adjusted basis (the so called SEDBUK efficiency). It is seasonally adjusted because the boiler will work with a higher efficiency in winter, when return temperatures are low for space heating, and the boiler is running more continuously, so energy lost heating the boiler itself and its flue is a smaller overhead of the total energy delivered.

Solar energy is biased towards the non-heating season, so it is likely that the boiler efficiency adjusted for seasonality of solar would be somewhat lower than the SEDBUK figure, however since only the SEDBUK figures are available the energy saving has been estimated based on a SEDBUK efficiency of 90% at the boiler.

Useful energy is divided by 0.9 to arrive at the fuel energy saved.