Solar hot water systems in new housing

– a monitoring report

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

GENERAL INFORMATION REPORT 88

INTRODUCTION

This Report describes the monitoring of eight solar hot water (SHW) systems in South Wales between 1998 and 2000. The monitored systems form part of a wider European Commission project, the primary aim of which was the installation of over 3000 systems in six member states of the European Union.

Monitoring was carried out on the UK systems in order to gather information on the performance of SHW systems and the energy savings that can be expected. The UK component of the European project consisted of 100 systems installed on three Housing Association developments in South Wales. Two groups of four similar properties in terms of property size and orientation were selected for monitoring on one of these sites.

The monitoring results are important for the evaluation of the existing systems, and provide essential data for developers who wish to consider the inclusion of SHW systems on future new-build developments.

The monitoring activities have been carried out in accordance with the 'Guidelines for the Assessment of Active and Passive Solar Technologies' published by the EC-Joint Research Centre[1].

The monitored systems were installed on a Gwalia Housing Association development on the edge of the small town of Gorseinon, located approximately 10 miles from Swansea. The houses are all built to high energy efficiency standards and are part of three terraces on the estate. Houses 3, 4, 5 and 8 are two-bedroom properties, and Houses 26, 28, 30 and 36 are three-bedroom properties. A photograph of the development is shown in figure 1.

Figure 1 Roof-mounted collectors on Gorseinon development

SOLAR HOT WATER SYSTEMS

SYSTEM DESIGN

The main component of a SHW system that is not commonly used by plumbers and heating engineers is the solar collector. Three different types of collector are available:

- selective surface flat plate
- non-selective surface flat plate
- evacuated tube.

Designed to withstand UK climatic conditions, all of these collector types are available from UK manufacturers and are guaranteed for up to 10 years. Collector efficiency varies according to the design, and this is usually reflected in the system price. Collector efficiency also varies according to the temperature of the fluid entering the collector, and with the level of solar radiation incident on the collector. Figure 2 is a close up of the selective surface flat plate collectors installed at Gorseinon.

Total overall system efficiency depends on system design configuration and the pattern of hot water usage. This is generally described in terms of the 'solar fraction' and represents the percentage of hot water use that was supplied by the SHW system.

COST ADVANTAGES OF LARGE-SCALE SOLAR HOT WATER SYSTEM INSTALLATION

The main benefit of installing the SHW systems in large-scale new-build developments is the resultant cost reduction from the installation of many systems in one location, and the fact that new housing is not currently subject to VAT. This project has demonstrated the potential cost reductions associated with the following:

- bulk purchasing reduces the cost of components
- repetition of a single design of system over many similar properties reduces design costs
- co-ordination of system installation with the general building activities reduces installation costs
- the installation of SHW systems as part of new housing developments is not subject to VAT – retrofit would attract VAT (see the box on the right).

Considerable cost reductions are achievable in the new-build context. Data from the Solar Trade Association shows that typical installed SHW system costs for retrofit on individual houses are usually between £2500 and £4000 per system. As a result of the bulk purchasing and installation of these systems at Gorseinon the installed cost was reduced to around £1400. It is expected that this cost reduction process will continue throughout the building industry as experience is gained and appropriate information and training is made available for non-specialist installers.

Since April 2000, solar hot water systems, along with a range of other energy efficiency measures, qualified for a reduction in VAT to 5%. More information is given in VAT information sheet 1/00 available from HM Customs and Excise on **www.hmce.gov.uk.**

Figure 2 Close up of the installed selective surface flat plate solar collectors

SOLAR HOT WATER SYSTEMS

THE INSTALLED SYSTEMS

The type and design of SHW system was determined by competitive tender. This was based on 100 installations across the three sites in the European project. All systems had to consist of a minimum of the solar collectors, single tank hot water storage, and controller.

The design and installation of the systems were required to comply with BS 5918: 1989.

The houses to be monitored were a mixture of two-bed (four person) and three-bed (five person) properties. The installed SHW installed systems consisted of 4 m² of selected surface flat plate collectors.

Each house had a conventional wet central heating system supplied by a regular non-condensing boiler that also met any shortfall in hot water provided by the SHW system.

Figure 3 shows a schematic for the SHW system that was installed in the houses.

Ideally, for new housing site layout should be adjusted to ensure that roofs face south (+/–) 45°. As solar systems were not an initial consideration this was not possible on this site. Even so, all the solar collectors monitored were orientated to receive 90% of the maximum possible solar radiation.

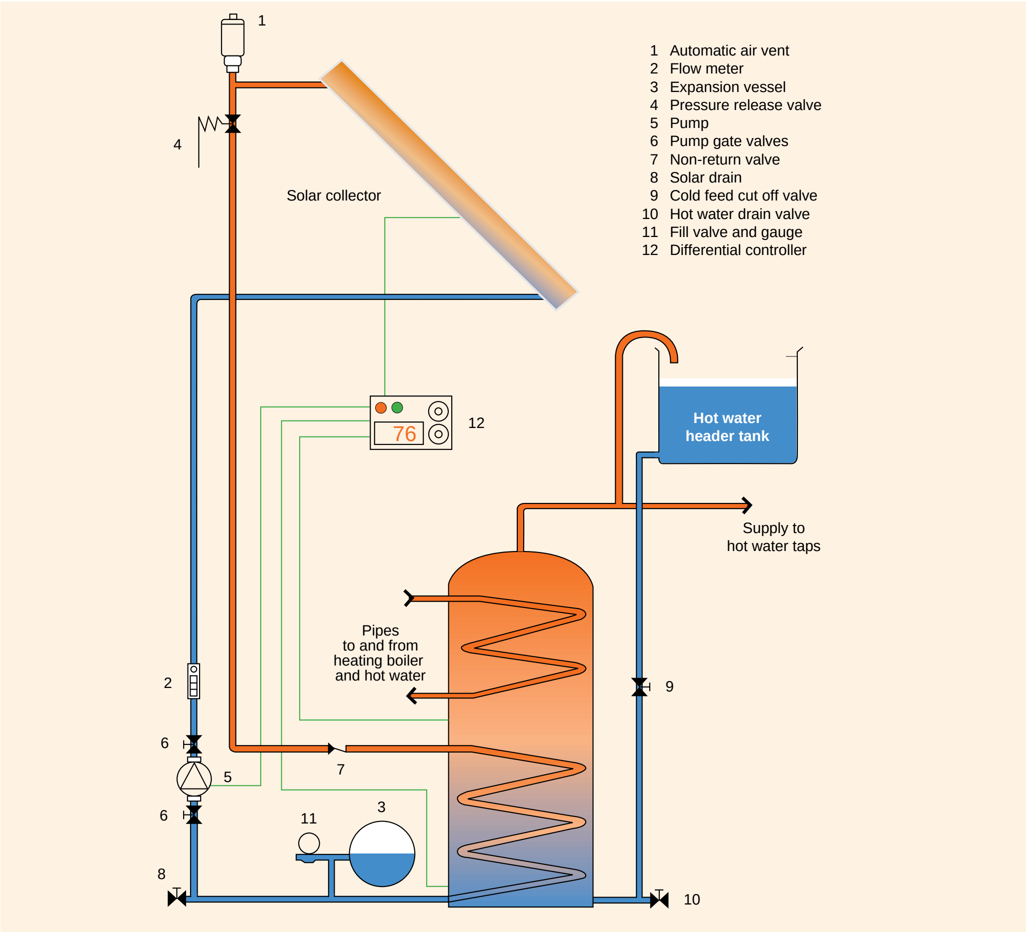

Figure 3 Solar hot water system layout (courtesy of AES Systems Ltd)

MONITORING AND RESULTS

In order to assess effectively the performance of the installed systems the following parameters were measured:

- solar input using a heat meter across the heat exchanger from the solar collector
- hot water demand using a heat meter between the cold water supply and the hot water delivery pipe
- useful energy delivered by the auxiliary heater (gas boiler) using a heat meter across the heat exchanger on the storage tank
- run time of the solar system pump using a time counter (the power demand of the pump was also known)
- solar irradiation using a photovoltaic (PV) pyranometer mounted in the plane of the solar collector
- ambient temperature.

There are a number of ways in which the performance of the SHW systems can be measured. The most common are 'useful solar output' (USO), 'normalised useful solar output', and 'solar fraction' (SF). Using the information collected from the monitoring equipment, each of these has been calculated for the installed systems and the results are given on the following pages.

There were a number of occasions during the monitoring period when data losses occurred or properties were unoccupied. In particular, data for Houses 4 and 5 was largely incomplete for the monitoring period and so has not been included in the data analysis. Incomplete data on other systems means that only the results from Houses 28, 30 and 36 are presented in this Report. However, results from all the systems have been used to corroborate the overall findings.

USEFUL SOLAR OUTPUT

This is the useful solar energy delivered to the load by the solar system.

For a combined cylinder system (ie water is pre-heated in the bottom of a large tank before being heated to the required delivery temperature by an auxiliary boiler) the most accurate method of calculating the USO is:

USO = collector heat output (kWh)

However, this approach assumes that all the heat put into the cylinder is useful and ignores the additional losses that may occur. These additional losses result from the increased volume of stored hot water and higher temperatures of that water (mainly in summer months) compared with a conventional domestic cylinder. These additional losses are generally referred to as the 'pre-heat losses'.

As it is not possible to measure the pre-heat losses in a combined cylinder system, the USO figures overleaf are higher than is actually the case.

Table 1 (overleaf) shows how the USO varies for the monitored houses from month to month. Data from table 1 have been plotted in figure 4 (overleaf).

NORMALISED USEFUL SOLAR OUTPUT

Using the USO data, it is possible to calculate the annual USO normalised for collector area (4 m^2). Table 2 (see page 7) illustrates the results for these houses.

The average annual normalised USO using these three houses is 294 kWh/m^2.

SOLAR FRACTION

The formal definition of SF is the ratio of the USO to the total load and is, therefore, the proportion of the hot water energy load that a solar system provides. The total load is to include storage and distribution losses (but not inefficiencies due to the auxiliary heater), that is:

SF = USO/(load + losses)

Figure 5 (see page 7) shows the simple energy inputs and outputs of the system.

MONITORING AND RESULTS

The calculation of the SF for a combined cylinder system is subject to the same errors as the USO. This is due to not being able to calculate accurately the pre-heat losses as described earlier. Consequently, the monitored SF is over-stated.

An analysis of the likely pre-heat losses was undertaken and an adjustment made to the SFs to reflect this. For completeness, figure 6 shows the monitored and adjusted annual average SFs for Houses 28, 30 and 36.

	Useful solar output (kWh)			
	House 28	House 30	House 36	Solar irradiation* (kWh/m^2)
April	171.20	146.80	179.60	121.42
May	129.70	119.50	152.10	107.46
June	170.10	162.20	127.70	141.80
July	177.94	163.27	179.39	153.28
August	126.60	133.80	153.80	112.87
September	125.10	135.00	120.70	95.99
October	75.20	79.50	89.30	63.10
November	38.70	32.20	42.90	34.10
December	16.20	16.10	22.70	21.32
January	21.70	16.80	25.40	24.46
February	39.30	16.30	31.80	41.61
March	97.60	90.70	106.30	79.67
Total	**1189.34**	**1112.17**	**1231.69**	**997.08**

* Solar irradiation measured in same plane as solar collectors (year measured).

Table 1 Useful solar output data from 4 m^2 solar panel per house

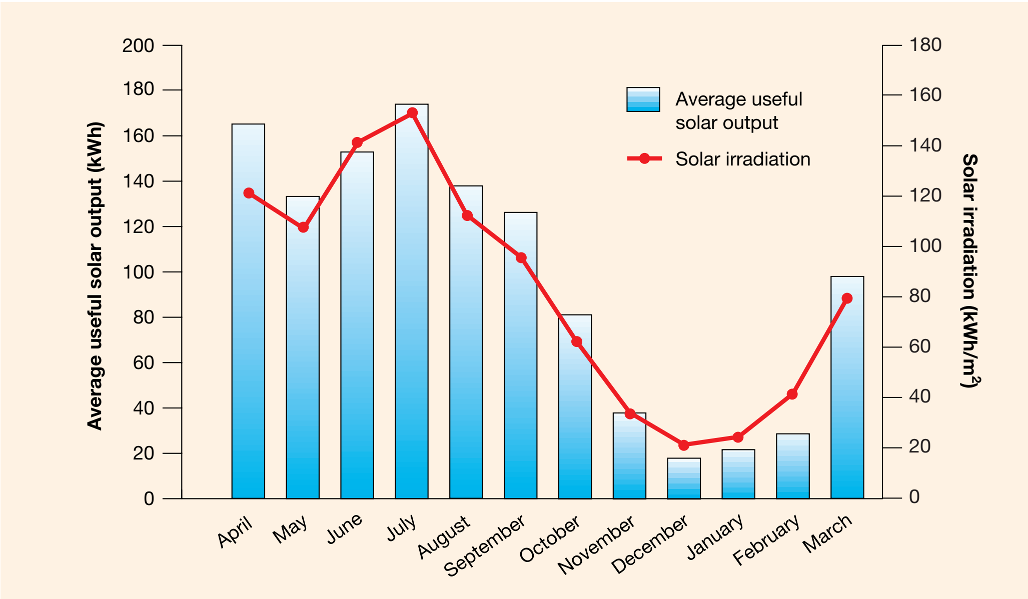

Figure 4 Variation in useful solar output with time for Houses 28, 30 and 36

MONITORING AND RESULTS

For the three houses, the monitored average SF is 69%. After making allowances for the pre-heat losses, the average SF is 55% (see table 3).

GAS/ELECTRICITY SAVED

It is not strictly possible to calculate how much energy has been saved, because the usage of hot water may be influenced by not having to pay for the energy used to heat it. However, any tendency towards high hot water use in summer months will be countered by the presence of mains water metering. An interview conducted for a separately funded project specifically asked tenants whether their hot water usage had been modified now that they had solar water heaters. The vast majority (30 out of the 33 who were questioned) said that it had not.

The most accurate method for estimating fuel savings is to base it on the calculated SF and the user's load data. Table 4 (page 8) shows the calculated energy savings.

It is possible to calculate the cost savings and the carbon dioxide (CO_2) mitigation that would be achieved for these energy savings. Table 5 on page 8 shows the calculated savings.

	House 28	House 30	House 36	Average
Annual normalised USO (kWh/m²)	297	278	308	294

Table 2 Annual normalised useful solar output values

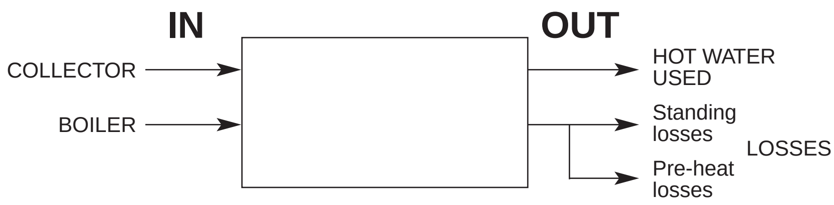

Figure 5 Energy flow for solar hot water system

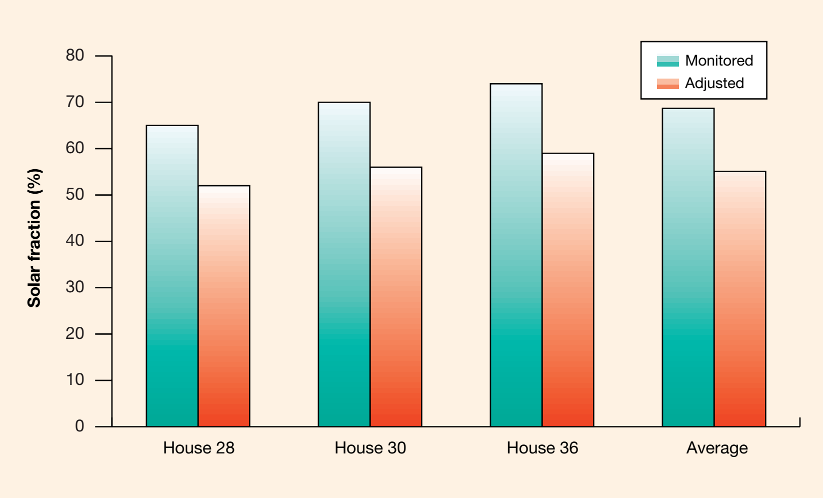

Figure 6 Annual solar fraction for Houses 28, 30 and 36

	House 28	House 30	House 36	Average
Annual solar fraction (%)	65/52	70/56	74/59	69/55
Number of occupants	4	4	4	

Table 3 Monitored and adjusted solar fraction (allowing for pre-heat losses)

MONITORING AND RESULTS

Month	Energy saved (kWh)			
	House 28	House 30	House 36	Average
April	107.5	74.3	123.8	
May	89.3	77.0	131.2	
June	102.7	81.7	86.7	
July	113.8	71.3	106.4	
August	87.3	90.4	113.2	
September	85.5	97.2	79.2	
October	62.2	58.7	74.9	
November	41.8	24.9	42.8	
December	16.1	13.3	24.7	
January	25.2	12.6	26.2	
February	35.0	12.3	28.1	
March	80.9	71.0	79.8	
Total	**847.2**	**684.8**	**917.0**	**816.33**

Table 4 Energy savings

	House 28	House 30	House 36	Average
Gas savings (£)*	17	14	18	16.33
CO_2 savings (kg)**	215	173	232	206.66

* Based on 1.49p/kWh
** Based on 0.19 $kgCO_2$/kWh
Both savings assume a boiler efficiency of 75%

Table 5 Annual gas cost savings and CO_2 mitigation

The likely savings in electrically heated homes are more difficult to estimate, because the energy used in a non-SHW system is likely to consist of a high percentage of off-peak electricity (80%-90% depending on occupancy and tank size) and a relatively minor on-peak top up. Depending on the pattern of hot water usage, this may well be substituted by a solar system providing much of the hot water, but with a significant proportion being provided with on-peak electricity. The extent to which this would reduce the financial savings will depend on the solar/electricity mix and the tariffs used, although the CO_2 savings would be unaffected by the choice of tariff. The financial savings in table 6 (opposite) are based on on-peak electricity being the displaced fuel and, as such, are a maximum saving for the houses monitored.

Assuming a displaced fuel of gas and using the houses where full data is known (Houses 28, 30 and 36), and an annual average energy saving of 816 kWh, the total annual CO_2 mitigation per house would be about 200 kg. For a 20-year period, the saving per house would be 4 tonnes.

PARASITIC ENERGY CONSUMPTION

The energy consumed by the solar water heating pump was noted for a 12-month period. Results for Houses 28, 30 and 36 are shown in table 7 (opposite).

It can be seen that the parasitic energy is not inconsiderable. However, this energy use would be offset to a certain extent by the fact that the pump for the gas boiler would be required for less time.

SYSTEM ECONOMICS

A lifecycle cost analysis (LCCA) has been carried out for the installed SHW systems. This calculates the unit cost of the energy from the solar collectors, taking into account the total installed system cost, which has been discounted over the system lifetime. For the analysis the following assumptions were made:

- system lifetime of 20 years
- total installed system cost of £1415, based on project data
- discount rate of 10%
- annual operation and maintenance (O&M) costs of £20.

The LCCA was calculated only for those houses that had sufficient monitored data. This includes House 8, which, whilst data was incomplete, had sufficient data for this analysis.

Figure 7 and table 8 show the results of the LCCA as illustrated by the annualised unit energy cost. This is the 'effective' cost of the energy provided by the SHW system.

It is noted that the above calculated unit energy costs for the monitored houses are greater than would generally be expected. This is due to the very low user loads of around 1000 kWh per year.

Other sources estimate that a typical hot water load would be 3000 kWh[2].

It can be seen that although House 8 had the highest SF, House 28 would actually benefit from the lowest energy costs over the lifetime of the system, as their hot water demand is higher than other houses.

	House 28	House 30	House 36	Average
Electricity savings (£)*	69	56	75	66.6
CO_2 savings (kg)**	390	315	422	375.6

* Based on 8.13p/kWh
** Based on 0.46 $kgCO_2/kWh$

Table 6 Estimated annual electricity cost savings and CO_2 mitigation

House number	Total parasitic energy consumed annually (kWh)	Parasitic energy consumed as % of USO	Cost of parasitic energy (£)
28	90.2	8.6	7.33
30	75.9	7.7	6.17
36	92.6	8.5	7.53
Average	86.2	8.3	7.01

Table 7 Parasitic energy consumption for Houses 28, 30 and 36

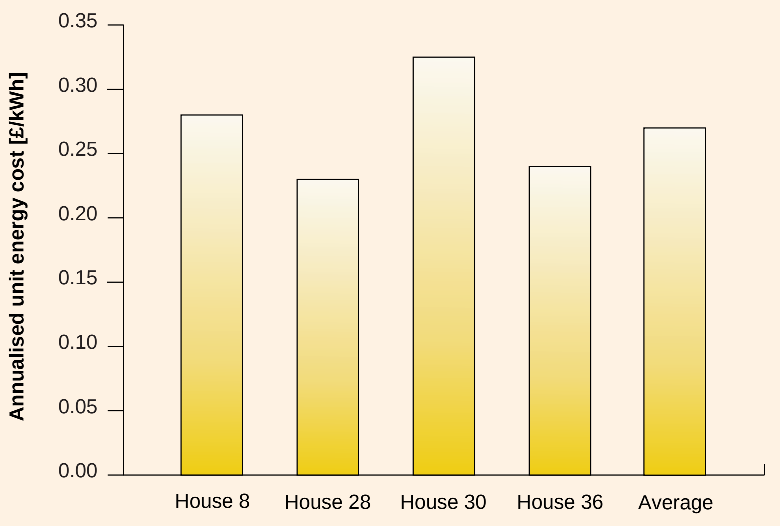

Figure 7 Annualised unit energy costs for the monitored houses

	House 28	House 30	House 36	Average
Annualised unit cost (pence)	23	34	24	27

Table 8 Annualised unit energy costs for Houses 28, 30 and 36

SYSTEM ECONOMICS

Figures 8 and 9 demonstrate the effect of varying the SF, the installed cost and the energy source on the energy cost and the simple payback period for a load of 3000 kWh. Please note that these diagrams are 'what-if' scenarios, and do not represent monitored system data. In particular it should be noted that the energy from the solar system will be limited for periods of the year and so any increase in hot water load may not be met by a proportionate increase in energy from the solar system. Consequently, it is probable that the SF would reduce as hot water use increases.

The 'payback' is the length of time in which the installation cost is recouped based on the cost of the energy that is saved. This has been calculated for three scenarios – displacing gas heated water, displacing on-peak electrically heated water and, finally, displacing fuel (with a hypothetically inflated energy cost carbon emission, etc) heated water. It can be seen from figure 9 that the shortest payback periods are attained for the highest SF and the highest price displaced energy.

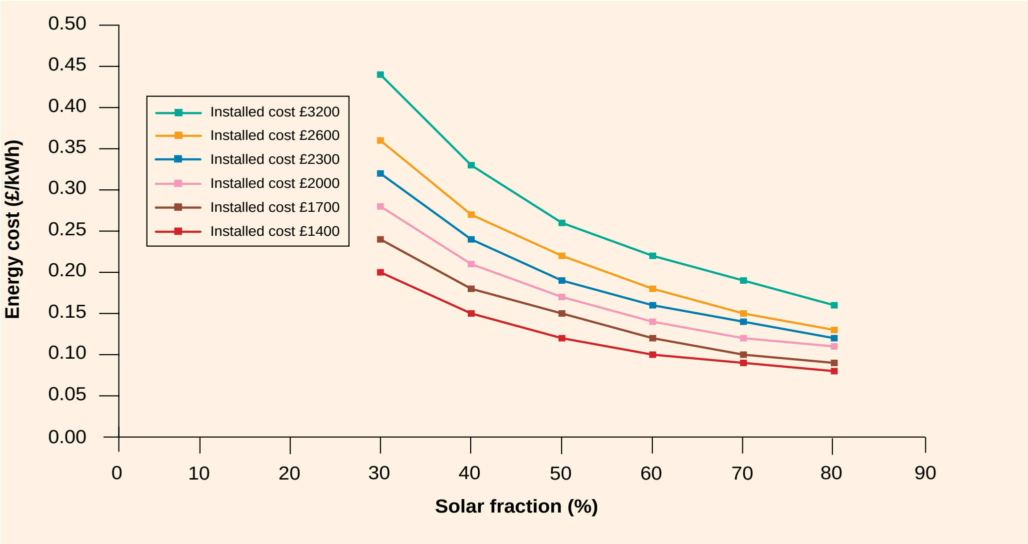

Figure 8 Effect of installation cost and solar fraction on annualised energy cost (assumes hot water load of 3000 kWh)

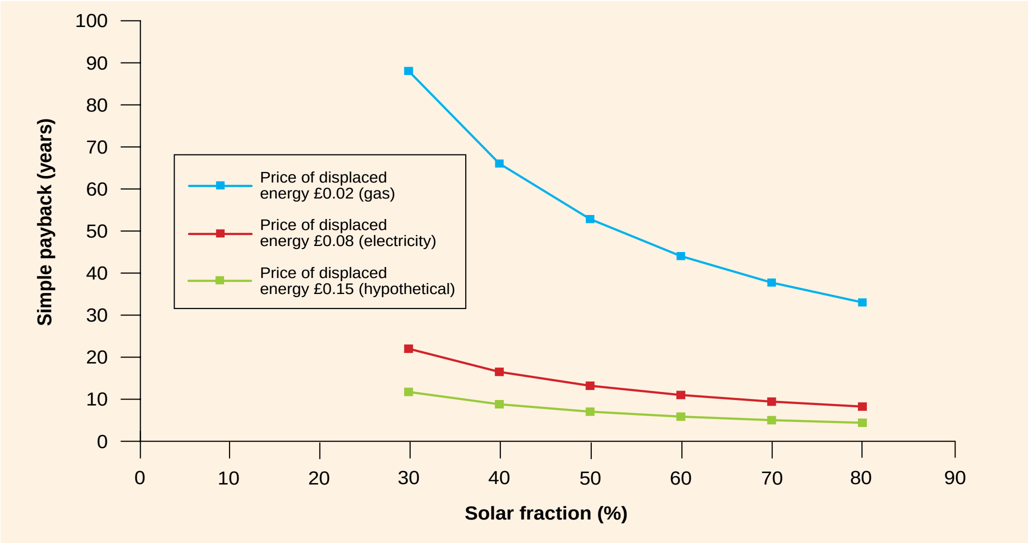

Figure 9 Variation in payback with solar fraction and price of displaced energy (assumes hot water load of 3000 kWh)

SYSTEM ECONOMICS

COMPARISON WITH OTHER SYSTEMS

Data from the monitored systems in South Wales can be compared with that from other systems. A report published in 1999[3] provides data from a total of 171 systems in Denmark, Germany, the Netherlands and Sweden. Summary information is provided in table 9, alongside data from the systems in Wales.

When comparing the USO of the South Wales systems with the other countries, it is one of the lowest. However, referring to the last line of table 9, it can be seen that there is variation in the irradiation for the different countries. If the USOs are normalised to the appropriate irradiation, then the South Wales systems are comparable at least with systems from Denmark, Germany and Sweden – 295 kWh/year compared to 321, 279, 306 kWh/year respectively.

It should be noted that the USO for the Netherlands is very high but that the SF is very low. The reason for this discrepancy is not clear, although Dutch systems tend to have a higher collector area to cylinder volume ratio compared with other countries.
The SF of the South Wales systems is within the spread of figures for the other countries. Indeed, after taking into account the different irradiation levels that exist (SF normalised to irradiation), the South Wales systems give the highest values – 55% compared to 50%, 49%, 36% and 46%.

The solar irradiation levels during the monitoring period were approximately 2% below the 10-year average for the South Wales coast.

NON-ENERGY ISSUES

In addition to the energy performance of the installed SHW systems, the project identified a number of issues that are worthy of note.

There were a number of reports of systems not working correctly shortly after tenants had moved in. Investigation revealed that in some cases tenants had turned off the system thinking it would save electricity. In other cases, tenants using key meters occasionally ran out of credit. Both these events resulted in the solar collectors overheating and damaging the air vents. This caused the solar systems to be out of order until repairs were carried out.

A tenant survey has shown that, overall, the occupants were extremely satisfied with the systems. However, the temperature of the hot water at the taps during hot weather did cause particular concern. Many tenants stated that it was frequently ‘scalding’. There are a number of ways in which this problem can be addressed. Some suppliers automatically install scalding prevention measures, however this is far from universal.

	Denmark	Germany	Netherlands	Sweden	UK (South Wales)
USO (kWh/m^2/yr)	392	282	643	331	294
USO normalised to irradiation*	321	279	594	306	295
Solar fraction	61%	49%	39%	50%	55%
Solar fraction normalised to irradiation*	50%	49%	36%	46%	55%
Annual irradiation in plane of collector (kWh/m^2/yr)	1223	1009	1083	1082	997

* Normalised to solar irradiation levels of 1000 kWh/m^2/yr

Table 9 European system characteristics

CONCLUSIONS AND FURTHER INFORMATION

The results of the monitoring project provide a balanced assessment of the likely performance of SHW systems when installed in mass housing, ie where the occupant does not make a specific decision to purchase a SHW system and can, therefore, be considered as a 'disinterested' user. It is likely that greater savings can be made at the one-off or 'enthusiast' user end of the market where the purchaser may be prepared to make lifestyle changes to maximise the benefits of the SHW system.

SHW systems are a very visible energy efficiency measure. Although this is sometimes seen as a disadvantage, it can also be a positive factor in that, unlike many other measures, it makes a clear environmental statement about the house and its occupants/owners.

The financial savings from the monitored SHW systems are modest for both gas and electric systems (where off-peak electricity is generally the displaced fuel). However, annual CO_2 savings of between 0.4 tonne and 1.1 tonne per dwelling are possible where electricity is the displaced fuel (based on domestic hot water use of 1000 kWh and 3000 kWh per year respectively).

The capital cost of SHW systems currently results in long payback periods and annualised energy costs higher than the displaced fuel, although this needs to be placed in the context of the environmental damage caused by the continued use of fossil fuels.

SHW systems can, however, make a useful contribution to the energy performance of a dwelling, especially in new-build properties with high insulation standards and efficient heating systems. Care needs to be taken that the cost of the SHW system does not prevent cheaper, more cost-effective measures being adopted.

Summary of results	
Normalised useful solar output	294 kWh/m^2/year
Monitored solar fraction	69%
Adjusted solar fraction	55%
Resulting savings	816 kWh/year, £16/year (gas)

REFERENCES

[1] 'Guidelines for the Assessment of Active and Passive Solar Technologies', EC-Joint Research Centre, 1992

[2] 'Large Scale Solar Purchasing', The Solar Trade Association, 1988

[3] 'Active Solar Heating Performance and Data Review', ETSU, S/P00270/REP, 1999

FURTHER INFORMATION

Further information on solar water heating can be obtained from the following organisations.

CADDET Renewable Energy

www.caddet-re.org

Tel 01235 436806

Solar Trade Association

www.solartradeassociation.org.uk

Tel 01908 442290

This Report is based on material drafted by IT Power as part of a collaborative project with BRECSU for the Energy Efficiency Best Practice programme.

Energy Efficiency Best Practice in Housing

Tel: 0845 120 7799
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