ACTIVE SOLAR HEATING SYSTEM PERFORMANCE AND DATA REVIEW

ETSU S/P3/00270/REP

Contractor
IT Power

Prepared by
Dr J Bates
Ms L Bertarelli
Ms G Schmidt

The work described in this report was carried out under contract as part of the New & Renewable Energy Programme, managed by ETSU on behalf of the Department of Trade and Industry. The views and judgements expressed in this report are those of the contractors and do not necessarily reflect those of ETSU or the Department of Trade and Industry.

First published 1999

TABLE OF CONTENTS

1. SUMMARY

The UK Department of Trade and Industry (through ETSU) commissioned this study as part of its active solar programme. It was carried out between November 1998 and June 1999. This report has been prepared by IT Power for ETSU under the Agreement Number S/P3/00270/00/00 as the final report for the project entitled "Active Solar Heating System Performance and Data Review". This report details the work carried out during the project, the results from that work and relevant conclusions and recommendations.

The objective of this project was to provide the DTI with independent information on ASH system performance and costs in Europe. Data was then assessed regarding its relevance to the UK.

The work was divided into five main activities:

- Activity a – Review of available data;
- Activity b – Collection of data from UK systems;
- Activity c – Collection of data from other European systems;
- Activity d – Analysis of data

The constraints identified during the project were the following:

1. Obtaining data:
- Very few systems within the UK are monitored (due to the extra costs involved).
- There are no National or International Standards for monitoring of Active Solar Heating Systems and this has meant that the data collected are frequently incompatible making comparative analysis difficult if not impossible.
- Many systems are small domestic systems. Monitoring is often undertaken by the systems owner on an ad hoc basis.
- Cost data were extremely difficult to obtain.
- There is a general reluctance to provide field data – the time entailed to put the data together, complications with the monitoring equipment and confidentiality were barriers to accessing the data.

2. Analysis of data:
- Comparison of data was difficult as the available data varied considerably from one system to the other in respect to the parameters monitored.

In light of the above limitations, data for a total of 171 systems were obtained from Denmark, Germany, The Netherlands and Sweden. The data were analysed to assess system performance. Several key issues were identified during the analysis process.

System Prices

In The Netherlands, recent prices for ASH systems installed on new build, large scale schemes have been in the region of 1500 Euro for a 2.75 m^2 system, equating to an installed price of 545 Euro.m^{-2}. Discussions with UK manufacturers confirm that these prices could be matched in the UK should the installation be allowed to proceed unhindered by non-specialist contractors and fully integrated into the

building process. Recent discussions with a number of Housing Associations in the UK have indicated that prices of this level would encourage the use of ASH systems on a regular basis in new housing developments.

Estimation of approximate payback periods were between 5.5 years and 16 years for varying solar fractions and depending on the overall hot water consumption, the price of displaced fuel (electricity – peak or economy, gas, oil) and the load profile, i.e., the hot water consumption pattern, etc.

Energy costs ranged between 34.5 cents per kWh and of 1.7 cents per kWh. The lowest energy costs were associated with the large installations. There were little data available on maintenance costs – only one system provided information for which maintenance costs were estimated at 198.3 Euro per year (11 Euro per family per year) representing 0.6 % of the price of the installed system.

Performance Data Analysis

A number of interesting differences between systems installed in different countries were noted. In Sweden, each residence had an average of 10 m^2 compared to an average of 3 m^2 in The Netherlands. The large collector areas seen in Sweden were because the systems were often used for space heating applications as well as for hot water.

The ratio of collector area to storage tank volume is significantly higher in The Netherlands than the other countries, 26 m^{-1} compared to 11 m^{-1} to 19 m^{-1}, indicating that these systems have a much smaller storage tank volume. The collector loop efficiency seen in the systems in The Netherlands was double that in the other countries, as was the energy delivered to the storage per square metre of collector area even though the average annual in-plane irradiation was not significantly different.

The solar fraction for systems installed in The Netherlands was significantly lower in comparison to the other countries (39 % cf 49 % to 61 %). This is to be anticipated as the smaller collector area will generate a lower proportion of a household's hot water requirements.

2. INTRODUCTION

In the UK, relatively few active solar heating (ASH) systems that have been installed are subjected to a detailed monitoring campaign, and data from those systems that are monitored are not often publicly available. As a result, there is little information on the performance of ASH systems in the field and there is a lack of understanding of the costs of the energy generated by these systems.

In other European countries, more performance data is available. Although system designs differ between different countries (for instance, most systems in The Netherlands are drainback systems) data from other countries with similar climatic conditions may be able to provide information relevant to the UK.

The objective of this project was to provide the DTI with independent information on ASH system performance and costs in Europe. This will enable an accurate assessment of the costs of the energy generated by these systems in order to maximise the benefit to the Solar Water Heating industry as well as for the users and potential users of these systems.

IT Power was contracted by the UK DTI, through ETSU, to carry out a detailed analysis of system performance and costs for active solar heating (ASH) systems installed in Northern European countries. All data were assessed regarding their relevance to UK conditions. Domestic systems were the main focus of the project although some larger systems such as district solar heating systems were also investigated.

The specific project objectives were to:

- Analyse available performance data on ASH systems from in Northern Europe;
- Assess the relevance of the data obtained from other Northern European countries to the UK;
- Provide independent information on ASH system performance and costs.

The objectives have been achieved by:

- Identifying and collating a list of organisations/institutes/people involved in ASH monitoring in Northern Europe;
- Collecting the available performance data;
- Analysing the data to enable comparison between different systems and different locations.

The deliverables from the project were:

- A comprehensive list of UK and European contacts that have been or are presently involved in monitoring ASH systems;
- Analysis of the data and an assessment of the relevance of the data to the UK;

3. PROJECT RESULTS

To achieve the objectives of the project the work was divided into five main activities:

- Activity a – Review of available data;
- Activity b – Collection of data from UK systems;
- Activity c – Collection of data from other European systems;
- Activity d – Analysis of data
- Activity e – Project Management and Reporting

The results of these activities are described in the sections below.

3.1 Identification and Review of Available Data

The purpose of the data review activity was to identify sources of data which could be collated in order to evaluate system performance for various different system configurations. The scope of the investigation was targeted towards small domestic systems (individual and large-scale installations), although sources for large commercial/ public systems and district heating projects were also noted. A list of desired monitoring parameters was drawn up; and this is included in Annex I.

In order to research the available data, a database of around 85 contacts was established, including universities, institutes, housing associations, consultancies and manufacturers that have been or are presently involved in monitoring ASH systems. This comprehensive list of UK contacts is provided in Annex II and European contacts are listed in Annex III. Information about the type of system, and details of the monitoring (if any) were recorded for each of the possible sources. Many of the organisations had conducted only laboratory tests and had no data for recently installed systems: many organisations were also not prepared to disclose data. Forty of the possible sources identified were involved in field monitoring of solar collectors and these were selected for further investigation.

In addition, an Internet search and a literature review of recent solar conference proceedings was undertaken. This included publications from:

- Eurosun '96, Freiburg, Germany, September 1996;
- International Nuon Conference on Utilities, Apeldoorn, The Netherlands, April 1996;
- North Sun '97, Espoo-Otaniemi, Finland, June 1997;
- North Sun '94, Glasgow, Scotland, September 1994;
- ISES World Conference 'In Search of the Sun', Harare, Zimbabwe, 1995;
- Solar Energy Journals, 1992 to present.

It was noted at this point that the available data existed in different formats, and that this would be likely to cause difficulty in the data analysis. A fairly simple method of data analysis was therefore thought most appropriate to effectively compare the performance of the collectors.

3.2 Collection of Data for UK Systems

An estimated 45 000 domestic hot water systems had been installed in the UK by 1994: the projected amount for the year 2000 is 55 000 systems[1]. The UK market is relatively small compared to that in other European countries as many people believe the climate is not appropriate for solar energy.

Most of the ASH systems sold are for water heating in single-family homes. Some of the systems use glazed flat-plate collectors, while others use evacuated tube collectors. Most are indirect systems which include a separate collector circuit filled with an antifreeze solution to prevent freezing, eliminating the need for drain-down.

There are two predominant system designs in use in the UK:

i) single water storage cylinder incorporating the solar heat exchanger (positioned at the bottom of the cylinder) and a conventional back-up heating source (positioned at the top of the cylinder);
ii) a preheat cylinder incorporating the solar heat exchanger which feeds water directly into a secondary hot water cylinder.

Manufacturers, installers and end-users were contacted during this activity in order to compile a comprehensive list of ASH installations in the UK which were and/or are monitored (Annex II). After this survey of monitored UK installations, as much data as possible was collected. A questionnaire detailing the information that was required from each system was developed and sent to the relevant contact. The questionnaire can be found in Annex IV.

Due to the fact that very few ASH systems have been monitored in the UK, it was difficult to obtain suitable UK data. However an increasing number of ASH systems are currently being installed that incorporate a defined monitoring regime meaning that within the next 18 months a substantial amount of data should be available. A list of these systems is included in Annex II.

For example, the Solar Trade Association (STA) has implemented a monitoring programme on four different ASH systems installed at a range of different sites in the UK. Unfortunately data is not yet available from this programme. In addition there are a number of recently installed large-scale new-build projects, from which data can be potentially obtained. However, the amount of data from these projects was very limited as monitoring had only just got underway mid-way through this project.

Limited data from individuals monitoring evacuated tube collectors on their properties was also potentially available. However, as these had all been manually recorded, concern was expressed over the reliability of the data. A number of other sources which were potentially willing to supply data from larger systems were also identified, for example, in sheltered housing or council offices.

The following points were noted during this activity:

- Very few ASH systems within the UK were rigorously monitored (primarily due to the extra costs involved);

[1] EC, DGXVII. February 1996. Sun in Action: The solar thermal market, A strategic plan for action in Europe.

- Many systems were small domestic systems and monitoring was often undertaken by the system owner on an ad hoc basis and concern was expressed over data reliability;
- Many organisations/people involved in monitoring ASH systems had encountered difficulty with the monitoring equipment (data loggers, etc.) – again uncertainty was expressed on data reliability;
- There was a striking variation in the parameters monitored in each ASH system - some organisations were not necessarily aware of what parameters should be monitored and why they should be monitored;
- There was a general reluctance to provide field data – the time entailed to put the data together, complications with the monitoring equipment and confidentiality were barriers to accessing the data.

3.3 Collection of Data from Overseas Systems

Data was collected for systems in the following countries: Denmark, Germany, The Netherlands and Sweden. These countries have a climate relatively similar to the UK's and also have extensive experience with ASH systems. A list of European contacts is provided in Annex III.

Data on system performance and cost, cost of energy delivered, system design and collector type, new-build or retrofit, multiple new-build and roof integration was collected where possible. Data on maintenance (costs as well as information on how much maintenance is actually carried out) and on the system users was also gathered, as far as this data was available. Possibilities for performance improvement and cost reductions were also investigated.

A questionnaire was distributed to each of the potential data providers (Annex IV).

Data from monitored systems in Denmark (small domestic systems and one large district heating system), Finland (small domestic systems), The Netherlands (all domestic systems), Sweden (small, large and district heating), Norway and Germany (small domestic systems) were identified. However, data were only obtained for a total of 171 systems from Denmark, Germany, The Netherlands and Sweden. The data are summarised in Annex V. At the end of 1999 data from a number of E.U. countries should become publicly available through the E.C. funded SUN-SHINE project.

The text boxes below detail the ASH market situation in each of the countries investigated and provide background information on the data that were collected in this study.

DENMARK

There are about 16 000 systems in use in Denmark, with a total collector area of 150 000 m^2. By the year 2000 it is projected that 37 000 domestic hot water systems will be in use[2].

The main market for solar water heating systems in Denmark is in small, one-family systems. They are approximately 5 m^2 flat plate selective collector with 250 litre storage. Systems are closed-loop with antifreeze protection. Storage with integrated auxiliary heating in the top is normally sold as a unit supplied with all the equipment necessary for the collector loop (pump, expansion, control system, etc.). There are 15 different collectors being sold on the Danish market. The typical Danish collector consists of toughened glass, sun strip absorber with a selective surface, glass wool insulation behind the absorber and an aluminium casing.

There are about 18 solar system manufacturers in Denmark (2 main manufacturers have sold collectors for more than 15 years, these are: Ar-Con and Batec).

The purchase price and installation of a complete solar system (5 m^2 solar collector and a 300 litre storage tank) is on average 4 580 Euros.

DATA

Datafiles were obtained for 18 ASH systems. All systems, except one, are domestic, single family installations. The datafiles were obtained from ARCON, Cenergia and the Danish Energy Technology Institute.

ARCON, a Danish manufacturer, has built the largest thermal solar collector plant in the world, the size of the collector area is 8 064 m^2 and storage tank capacity is 2 100 m^2. The annual output of the plant is 3 250 MWh, covering approximately 13 % of the annual heat requirement of the District.

Cenergia is the technical co-ordinator of the Thermie European Housing Ecology Network (EHEN) project. The goal of this project is to build eleven new low-energy low-CO_2 demonstration projects in Denmark (Kölding and Ballerup), The Netherlands (Winterswijk), Ireland (Dublin), Italy (Torino), Portugal (Sintra), Spain (Madrid and Lleida) and the UK (Milton Keynes, Saffron Walden, Hull and Swansea). Some of the systems have been monitored for over 3 years, but most of the systems have been monitored for a shorter period of time. Cenergia provided data for a domestic, multiple family, retrofitted ASH system installed in 1996 in Ballerup, Denmark. The collector size is 55 m^2. Provision of further data proved difficult due to the time limitations.

Danish Energy Technology Institute has been involved in a number of ASH monitoring programmes for the Danish Government. In 1992, a programme was initiated to monitor 25 small domestic ASH systems for a period of 4 years. The project is now completed and 16 datafiles were provided. In 1999 a second programme was initiated to monitor 28 district ASH systems.

Detailed information on the systems analysed is provided in Annex V.

GERMANY

At the end of 1994 there were an estimated 12.5 m^2 of solar collectors per 1 000 capita installed in Germany[3]. An estimated 80 % of ASH systems are used for domestic water heating for family homes although more recently there have been efforts to develop large-scale systems.

More than 50 % of the installed systems are roof integrated. Due to climatic conditions in Germany, the systems are two-cycle systems with a water-glycol cycle, which charges the solar storage by means of an internal heat exchanger. The collector types in operation are approximately 70 % flat plate collectors and 30 % evacuated tube collectors.

70 % of the flat plate collectors installed in Germany are manufactured in Germany. The market is shared by approximately 20 medium to small producers and between 5 to 10 bigger manufacturers.

ASH systems are usually retrofitted on an existing building and prices are between 6 134 and 8 180 Euros including installation. Systems using evacuated tube collectors cost up to 10 225 Euros.

DATA

Performance data on five systems was provided by the Technische Universität Dresden. The Technische Universität Dresden has been involved in a number of monitoring programmes of domestic, commercial and district ASH systems. Details of the data can be found in Annex V.

SWEDEN

[2] EC, DGXVII. February 1996. Sun in Action: The solar thermal market, A strategic plan for action in Europe.
[3] EC, DGXVII. February 1996. Sun in Action: The solar thermal market, A strategic plan for action in Europe.

Solar systems in Sweden are generally used for both hot water production and space heating. Systems often use a wood burner as a back energy source, although oil burners and electricity heating systems are also used. During recent years a large part of the market has been "do-it-yourself" systems based on high quality components marketed in DIY courses.

Some drainback systems are used in Sweden, but glycol or oil is used as an anti-freezing fluid in most installations. Larger systems for many apartment buildings with a central tank are of currently of interest in Sweden, though only a few such systems have been installed. Most of the systems installed in Sweden are imported from Denmark. The two leading manufacturers in Sweden are TeknoTerm Energi AB and Solsam Sunergy AB.

Prices for system purchase installation are approximately 5 045 Euro (10 m^2 flat plate collectors in connection with a 500 litre water tank).

DATA

Datafiles for 16 systems were provided by Chalmers University of Technology. The systems ranged from small domestic, single family ASH systems with a collector surface area of 5 m^2 to large domestic, multi-family installations with collector surface area of 740 m^2. Details of the datafiles systems can be found in Annex V.

THE NETHERLANDS

An estimated 10 000 domestic hot water systems were in use in 1994 and the projected use for the year 2000 is 50 000[4].

Unlike other countries, drainback systems are customary in The Netherlands. An estimated 95 % of domestic hot water system use a forced circulation drainback system. This is due to the fact that water companies prefer water as a collector fluid to glycol. Systems are usually sold as a complete system with a 3 m^2 collector and 100 to 150 litre storage tank. The market in The Netherlands has shifted from individual buyers to large projects. In these projects up to 1 000 systems are installed in a new housing development.

There are 5 companies manufacturing active solar systems in The Netherlands. The two main manufacturers are Luigjes ZonneEnergie (LZE) and Zonne-Energie Nederland (ZEN).

The price of the average system is 1 500 Euros including installation (excluding VAT).

DATA

In total data from 142 systems were obtained for small domestic ASH systems. These data were collated and evaluated by Ecofys, a Dutch consultancy, on behalf of Novem. Data were provided in averages based on similar system designs. The data are summarised in Annex V.

3.4 Data Assessment and Analysis

Performance data were obtained from a total of 171 systems installed in Denmark, Germany, The Netherlands and Sweden. All the systems except one were domestic systems, the remaining one was a large district solar water heating system in Denmark. The systems for which data were collected are summarised in Table 5. A full list of collected data is given in Annex V.

Following the successful collection of the performance data, an assessment exercise was undertaken to evaluate the compatibility of the data. One key issue that arose from the data assessment exercise was the lack of compatibility between the data. In most cases, different parameters were monitored so that direct comparisons between data were always not possible.

Although data were collected on whether the systems were retrofitted or were new build, there was little or no difference in the performance of these systems. Data on costs were insufficient to make a judgement as to whether there was a price difference between new-build or retrofitted systems. However, in the UK incorporating an ASH system in a new-build situation would mean that VAT was not

[4] EC, DGXVII. February 1996. Sun in Action: The solar thermal market, A strategic plan for action in Europe.

payable on the system, thereby generating a 17.5 % cost saving. Furthermore, it was not possible to gather data on roof-integrated systems although data were obtained for a façade mounted system.

Most of the systems for which data were collected were flat plate collectors, with data for one evacuated tube collector only. It was not possible therefore to draw any conclusions as to any differences in performance of the collector types.

3.4.1 System Prices

In addition to the performance data, information was also collected on system prices in Denmark, The Netherlands, Sweden and the UK. The price information was provided by the system manufacturers and suppliers. The information is summarised in Table 1.

Table 1: Price summary for ASH systems in Denmark, The Netherlands, Sweden and the UK

Manufacturer/ Supplier	System type	Collector type	System size (m^2)	Guarantee (years)	Price (Euro)	VAT	Including installation
DENMARK							
Aidt Miljo A/S	PP collector	Flat plate	3	N/A	332 (111 m^{-2})	NO	NO
	Copper absorber	Flat plate	3	N/A	417 (139 m^{-2})	NO	NO
	Low-flow model 300, 285 litre, Low-flow	Flat plate	3	N/A	1659-1743 (550-580 m^{-2})	NO	YES
	Economy model, 160 litre, Normal flow	Flat plate	3	N/A	1324-1408 (440-470 m^{-2})	NO	YES
ED Heating	ED27	Flat plate	2.7	N/A	595 (220 m^{-2})	NO	NO
	BV54 (ED27 collector, 280 litre cylinder)	Flat plate	5.4	N/A	3150 (583 m^{-2})	NO	YES
Arcon	Collector S-250	Flat plate	2.5	N/A	385 (154 m^{-2})	NO	NO
	Collector ST	Flat plate	2.5	N/A	460 (184 m^{-2})	NO	NO
	Collector S-350-10	Flat plate	3.5	N/A	475 (136 m^{-2})	NO	NO
	Collector SI-250-N	Flat plate	2.5	N/A	400 (160 m^{-2})	NO	NO
THE NETHERLANDS							
Aton	Aton B100.6-ENG (collector C2.6, 100 litre cylinder, pump & controller, tube with insulation)	Flat plate	2.7	N/A	1543 (571 m^{-2})	NO	NO
	Aton B100.1-ENG (1 pressurised 100 litre cylinder, pump & controller, tube with insulation)	Flat plate	2.7	N/A	1702 (630 m^{-2})	NO	NO
SWEDEN							
TeknoTerm	EST	Flat plate	2.5	N/A	656 (262 m^{-2})	NO	NO
Solsam Sunergy	Solsam LGB villa	Flat plate	2.5	5	1890 (756 m^{-2})	NO	NO
	Solsam LGB villa (kit)	Flat plate	3.7	5	2801 (757 m^{-2})	NO	NO
UK							
Filsol Ltd.	Domestic solar panels	Flat plate	4	10	2126 – 2552 (818 - 982 m^{-2})	NO	YES
	Domestic installation kit	Flat plate	4	10	2029 (507 m^{-2})	NO	NO
	FS01 (boxed solar panels including absorber plate)	Flat plate	1.67	10	491 (294 m^{-2})	NO	NO
	FS02 (boxed solar panels including absorber plate)	Flat plate	2	10	539 (269 m^{-2})	NO	NO
	FS01 (absorber plate)	Flat plate	1.67	10	215 (129 m^{-2})	NO	NO
	FS02 (absorber plate)	Flat plate	2	10	246 (123 m^{-2})	NO	NO
Construction Resources	ZEN Aquasol Duo (collector, cylinder, & integrated pump and controller)	Flat plate	2.7	N/A	1700 – 1972 (630 – 730 m^{-2})	NO	NO
	ZEN Aquasol Duo (collector, cylinder, & integrated pump and controller)	Flat plate	4.15	N/A	827-971 (199-234 m^{-2})	NO	NO
	Agena Azur 20 (collector)	Flat plate	2	N/A	1963 – 2305 (473 – 555 m^{-2})	NO	NO
	ES Solar roof (collector)	Flat plate	1	N/A	246 (246 m^{-2})	NO	NO
Solar Club	Filsol (FS01)	Flat plate	3.34	10	915 (274 m^{-2})	NO	NO
	Filsol (FS02)	Flat plate	4	10	997 (249 m^{-2})	NO	NO
	AES	Flat plate	4.4	N/A	840 (191 m^{-2})	NO	NO
	AES	Flat plate	3.34	N/A	915 (275 m^{-2})	NO	NO
	Rayotec	ETC	20 tubes	N/A	689	NO	NO
	Rayotec	ETC	30 tubes	N/A	1019	NO	NO
Thermomax	Evacuated tube TMS20	ETC	20 tubes	N/A	810	NO	NO
	Evacuated tube TMS30	ETC	30 tubes	N/A	1199	NO	NO
	Solar DHW system kit – TMS20	ETC	20 tubes	N/A	1082	NO	NO
	Solar DHW system kit – TMS30	ETC	30 tubes	N/A	1471	NO	NO

Table 2 summarises the price information given in Table 1 and compares this with the installed prices from the survey.

Table 2: Summary of Price data

Country	**Manufacturers Price Range – excluding installation (Euro.m^{-2})**	**Prices of Installed Systems from Survey**	
		Price (Euro.m^{-2})	**Comments**
Denmark	111 – 583	622 337	Single family retrofit, incl. VAT Large scale, new build excl. VAT
The Netherlands	570 – 630	811 - 975	Average price of retrofitted single family systems
Sweden	260 – 757	174 738	New build multi-family installation Retrofit, multi-family installation
United Kingdom	123 – 730	460 - 577	Average price of new build, single family systems in bulk purchase scheme.

From the data collected, installed costs per square meter of collector area ranged from 500 Eurom^{-2} to 1000 Eurom^{-2} . In The Netherlands, recent prices for ASH systems installed on new build, large scale schemes have been in the region of 1500 Euro for a 2.75 m^2 system, equating to an installed price of 545 Euro.m^{-2}. Discussions with UK manufacturers confirm that these prices could be matched in the UK should the installation be allowed to proceed unhindered by non-specialist contractors and fully integrated into the building process.

Recent discussions with a number of Housing Associations in the UK have indicated that prices of this level would encourage the use of ASH systems on a regular basis in new housing developments.

Estimation of approximate payback periods can be made from Figure 1 which shows cumulative annual cost savings for an ASH system for different solar fractions. For the purposes of the figure, calculations were made against an annual hot water bill of 360 Euro which would typically be the case for a family of four using electric heating and an annual increase of 2 % for inflation. From the figure, a system costing 1500 Euro, the payback period would be between 5.5 years and 13 years for a solar fraction of 75 % and 30 % respectively. A system costing 3000 Euro would have a payback period of between 10 years and 16 years for a solar fraction of 75 % and 45 % respectively.

Obviously the payback period is highly dependent upon a number of issues such as the overall hot water consumption, the price of displaced fuel (electricity – peak or economy, gas, oil), the load profile, i.e., the hot water consumption pattern, etc.

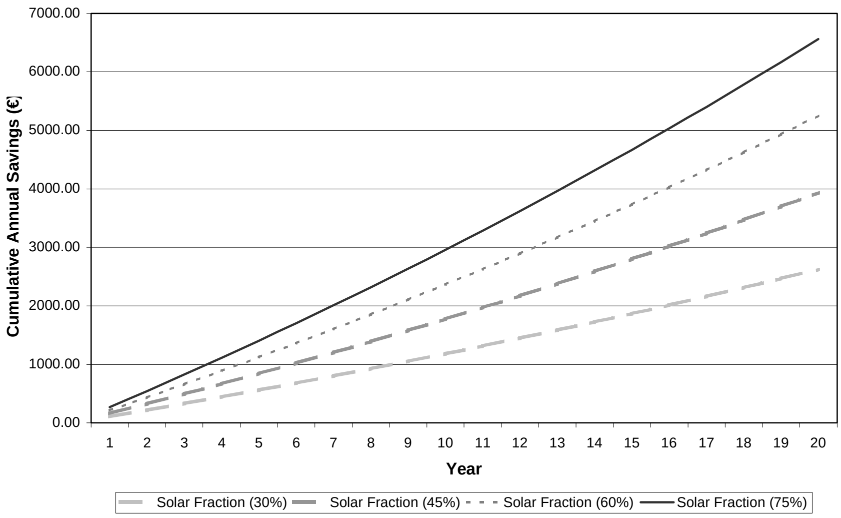


Figure 1: Cumulative Annual Savings for an ASH System

3.4.2 Maintenance Costs

Little data were available on maintenance costs of the ASH systems. However, data were available for one system, a 55 m^2 flat plate system installed on an 18 family residence in Denmark (systems 10). Maintenance costs were estimated at 198.3 Euro per year (11 Euro per family per year) representing 0.6 % of the price of the installed system.

3.4.3 Energy Costs

An important economic justification for an ASH system is the effective cost of the energy delivered by the system. This can be determined from the installed system cost (plus maintenance costs ideally) and the expected energy generated over the lifetime of the ASH system. Figure 2 shows the energy costs for the systems for which the necessary data were provided. From the figure it can be seen that energy costs ranged between a maximum of 34.5 cents per kWh and a minimum of 1.7 cents per kWh. The lowest energy costs were associated with the large installations (system 1 had a collector area of 8064 m^2 and system 43 a collector area of 740 m^2).

The highest energy costs were associated with the five systems in Germany. The particularly high costs associated with system 20 were probably because the collector suffered from a degree of shading in the morning. The high costs associated with system 22 may have been due to the reported high rate of dirt accumulation on the collector and the high costs associated with system 23 may have resulted from the reported problems with controller regulation.

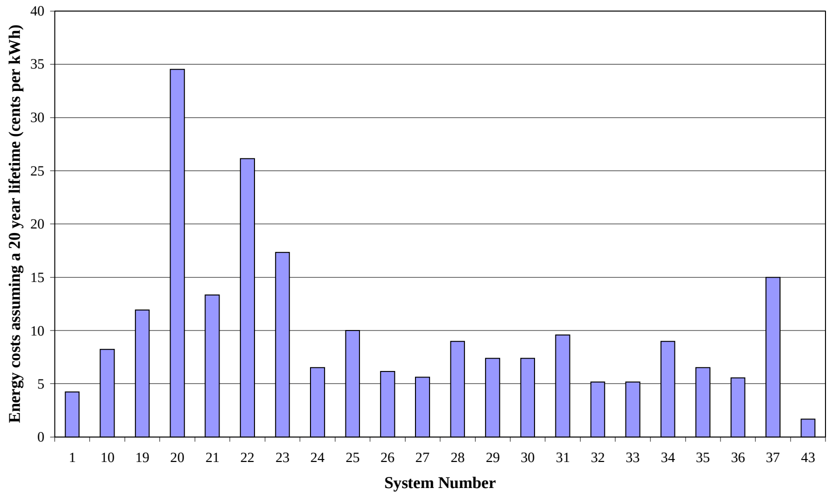


Figure 2: Energy costs per kilowatt hour over a 20 year system lifetime

3.4.4 Performance Analysis

In order to assess the performance of an ASH system, the following parameters should ideally be measured:

- energy delivered from collector to storage tank,
- energy consumed by the load,
- energy delivered by auxiliary heater,
- irradiation in collector plane,
- flow rate through the collector loop,
- ambient temperature,
- energy consumed by solar system (e.g. to drive pump).

However, very few systems are actually monitored at all, and even fewer are monitored comprehensively - largely due to the costs involved. This lack of comprehensive data meant that detailed analysis of the performance of the solar water heating systems was not possible.

Most of the systems for which data were collected monitored the solar fraction and the total energy consumed. In a few cases the energy delivered by the back-up heating source was also monitored enabling systems losses to be taken into account. It must be noted that although the losses in a solar water heating system are often not insignificant, it is common practice to only monitor two of the following three parameters:

- energy delivered from collector to storage tank,
- energy consumed by the load,
- energy delivered by auxiliary heater,

with the third parameter derived from the other two. This has the disadvantage that the system losses are not taken into account. However, this would be an issue whatever analysis is undertaken from the collected data. Losses can be between 10 % and 60 % in an extreme case.

Most of the systems for which data were collected had monitored the following parameters:

- annual irradiation in collector plane
- energy delivered by ASH system to storage cylinder
- solar fraction

In addition to the monitored parameters, data were also provided on the collector area and the storage tank volume.

From these data it was possible to calculate the collector loop efficiency (energy delivered to the storage by the ASH system divided by the incident energy on the collector) and the energy delivered by ASH system to storage cylinder per square meter of collector area.

A key parameter determining the performance of an ASH systems is the amount of energy falling on the solar collector. A summary of average annual irradiation data for locations in each of the four countries for which data were provided is given in Table 3. From the table it can be seen that the average irradiation is very similar for all four countries with a mean value for a horizontal surface of 1007 $kWh.m^{-2}.yr^{-1}$ and 1161 $kWh.m^{-2}.yr^{-1}$ for a surface inclined 30° to the horizontal.

Table 3: Average annual irradiation data

	Denmark	**Germany**	**Sweden**	**The Netherlands**	**UK**	**Average value**
Average annual global irradiation on horizontal surface ($kWh.m^{-2}$)[5]	1031 (Hojbakkegard)	1024 (Berlin)	1047 (Stockholm)	991 (Vlissingen)	944 (Kew)	1007 (σ_n 40.9)
Average annual global irradiation on inclined surface, 30° to horizontal ($kWh.m^{-2}$)[6]	1186 (Hojbakkegard)	1153 (Berlin)	1219 (Stockholm)	1179 (Vlissingen)	1066 (Kew)	1161 (σ_n 57.8)

A summary of the systems for which performance data were obtained is given in Table 4.

Table 4: Summary of performance data collected

[5] European Solar Radiation Atlas: Volume I, Horizontal Surfaces.
[6] European Solar Radiation Atlas: Volume II, Inclined Surfaces.

Country	Number of System	General Comments
Denmark	1-18	1 large district system, 1 multi family residence, 16 single family residences. All flat plate collectors. All domestic systems retro-fitted.
Germany	19-23	Retro-fitted systems: 4 on multi-family residences, 1 office based system. Evacuated tube/CPC tube collector.
The Netherlands	24-37	Averages of 142 systems, all single family residences, mainly flat plate collectors and some integrated storage systems, 44 new build systems.
Sweden	38-53	2 multi-family residences, 14 single family residences, all flat plate collectors. 10 new build, 6 retrofitted.

All the systems apart from those in The Netherlands used glycol for protection against freezing whereas a drainback system was used to provide protection in The Netherlands (although glycol was used in thermosyphon systems). Most of the systems were pumped systems – although some data were available for thermosyphon systems in The Netherlands. The use of thermosyphon systems did not seem to have a significant impact on system performance.

The collector loop flow rates through the systems were typically in the region of 0.01 $l.m^{-2}.s^{-1}$ and 0.02 $l.m^{-2}.s^{-1}$. Few systems had flow rates outside this range – the lowest recorded flow rate was 0.003 $l.m^{-2}.s^{-1}$. The performance data are summarised in Table 5.

Table 5: Summary of performance of ASH systems in the four countries

Country / Parameter	DNK	DEU	NLD	SWE	Average
Average annual irradiation on surface inclined at 30° to the horizontal	1186	1153	1179	1219	1161
Annual irradiance in collector plane	1223	1009	1083	1082	1123
Average collector area per residence[7]	5	-	3	10	6
Average ratio of collector area to storage tank volume (m^{-1})	19[8]	13	26	11	18[8]
STD Deviation	4	4	5	6	7
Average energy delivered by ASH system to storage cylinder ($kWh.m^{-2}.yr^{--1}$)	392	282	643	331	429
STD Deviation	106	133	169	252	220
Average solar fraction (%)	61	49	39	50	51
STD Deviation	17	22	14	16	18
Average collector loop efficiency (%)	32	28	60	25	37
STD Deviation	8	12	17	10	19

A number of interesting differences between systems installed in different countries are highlighted in Table 5. In particular, the difference in collector area that was

[7] For single family residences only
[8] Note: this does not include the data for the large district solar heating system.

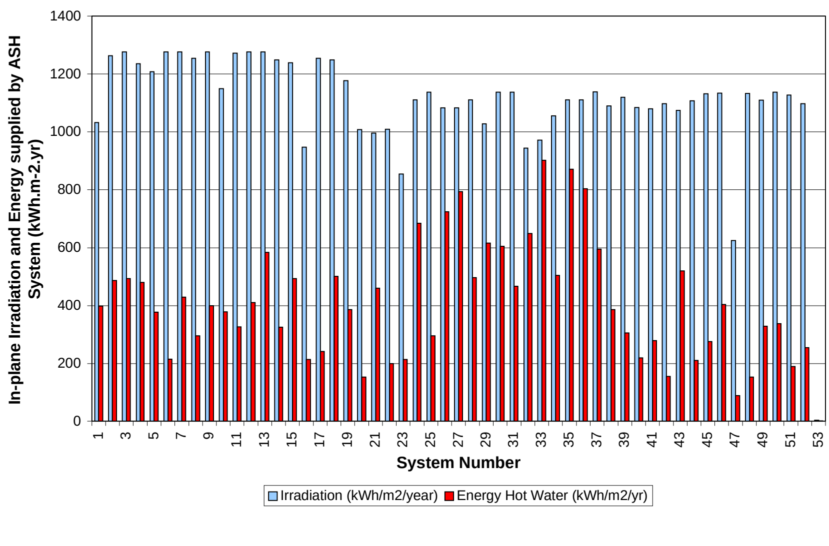
typically installed on a single family residence. In Sweden, each residence had an average of 10 m^2 compared to an average 3 m^2 in The Netherlands. The large collector areas seen in Sweden was because the systems were often used for space heating applications as well as for hot water.

The ratio of collector area to storage tank volume was also significantly higher in The Netherlands than the other countries, 26 m^{-1} cf 11m^{-1} to 19^{-1} m^{-1}, indicating that these systems had a much smaller storage tank volume[9]. The low storage tank volume means that every time water is drawn off from the hot water system and the storage tank refilled with cold water, the temperature differential between the collector loop fluid and the water in the storage tank is maximised thereby increasing the heat transfer from the collector loop to the storage.

This was probably why the collector loop efficiency seen in the systems in The Netherlands was double that seen in the other countries and also an explanation for the fact that the energy delivered to the storage per square metre of collector area was significantly higher in The Netherlands than the other countries even though the average annual in-plane irradiation was not significantly different. Unfortunately this hypothesis can only be confirmed with detailed information on hot water consumption patterns and these data were not available.

Another point about the systems installed in The Netherlands was the low solar fraction in comparison to the other countries (39 % cf 49 % to 61 %). This was anticipated as the lower collector area would provide a lower proportion of a household's hot water requirements.

Figure 3 shows the performance of the systems in terms of energy delivered by the collector loop per square metre of collector: the average value was 429 kWh.m^{-2}.yr^{-1} with a standard deviation of 220 kWh.m^{-2}.yr^{-1}. The data for system 53 was only recorded for a 77 day period between 16 July and 30 September 1999 and does not appear on the scale used on the figure. The irradiation falling on the collector plane in this period averaged 3.16 kwh.m^{-2}.d^{-1}, and the energy delivered to the hot water storage tank in the period was 1.597 kwh.m^{-2}.d^{-1}.



[9] For systems installed in the UK, a typical ratio of collector area to storage tank volume is in the region of 13 – 17 m^{-1}.

Figure 3: Energy delivered by the ASH system to the storage cylinder per m² of collector area and annual in-plane irradiation

Figure 4 shows the collector loop efficiency and the solar fraction for the systems. The solar fraction varied from between 12 % (system 37) and 89 % (system 9). The collector loop efficiency varied from 12.4 % (system 43) to a reported 93 % (system 33).

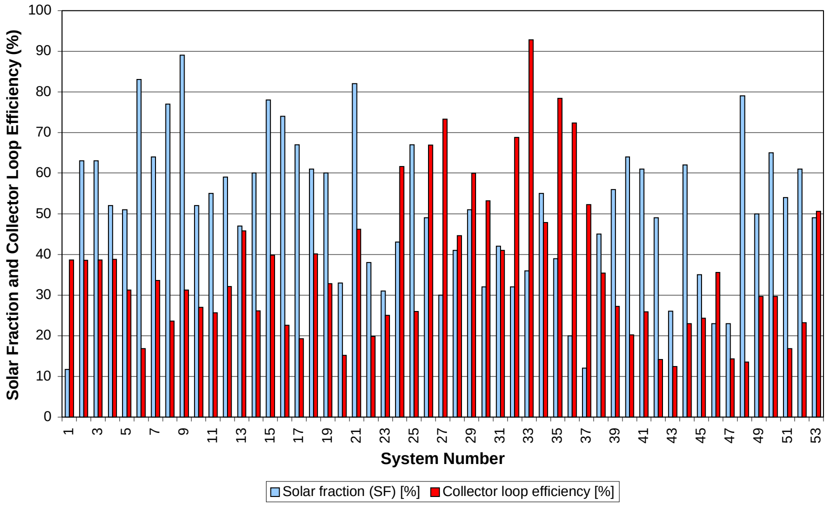


Figure 4: Solar Fraction and Collector Loop Efficiency for the Systems

The frequency distribution of the solar fraction and the collector loop efficiency are shown in Figure 5 and Figure 6 respectively for systems on single family residences only. From these figures, the collector loop efficiencies lie predominantly in the region of 20 % to 40 % and the solar fraction between 40 % and 70 %. Both these parameters are dependent on both the system design and the hot water usage patterns.

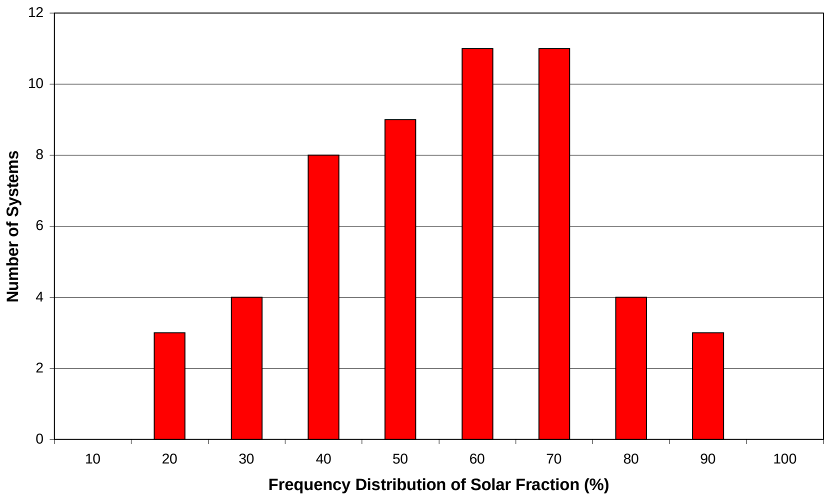


Figure 5: Frequency Distribution of Solar Fraction

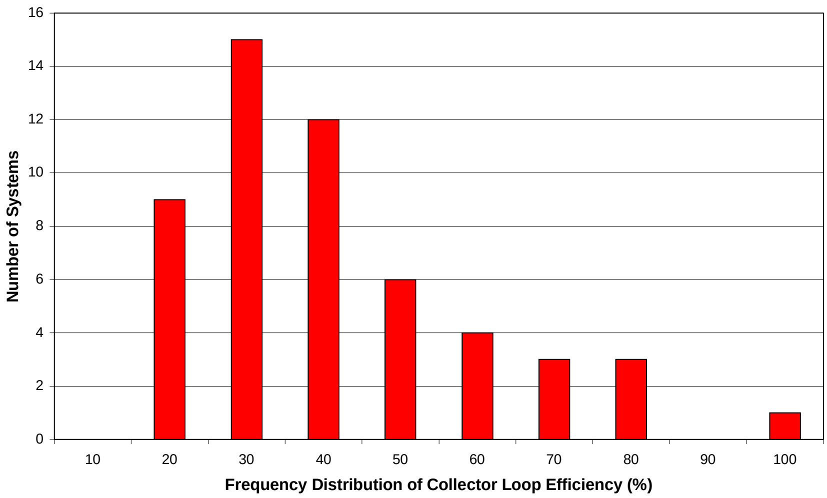


Figure 6: Frequency Distribution of Collector Loop Efficiency

Figure 7 shows the energy delivered by the ASH system to the storage cylinder. There was a large variation in the energy delivered by the collector to the storage cylinder – from 89 kWh.m^{-2}.yr^{-1} to 902 kWh.m^{-2}.yr^{-1}. It should be noted that the system delivering 89 kWh.m^{-2}.yr^{-1} was a façade mounted system and that the systems delivering 902 kWh.m^{-2}.yr^{-1} were average data from 6 low flow rate systems (0.003 l.m^{-2}.s^{-1}).

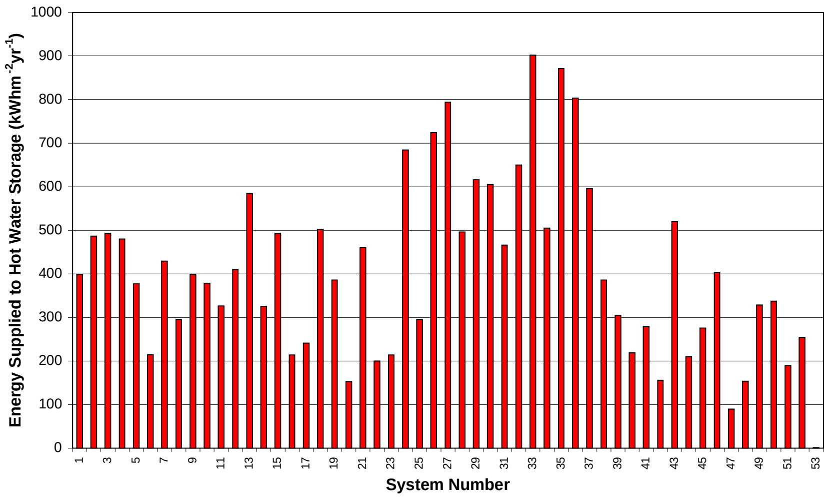


Figure 7: Energy Delivered by the ASH System to the Storage Cylinder

Figure 8 shows the ratio of collector area to storage tank volume. The values ranged from a low of 1.16 m^{-1} (System 43) to a high of 35.25 m^{-1} (System 25). System 43 was a large communal system in Sweden serving 48 apartments with a 740 m^2 collector area and a 640 000 litre storage volume. The system was also used to contribute to space heating requirements and had a solar fraction of 26 %. System 25 represents data from 2 retrofit systems on single dwellings in The Netherlands with comparatively larger collector areas of 4.23 m^2.

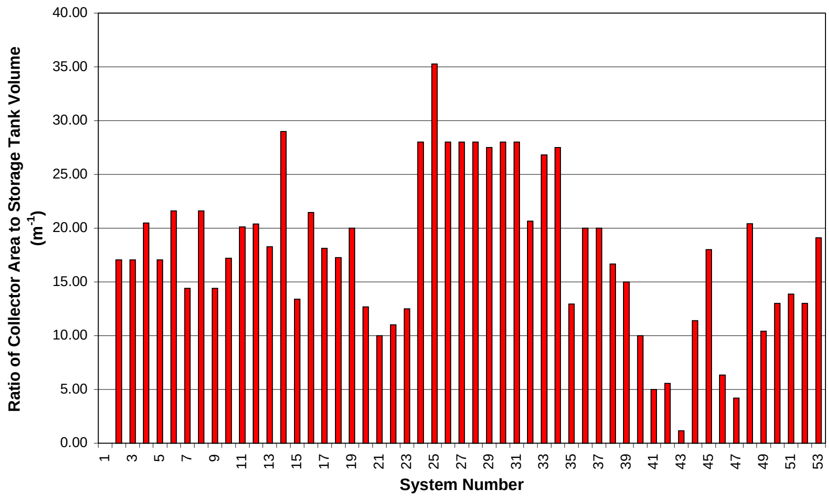


Figure 8: Ratio of Collector Area to Storage Tank Volume

Figure 9 shows the frequency distribution of the ratio of collector area to storage tank volume for single family residences only. The ratio was predominantly in the range of 15 m^{-1} to 30 m^{-1}, with the systems in stalled in The Netherlands in the 20 m^{-1} to 30 m^{-1} range.

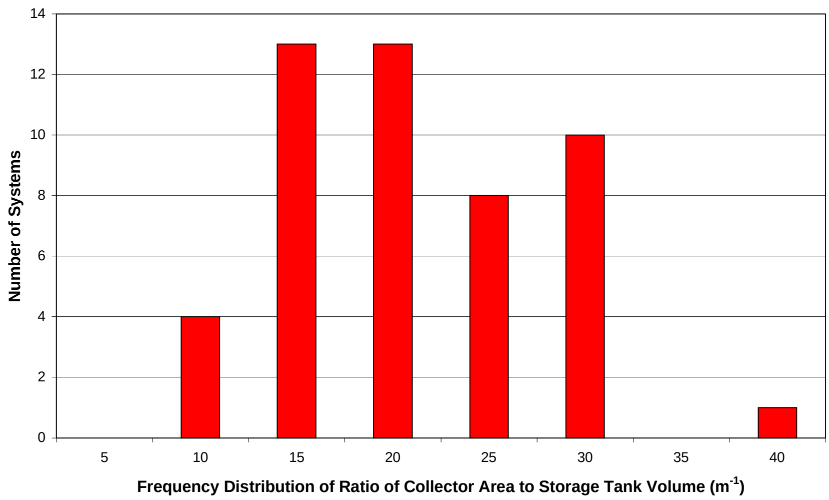


Figure 9: Frequency Distribution of Ratio of Collector Area to Storage Tank Volume

3.4.5 Potential for Performance Improvements and Cost Reductions

There are a number of areas for performance improvement of ASH systems and these have been dealt with in detail by Task 14 of the International Energy Agency's Solar Heating and Cooling Programme[10]. The key performance improvements were identified as involving being 'low' or 'matched' flow systems (2-4 $g.s^{-1}.m^{-2}$.). The report indicated that absorber design was one area where collector costs could be reduced – with low flow designs providing opportunities for absorber cost reduction. Costs of low-flow fin-tube absorbers could be reduced by reducing the amount of material necessary for the tubes and fins.

[10] 'Advanced Solar Domestic Hot Water Systems' William Duff, IEA SHCP Report T.14.DHW.1 (August 1996)

The main performance advantage of low-flow systems is due to extensive stratification in thermal storage, and storage design can affect stratification. An optimum solar storage system would have the following characteristics:

- solar storage tank volume should be sufficiently large (depending on solar fraction and economics)
- temperature differences in the tank should be equalised as slowly as possible
- the capacitance of the collector side heat exchanger should be sufficiently large (approx. 50 W.K^{-}1.m^{-2}).
- the storage should be carefully insulated and thermal bridges avoided in the upper part of the tank.

Low-flow systems also make the use of smaller diameter piping and even non-metallic flexible piping is a possibility, reducing both equipment and installation costs.

Cost reductions arising from the use of these 'dream systems' were estimated to be in the order of 18 % to 39 %.

3.4.6 Relevance of Data to UK

The performance data gathered was certainly relevant in the UK situation. As seen from Table 3 the annual global irradiation in the UK (Kew - 944 kWh.m^{-2}) is only slightly lower than in The Netherlands (Vlissingen – 991 kWhm^{-2}). The major differences in system design were largely in The Netherlands where a much smaller storage tank was used for a given collector area. The collector area in The Netherlands also tended to be lower than in the other countries. This has a number of implications for the system performance:

i. improved collector loop efficiency and increased energy delivered to the storage tank per m^2 collector area
ii. reduced solar fraction due to lower collector area and lower storage volume

The use of low flow systems suggested a much improved performance with a collector loop efficiency of nearly 93 % reported. The use of this system design would be easily implemented in the UK although further investigation should be undertaken in order to confirm these results and identify optimum flow rates.

Systems used in Sweden tended to use the ASH system to provide space heating in addition to supplying hot water to multiple residences. There is no technical reason why ASH systems cannot be used for this purpose in the UK although it is unlikely that this market would develop in the short term. The use of large scale systems supplying multiple residences per se is unlikely to find widespread application in the UK. Furthermore, the more temperate climate in the UK results in a shorter heating season and a longer cooling season in summer meaning that space heating applications are likely to be more limited than in Sweden.

Generally speaking, there is no reason as to why the different system designs seen in other Northern European countries, particularly those seen in The Netherlands cannot be replicated in the UK.

The implementation of a number of the design changes as suggested in the IEA Task 14 Report[10] should also be possible in the UK.

4. DISCUSSION

Performance data were collected from ASH systems in Denmark, Germany, The Netherlands and Sweden. The data were analysed to enable a comparison of the different systems. It was not possible to collect performance data from systems in the UK, partly due to the scarcity of such data and also due to the perceived confidentiality of such information. However, a number of solar water heating projects with detailed monitoring are currently in the design, construction or commissioning phase, and data should be more freely available in the near future.

There were difficulties encountered in analysing the data that were gathered from the systems installed in Denmark, Germany, The Netherlands and Sweden due to the differences in the monitoring regimes. Although monitoring guidelines for solar water heating systems exist[11], they are not prescriptive in what parameters should be monitored. As a result, the data were not necessarily comparable. In addition to the necessary climatic data, the energy produced by the solar water heater, the energy supplied by the backup system (conventional boiler) and the energy of the hot water used should be monitored thus enabling the determination of system losses. However, frequently only two of the three parameters were monitored, with the third calculated from the other two, meaning that losses are not accounted for. As real systems have losses which are not negligible, the data are less informative.

However, an analysis of the data obtained suggested significant differences in the performance of systems in the different countries. The energy delivered by the ASH systems to the storage systems per square metre of collector was twice as high in The Netherlands than the other countries as was the collector loop efficiency. However, the average solar fraction was much lower in the systems in The Netherlands.

One possible reason for this difference in performance is the ratio of collector area to storage tank volume tended to be much lower in systems in The Netherlands (average value of 26 m^{-1}), so that a typical 3 m^2 system would have a 120 litre storage cylinder, compared to 220 litres in the other countries. It must be noted that many factors influence the performance of an ASH system. One of these factors is the hot water usage pattern of the occupants. For instance, systems where most hot water is used in the afternoon will perform better than those where most of the water is used early in the morning. Unfortunately little data is available on usage profiles.

The size of systems also affects system performance. A system with a large solar fraction (i.e. a large proportion of a building's hot water requirements will be met by the solar water heating system) will typically produce more hot water than needed during the summer months, which will have a negative effect on the cost of hot water used. Systems in Sweden tended to be larger in terms of collector area as the systems were often designed to contribute towards both hot water and space heating requirements.

[11] D Gilliaert, A Landabaso, W B Gillett, P A Ruyssevelt: *Guidelines for the Assessment of Active and Passive Solar Technologies*, published by the Institute for Systems Engineering and Informatics, Joint Research Centre, European Commission

One key difference in systems design was also noted in The Netherlands and that was the use of drainback systems to protect against freezing in the collector. In the other countries the use of a water/glycol mixture was more commonly used.

5. CONCLUSIONS

- Performance data from ASH systems in Denmark, Germany, The Netherlands and Sweden have been collected and analysed although little data from the UK was available.

- Data gathered from the systems installed in Denmark, Germany, The Netherlands and Sweden were difficult to compare due to the differences in the monitoring regimes. No data was available on usage profiles.

- Analysis of data from retrofitted and new build systems showed there was little or no difference in the performance of these systems. Data on costs were insufficient to make a judgement as to whether there was a price difference between new-build or retrofitted systems.

- In the UK incorporating an ASH system in a new-build situation would mean that VAT was not payable on the system, thereby generating a 17.5 % cost saving.

- Most of the systems for which data were collected were flat plate collectors, with data for one evacuated tube collector only. It was not possible therefore to draw any conclusions as to any differences in performance of the collector types.

- Energy delivered by the ASH systems to the storage systems per square metre of collector was twice as high in The Netherlands than the other countries.

- Energy costs ranged between 34.5 cents per kWh and of 1.7 cents per kWh. The lowest energy costs were associated with the large installations.

- Little data were available on maintenance costs of the ASH systems. However, data were available for one system, and were estimated at 198.3 Euro per year (11 Euro per family per year) representing 0.6 % of the price of the installed system

- The collector loop efficiency in The Netherlands was typically double that seen in the other countries.

- The average solar fraction was much lower in the systems in The Netherlands possibly due to the use of smaller storage tanks.

- Systems in Sweden tended to be larger in terms of collector area as the systems were often designed to contribute towards both hot water and space heating requirements.

- One key difference in systems design was that drainback systems were used more commonly in The Netherlands whereas in other countries a water/glycol mixture was more often used.

6. FURTHER WORK

This project has highlighted some serious issues that need to be addressed regarding the performance monitoring of ASH systems. In particular, a recognised standard for the monitoring of these systems would be of considerable use given the difficulties in comparing the data in this project.

The lack of consistent and available data from the UK has caused some difficulties in the project. Although some data are likely to be made available in the near future, concerns still exist as to the standardisation of the monitoring programmes. It is recommended that a detailed monitoring campaign of ASH systems is undertaken to provide detailed and accurate information on the performance of these systems.

There are a number of software tools available for the simulation of ASH systems performance with different tools offering a range of different simulation options. The difficulty of selecting a suitable software tool for the accurate simulation of ASH system performance has been noted and it would be of benefit if the evaluation and validation of existing tools were to be considered.

Annex I:

List of monitored parameters

Desired monitored parameters for the evaluation of solar collector system performance

The Joint Research Centre of the European Community has published *Guidelines for the Assessment of Active and Passive Solar Technologies* (1992). This document recommends that the following parameters are derived from monitoring an active solar system:

1. Minimum requirements

1. Useful solar output

The useful energy delivered to the load by the active solar system.

2. Normalised useful solar output

The useful energy delivered by the active solar system per unit area of collector absorber / aperture area. May be compared on a monthly mean daily or annual basis.

3. Solar fraction

The ratio of the total useful solar output to the total load.

2. Additional requirements

1. Solar utilisation factor

The ratio of normalised useful solar output to the solar irradiation on the collector plane.

2. Efficiency of auxiliary heating system

The ratio of useful auxiliary energy delivered to the load, to the energy consumed by the auxiliary heater.

3. Parasitic energy consumption

The energy consumed by any pumps and fans which are needed to operate the solar collector and storage system.

3. Basic monitoring installations

From the above recommendations, it can be deduced that the following parameters should be monitored.

1. Useful solar input is the heat energy supplied to the preheat / main storage cylinder. This quantity can be normalised if the dimensions of the solar collector are known. A flow meter and two temperature sensors are required for this measurement. The flow meter measures the volume of water supplied to the cylinder, and the temperature sensors measure the temperature at the feed and return of the heat exchanger to the cylinder. All sensors should be mounted as close as possible to the cylinder. From these measurements, the heat energy delivered can be calculated. It is possible to purchase heat meters which combine all these functions.

2. The solar fraction is derived from the heat energy delivered to the storage cylinder from both the solar collector and the auxiliary heater, and the total heat load, including distribution losses, drawn from the tank. These parameters are all measured as described above. In order to calculate the solar fraction accurately, and to account for the losses in the system, it is necessary to monitor all three parameters separately. In many cases, however, only two of the parameters are monitored, and the losses are assumed.

4. Additional monitoring installations

In order to monitor the factors of secondary importance it is necessary to measure the following:

1. Solar irradiation in the plane of the collector. This should preferably be measured with a thermopile type device, although cheaper silicon devices are frequently used.
2. Efficiency of the auxiliary heating system can also be measured by monitoring fuel input to energy output ratio, although this is not necessary for evaluation of the solar system.
3. Parasitic energy consumption can be measured using an energy meter across any pumps used to pump water around the solar collector circuit.

5. Summary of desired parameters for system evaluation:

- Heat energy delivered by solar collector (as a function of temperature and flow measurements)
- Heat energy delivered by auxiliary heater
- Heat energy consumed by load (including losses)

At least two of the above must be measured, and additionally the following:

- Solar irradiation in the plane of the collector
- Energy consumed by the solar system (e.g. to drive pump)

Annex II:

List of UK contacts & possible data-sources

No.	Organisation	Description	Data?
1	AES	STA member. Know of some individuals doing quite accurate monitoring in Scotland. Time constraint.	Maybe
2	Augusto Constructions	About to install ASH system in large new-build housing estate site. No data available at the point of analysis to include in this study.	Maybe
3	Bredondale Solar	STA member. Data was not obtainable.	No
4	Bristol EcoHome	Demonstration project for Renewable energy and passive solar designs used only for educational purposes - the house is not lived in. The ASH system has been monitored for 4 months.	Maybe
5	Bristol Energy Centre	Monitoring of the Thermie LEINH (Low Environmental Impact New Housing) system - Rockingham Gardens (44 social housing properties) - solar preheating of communal domestic hot water, using 20 m2 collector. The performance of the systems is very low - (20m2 of collectors with a total output 500kWh). Great discrepancy was expressed in the use and reliability of the data.	Maybe
6	Cardiff University	There were quite a few monitored systems around 10 - 20 years ago, but at present there is no monitoring being carried out (except for the STA project).	No
7	CAT	ASH system installed but no monitoring included.	No
8	Construction Resources / Ealing Family HA	27 monitored domestic ZEN systems in Caversham Reading. THERMIE funded. Monitoring started in Winter 1998. Not possible to obtain data for confidentiality reasons.	Maybe
9	Derby Area Technology Association (DATA)	Monitoring ASH on Grove House. Block of sheltered accommodation using 7* Filsol and 5*NEG collectors. System installed in Nov 97 and finally commissioned in Mar 98. Also mentioned Chesterfield Council doing similar project. Some monitored data is available but there are gaps in data and offsets that need to be determined. In addition, limited parameters are available.	Maybe
10	Ealing Family	SUNH project. Some data but difficulty in obtaining it.	Maybe
11	ECD Energy and Environment	Have created Ecodatabase on behalf of Housing Corp. Eco database useful information on ASH installations in UK.	No
12	Energy Engineering	STA member. No automatic data collection conducted.	No
13	European Housing Ecology Network co-ordinator	Involved in setting up Hastoe project. Links in with Thermie Sun Shine Project.	No
14	Fieldway Ltd	STA member	No
15	Filsol	STA member. Suggested STA study - and would recommend ETSU that this data is made available to ITP.	No
16	Guinness Housing Trust	Involved in Rockingham House THERMIE project, Bristol (Hastoe gave us contact) - contact Bristol Energy Centre for monitoring details.	No
17	Gwalia HA	Thermie funded. Not roof-integrated, UWCC are managing a survey of tenants, and were planning to start monitoring the systems. No data is available at present.	Maybe
18	Hastoe Housing Association	Thermie European Housing Ecology Network project. 10 houses in Milton Keynes all monitored, just started. Linked with Hull (sheltered housing) and Swansea (Gwalia) in UK and 8 others in Europe.	Maybe
19	Hyde Housing Association	SHINE project - refurbishment of two Victorian terraced households and one Edwardian house and a number of houses in Greenwich. Domestic hot water to be preheated by ASH. Just started, no data is available at present.	Maybe
20	IT Power	Thermie project. New-build systems installed in Spring/Summer 1997 in Wales, 8 monitored properties but due to commissioning difficulties data collection started in February 1999. Monitoring will record solar radiation, heat energy from solar collector and auxiliary heat source, heat energy to load and parasitic consumption of solar system.	Maybe
21	Kingfisher Housing Association	Purchasing existing property and retrofit with environmental features, including solar panels, cavity and roof insulation, low E double glazing, condensing boiler, TRVs, super cal cylinder etc. The aim of the house is to encourage council residents to adopt similar measures and then let the property when completed.	Maybe
22	Leicester City Council	Have installed two different systems on Council Buildings. Monitored data available (manually logged) but extreme difficulties in obtaining it.	Maybe
23	Liverpool John Moores Uni	Monitoring a ASH project in Liverpool. Just started, no data available at present.	Maybe
24	Low Energy Architecture Research Unit (LEARN)	School of architecture and interior design, University of North London - involved in SHINE. No data available.	No

No.	Organisation	Description	Data?
25	North British HA	Eastbourne, Gateshead and Hull Thermie funded projects (EHEN) with monitored ASH systems on new-build housing estates. Gateshead project is complete, uses Danish equipment Dansk Solvarm, however the performance is poor. Data available however not obtained prior to analysis phase of project.	Maybe
26	Oxford Solar House	Demonstration of PV / solar thermal systems. No monitoring is conducted.	No
27	Rayotec	Distributor for Thermomax and Seeboard. STA member. Data from users of Thermomax evacuated tubes, monitored as part of Seeboard project. Data is available, but this is taken manually by the users. Rayotec / Thermomax currently developing automatic data acquisition as part of solar system. To begin installation of these in Summer 1999. Data at present not available.	Maybe
28	Riomay	Supplier / installer of Nippon Electric Glass evacuated Tubes and flat plate systems. STA member. Do not have any data available.	No
29	Seeboard	Utility installing ASH, offer discount for monitoring. Use Thermomax, annual sales around £0.75 million. See Rayotec. No data is available at present.	No
30	Sevenoaks District Council	Carried out comparison of Thermomax with Hitachi Evacuated Tubes. Latter shown to be better; no data is however available.	No
31	Solagen	STA member. No electronically monitored systems. No data available.	No
32	Solanne	STA member. Difficulty in contacting.	No
33	Solar Store	STA member. No monitoring of systems.	No
34	Solarsense	STA member. Difficulty in contacting.	No
35	Solarworks	STA member. Some manually monitored systems, kcal, and temperatures of evacuated tube systems.	Maybe
36	Sovereign Housing Association	Part of SUNH SHINE project. No data is available at present.	Maybe
37	Spectrum	Installer / distributor of Sunda Solartechnik. About 6-7000 systems were installed in 1998, with £2m turnover, some of which are monitored. No data was obtained.	No
38	STA	4 systems, various designs and sites, all monitored: Filsol, Thermomax, AES…not Riomay. One year of data is available, but some monitoring problems have been encountered, and so data could not be made available.	Maybe
39	Summersun Solar	STA member. Manual measurement of temperatures: collector, tank, return and basic weather description could be made available.	Maybe
40	Sunmaster Ltd	STA member. Data was not obtained.	No
41	Sustainable Homes	Network of Housing Association working on sustainability issues. Publish HA Newsletter - with lots of sustainable energy articles. May be able to supply details of monitored systems in Scotland. No data was available.	No
42	The City Council of Bristol	LEINH (Low Environmental Impact New Housing). Co-ordinator of project. The Bristol site is called Rockingham and Wintour Phase I comprising 44 dwellings. Solar preheating of communal domestic hot water. Bristol Energy Centre responsible for monitoring.	No
43	The Energy Conservation and Solar Centre	Charity, provides advice on energy efficiency and RETs. No data was available.	No
44	Thermomax	German consumer test results. STA member. No raw data was available.	No
45	TJC Central Htg	STA member. Difficulty in contacting.	No
46	Wessex Solar Systems	STA member. Difficulty in contacting.	No
47	West Wales EcoCentre	Demonstration centre for PV RE systems. No ASH panels on the Ecocentre. No data available.	No
48	WS Atkins	OAP home, monitored performance of evacuated tubes revealed high efficiency but poor payback. Data was provided but concern on data reliability.	Maybe

Annex III:

List of European contacts & possible data-sources

No.	Organisation	Description	EU	Data?
1	NEF	European Solar Clubs project: survey of ASH systems in Austria. No data was available.	Austria	No
2	Esbensen Consultants	Technical co-ordinators of EC2000 project (Energy Comfort 2000) and also involved in the SHINE project (Thermie funded), for which they are monitoring a large roof-integrated system but in France, but this has only just started.	Denmark	Maybe
3	Cenergia Energy Consultants	Danish consultancy, leading Thermie Housing Ecology Network. Technical partners of the Green Cities project. Involved in SUNH Shine project. Provided data for one system in Denmark but due to time constraints, on their side, could not disclose more datafiles.	Denmark	Yes
4	EBO Consult	Referred to by EHEN. No response obtained.	Denmark	No
5	Lillevangsvej - Farum	SHINE - project will create 67 terraced houses. The energy savings for space heating is estimated to be 48% with a total predicted annual energy saving for a typical house of 40%. No monitoring data available.	Denmark	Maybe
6	Danish Technology Institute	Danish institute with evaluated performance results from 25 small domestic ASH systems. At present they have also just began monitoring 28 district solar hot water systems in Denmark, the monitoring started in January 1999 and will run for the full year 1999. Datafiles for 16 domestic ASH systems were provided.	Denmark	Yes
7	Helsinki University of Technology	Advanced Energy Systems. Difficulty in obtaining data.	Finland	No
8	VTT Building Technology	Referred to by EHEN. No reply.	Finland	No
9	ATT	Development of 46 units in one 4-storey apartment and 2 storey houses. A Finnish developed new generation of modular flat plate collectors will be demonstrated on the buildings. Just started. Not enough data was available at the point of analysis to include in this study.	Finland	Maybe
10	Synopsis	French consultancy involved in ASH. No monitoring data was available.	France	No
11	Archimedes	Co-ordinator of the SHINE project, SUNH (Solar Urban New Housing) and EC-2000. Difficulty in obtaining response. Not enough data was available at the point of analysis to include in this study.	France	Maybe
12	OPALE	SHINE - 2 social housing sites - 262 apartments. Solar collector on one building site (100m2). Data was unobtainable.	France	Maybe
13	Stuttgart Hochschule fuer Technik	Mostly laboratory solar monitoring (Dynamic tests).	Germany	No
14	BIG Heimbau AG	SHINE - 80 apartments to be refurbished. Solar collectors to preheat domestic hot water. Not enough data was available at the point of analysis to include in this study.	Germany	Maybe
15	Landeshauptstadt Hannover	EXPO Cities (Extensive Energy Planning of Cities). Partners include Portugal, Germany, Spain and The Netherlands. Active solar heating component.	Germany	Maybe
16	Institut für Thermodynamik und Wärmetechnik	German University, monitoring large district heating type projects. Monitoring conducted under laboratory conditions and simulation of performance.	Germany	Maybe
17	Technische Universität Dresden	German University which conducts monitoring of domestic / district heating / hotel systems in the field. Data is received.	Germany	Yes
18	Ennos GmbH, Germany (supply monitoring systems for ASH)	German monitoring company specialises in equipment for solar systems. Supply monitoring systems for ASH. No monitoring data was obtainable.	Germany	No
19	FhG – ISE	German R&D consultancy, with solar monitoring experience. One project, involved detailed monitoring of a domestic system installed in the last 4-5 months, but the house is not fully occupied therefore the results are not really valid at present. Other projects have only looked at the total annual sums of heat delivered and consumed, no data for solar radiation and information on user behaviour were recorded. Recommended that the data available would not be sufficient for evaluation of system performance.	Germany	Maybe
20	IST	German R&D organisation have monitored small ASH systems. Data was not obtainable.	Germany	No
21	ERG - UCD	No monitored systems in Ireland. Was involved in European Performance Monitoring Group for ASH and passive solar. But data is now outdated.	Ireland	No
22	ESAS, JRC Ispra	Has been involved in telemonitoring of ASH systems, will probably know what happens to all the THERMIE data. Contact could not provide useful information.	Italy	No
23	GASA Architects	Referred to by EHEN. No reply obtained.	Norway	No
24	SOLFORSK	Norwegian Solar Energy Research Centre, has done some ‘field testing’ of active solar. Data unobtainable.	Norway	Maybe
25	Solarnor	Installers and manufacturers of ASH systems. Could not disclose data for confidentiality reasons.	Norway	Maybe

No.	Organisation	Description	EU	Data?
26	Tirone Nunes	Hastoe project - involved in the technical side of things - referred by European Housing Ecology Network. Monitoring data only for Portugal.	Portugal	No
27	Chalmers University of Technology	Swedish Monitoring Energy Research Group. Provided datafiles for 16 systems in Sweden.	Sweden	Yes
28	Swedish Council for Building Research	Difficulty in contacting.	Sweden	No
29	Promandat	Swedish consultancy - possible contacts. Difficulty in contacting.	Sweden	No
30	Chr N Arkitektkontor AB	Referred to by EHEN. No response was obtained.	Sweden	No
31	Garsdens Bostader	SHINE project - 255 apartments, contained within 10 buildings will be refurbished. Prefabricated roof integrated modular solar collector will be used. Refurbishment to be completed late 1999. No monitoring data available at present.	Sweden	Maybe
32	ZW Energiteknik	Swedish energy consultancy / installer of solar systems. Difficulty in contacting.	Sweden	No
33	National Testing & Research Institute	Conducted tests on DHW-system under laboratory conditions. In 1992 tested 6 systems for 1 family house and in 1998 tested 6 small systems for summer houses. From these tests predictions of yearly and seasonal performance were calculated using system simulations. The same goes for a field study we did in 1993 where 60 small solar systems were studied (but not measured). Reports only available in Swedish.	Sweden	Maybe
34	Patrimonium	High rise building with 384 apartments - communal heating system - solar boiler with 760m2 of collector area - largest solar system mounted in Europe. The solar boiler will provide at least 15% of total energy demand for both DHW and space heating. Monitoring just started. Data not available at present.	The Netherlands	Maybe
35	Novem	Dutch Agency for Environment & Energy. Data could not be obtained.	The Netherlands	No
36	Ecofys	Dutch consultancy leading large-scale solar THERMIE project in Holland, UK, Belgium and Germany. Provided results for 132 systems in The Netherlands.	The Netherlands	Yes

Annex IV:

Questionnaire

ACTIVE SOLAR HEATING PERFORMANCE REVIEW
QUESTIONNAIRE TO PROJECT MONITORING STAFF

SYSTEM REFERENCE / LOCATION ……………………………………………

Questionnaire completed by ……………………………………………………..

1. What is the application type?

New-build or Retrofit

Domestic (residential) -> Single family (per building)
Multi-family (per building)

If multi-family, specify number of families ………………………………..

Single installation or Multiple installations

If multiple installations, specify number of houses ………………………………..

Hotel
School
Restaurant
Offices
Other (describe) ……………………………………………………..

Further details
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………………………………………………………………….

2. Total irradiation in the plane-of- collector over time period studied

…………………………

3. Total energy consumed for hot water heating…………………………

4. Solar fraction (unless supplying data necessary to calculate this)

…………………………..
– please specify how this is calculated,
– i.e. are system losses assumed to be negligible?, is the annual solar fraction derived from Dynamic System Testing?, etc

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………

5. Installed system cost (specify currency) ………………………….

6. Collector area ………………………….

7. Collector type & manufacturer ………………………

8. Storage tank volume………………………

9. Number of storage tanks ………………………

10. Collector orientation (azimuth) ………………………

11. Collector loop flow rate………………………

12. Pumped / thermosyphon system (delete as appropriate)

13. Freeze protection by drainback / glycol (delete as appropriate)

14. Auxiliary fuel type………………………

15. Year of installation………………………

16. Maintenance costs and requirements (if available, specify currency)

………………………

……
……
……
…………………………

17. Data on usage patterns (if available) ………………………

……
……
……
…………………………

18. Any other information
……
……
……
……
…………………………………………………………………………………………………

Annex V:

Datafiles in Table format

ASH - PERFORMANCE OF ACTIVE SOLAR HEATING IN NORTHERN EUROPE

	1	2	3	4	5	6	7	8	9	10
Country	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**
Data from	Internet	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Cenergia
System Reference	Marstal, Large Scale	DK3450	DK4050	DK8963	DK6100	DK2670	DK4534	DK4190	DK7800	-
Manufacturer	Ar-Con Solarheat HT	Ar-Con Solvarme	Ar-Con Solvarme	Ar-Con Solvarme	Ar-Con Solvarme	Batec Solvarme	Batec Solvarme	Batec Solvarme	Batec Solvarme	Batec
Collector type	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate
Collector area [m2]	8064	5.12	5.12	5.12	5.12	6.48	4.32	6.48	4.32	55
New build/Retrofit	New build	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit
Domestic/Single/Multiple	Solar District Heating	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Multi family
Single/Multiple installation	Large Scale	Single	Single	Single	Single	Single	Single	Single	Single	Single
No.HH/Flats/ca.	District	1	1	1	1	1	1	1	1	18 flats
Irradiation (kWh/m2/year)	1032	1263	1277	1236	1208	1277	1277	1254	1277	1150
Energy Hot Water (kWh/yr)	3213000	2493	2525	2457	1930	1390	1855	1916	1723	20819
Energy Hot Water (kWh/m2/yr)	398	487	493	480	377	215	429	296	399	379
(Collect. area / Storg. tank vol.) [m-1]		17.07	17.07	20.48	17.07	21.60	14.40	21.60	14.40	17.19
Solar fraction (SF) [%]	11.7	63	63	52	51	83	64	77	89	52
Collector loop efficiency [%]	38.61	38.55	38.62	38.83	31.20	16.80	33.63	23.58	31.23	27.00
Storage tank volume [litre]	33600	300	300	250	300	300	300	300	300	3200
No. of storage tanks	1	1	1	1	1	1	1	1	1	2
Collector orientation	south, 40°	south	South	south	south	South	south	south-south east	south-south east	south
Coll. loop flow rate [l/m2/s)]	not measured	not measured	not measured	not measured	not measured	not measured	not measured	not measured	not measured	0.0083
Pumped, thermosyphon	n/a	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped
Freeze protection	n/a	glycol	glycol	glycol	glycol	glycol	glycol	glycol	glycol	glycol
Auxiliary fuel type	Diesel	Natural gas/electricity	Biomass/Electricity	Electricity	Natural gas/electricity	Oil burner/electricity	Electricity	Electricity	Oil Burner/Electricity	District Heating
Year of installation	Nov. 1996	1990	1990	1991	1991	1990	1990	1990	1991	1996
Data on usage patterns	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Installed system costs	2,72 million Euros. Excl. VAT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	34,230 Euros (including VAT) (includes collectors, storage tank, pipes and control system)
Maintenance costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	198.3 Euro/year
How is SF calculated	energy hot water / district heating	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	Includes heat losses at 60%.
Any other information	Produced heat app. 0.25 Dkr per kWh; Measured Data from 1998; added 150 kW diesel driven generator system	Data from 1995. Electrical heater integrated in the solar tank.	Electrical heater integrated in the solar tank	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank. Little slope 25degrees. Cover of polycarbonate	Data from 1995 - Electrical heater integrated in the solar tank	Data from 1995. Electrical heater integrated in the solar tank. Electrical heater and sensor have been replaced.	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank.	Central solar system for domestic hot water - the average monitored hot water is 63 litres/day per flat. 2 m3 & auxiliary tank 1.2 m3

ASH - PERFORMANCE OF ACTIVE SOLAR HEATING IN NORTHERN EUROPE

	11	12	13	14	15	16	17	18	19	20
Country	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Denmark**	**Germany**	**Germany**
Data from	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Danish Tech. Inst.	Tech. Uni Dresden	Tech. Uni Dresden
System Reference	DK4700	DK4160	DK4720	DK9760	DK9293	DK5771	DK5871	DK6580	K, Dresden	La, Dresden
Manufacturer	Suntake	Ans Solvarme	Aidt Miljø A/S	Aidt Miljø A/S	Dansk Solvarme	Djurs Solvarme	Aidt Miljø A/S	Elysia ApS	Paradigma	n/a
Collector type	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	CPC tubes
Collector area [m2]	6.03	5.2	3.84	7.68	4.02	5.9	4.8	4.83	10	3.8
New build/Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit
Domestic/Single/Multiple	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Multi family	Domestic/ Multi family
Single/Multiple installation	Single	Single	Single	Single	Single	Single	Single	Single		
No.HH/Flats/ca.	1	1	1	1	1	1	1	1	6 HH	3 HH
Irradiation (kWh/m2/year)	1272	1277	1277	1249	1239	947	1254	1249	1177	1008
Energy Hot Water (kWh/yr)	1967	2133	2244	2501	1982	1260	1158	2423	3860	580
Energy Hot Water (kWh/m2/yr)	326	410	584	326	493	214	241	502	386	153
(Collect. area / Storg. tank vol.) [m-1]	20.10	20.39	18.29	28.98	13.40	21.45	18.11	17.25	20.00	12.67
Solar fraction (SF) [%]	55	59	47	60	78	74	67	61	60	33
Collector loop efficiency [%]	25.64	32.12	45.76	26.07	39.79	22.55	19.24	40.16	32.80	15.14
Storage tank volume [litre]	300	255	210	265	300	275	265	280	500	300
No. of storage tanks	1	1	1	1	1	1	1	1	1	1
Collector orientation	south	south	south	south	south-south west	West	south-south east	south	south, 45°	south, 45°
Coll. loop flow rate [l/m2/s)]	not measured	not measured	not measured	not measured	not measured	not measured	not measured	not measured	0.0139	0.0139
Pumped, thermosyphon	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped	Pumped
Freeze protection	glycol	glycol	glycol	glycol	glycol	glycol	glycol	glycol	glycol	glycol
Auxiliary fuel type	Oil burner	Electricity	Oil burner/electricity	Biomass/Electricity	Natural gas/electricity	Oil Burner/Electricity	Electricity	Oil Burner/Electricity	Natural Gas	Natural Gas
Year of installation	1990	1990	1990	1991	1991	1991	1991	1991	1997	1998
Data on usage patterns	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	250 l/d	101 l/d
Installed system costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	9202 Euros Excl. VAT	4003 Euros Excl. VAT
Maintenance costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
How is SF calculated	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load	energy supplied to the tank from collector circuit/load		
Any other information	Data from 1995	Data from 1995. Electrical heater integrated in the solar tank. The system has been boiling twice during the summer. Some shadow on the collectors	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank.	Data from 1995. Electrical heater integrated in the solar tank.	Energie hot water without losses; System is operating successfully	Energie hot water without losses; shade in the morning; data monitored from 5/98 - 4/99

ASH - PERFORMANCE OF ACTIVE SOLAR HEATING IN NORTHERN EUROPE

	21	22	23	24	25	26	27	28	29	30
Country	**Germany**	**Germany**	**Germany**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**
Data from	Tech. Uni Dresden	Tech. Uni Dresden	Tech. Uni Dresden	Ecofys	Ecofys	Ecofys	Ecofys	Ecofys	Ecofys	Ecofys
System Reference	St, Dresden	Le, Dresden	W, Dresden	LZE 60	LZE 4	LZE 14	ZEN 60	ZEN 14	Woudhuis (ZEN II)	INV 60
Manufacturer	Mazdon	n/a	n/a	Luigjes Zonne-energie	Luigjes Zonne-energie	Luigjes Zonne-energie	Zonne-energie Netherlands	Zonne-energie Netherlands	Zonne-energie Netherlands	Inventum
Collector type	ETC	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate
Collector area [m2]	5	2.2	10	2.8	4.23	2.8	2.8	2.8	2.75	2.8
New build/Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	New build	Retrofit
Domestic/Single/Multiple	Office/Single	Domestic/ Multi family	Domestic/ Multi family	Domestic/Single Family	Single	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family
Single/Multiple installation				Multiple (24 collectors)	Multiple (2 collectors)	Multiple (7 collectors)	Multiple (22 collectors)	Multiple (4 collectors)	Multiple (25 collectors)	Multiple (9 collectors)
No.HH/Flats/ca.	1	2 HH	3 HH	3.7 ca./HH	4.5 ca./HH	4.4 ca./HH	4.1 ca./HH	4.0 ca./HH	3.3 ca./HH	3.3 ca./HH
Irradiation (kWh/m2/year)	996	1009	855	1111	1138	1083	1083	1111	1028	1138
Energy Hot Water (kWh/yr)	2300	440	2136	1917	1250	2028	2222	1389	1694	1694
Energy Hot Water (kWh/m2/yr)	460	200	214	685	296	724	794	496	616	605
(Collect. area / Storg. tank vol.) [m-1]	10.00	11.00	12.50	28.00	35.25	28.00	28.00	28.00	27.50	28.00
Solar fraction (SF) [%]	82	38	31	43	67	49	30	41	51	32
Collector loop efficiency [%]	46.18	19.82	24.98	61.61	25.97	66.87	73.28	44.65	59.94	53.18
Storage tank volume [litre]	500	200	800	100	120	100	100	100	100	100
No. of storage tanks	1	1	1	one tank per collector	one tank per collector	one tank per collector	one tank per collector	one tank per collector	one tank per collector	one tank per collector
Collector orientation	south, 55°	south, 45°	south, 45°	South - elevation 40°	South - elevation 40°	South - elevation 40°	South - elevation 40°	South - elevation 40°	South - elevation 40°	South - elevation 40°
Coll. loop flow rate [l/m2/s)]	0.0139	0.0139	0.0139	0.0198	0.0131	0.0198	0.0198	0.0198	first 4 minutes 0.02 , then .01	0.0198
Pumped, thermosyphon	Pumped	Pumped	Pumped	pump control	pump control	pump control	pump control	pump control	pump control	pump control
Freeze protection	glycol	glycol	glycol	drain back	drain back	drain back	drain back	drain back	drain back	drain back
Auxiliary fuel type	Natural Gas	Natural Gas	Natural Gas	Electricity/Natural Gas	Natural Gas	Electricity/Natural Gas	Electricity/Natural Gas	Electricity/Natural Gas	Natural Gas	Electricity
Year of installation	1998	1998	1997	1991	1991	1991	1991	1991	1994/95	1991
Data on usage patterns	75 l/d	69 l/d	334 l/d	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Installed system costs	6135 Euros Excl. VAT	2301 Euros Excl. VAT	7413 Euros Excl. VAT	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl
Maintenance costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
How is SF calculated				solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water
Any other information	Energie hot water without losses; System is operating successfully; data monitored from 5/98 - 4/99	Energie hot water without losses; high rate of dirt accumulation on the collector; data monitored from 5/98 - 4/99	Energie hot water without losses; problems with regulation; data monitored from 6/98 - 4/99							

ASH - PERFORMANCE OF ACTIVE SOLAR HEATING IN NORTHERN EUROPE

	31	32	33	34	35	36	37	38	39	40
Country	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**The Netherlands**	**Sweden**	**Sweden**	**Sweden**
Data from	Ecofys	Ecofys	Ecofys	Ecofys	Ecofys	Ecofys	Ecofys	Chalmers University	Chalmers University	Chalmers University
System Reference	INV 14	Solahart	Aton	Woudhuis (ZEN I)	Solistor	Solution 2	Solution 1	TTE1	TT4	TT12
Manufacturer	Inventum	Solahart	Aton	Agpo/ZEN	Solistor	Solution	Solution	Tekno Term ST	Tekno Term ST	Tekno Term ST
Collector type	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate
Collector area [m2]	2.8	3.72	2.68	2.75	2.2	2.8	1.4	5	7.5	15
New build/Retrofit	Retrofit	Retrofit	Retrofit	New build	Retrofit	New build	New build	Retrofit	New build	Retrofit
Domestic/Single/Multiple	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domestic/ Single family	Domest./Singl.fam.(4Pers.	Domest./Singl.fam.(4Pers.	Domest./Singl.fam.(4Pers.
Single/Multiple installation	Multiple (2 collectors)	Multiple (4 collectors)	Multiple (6 collectors)	Multiple (14 collectors)	Multiple (8 collectors)	Multiple (3 collectors)	Multiple (2 collectors)	Single	Single	Single
No.HH/Flats/ca.	3.0 ca./HH	4.0 ca./HH	3.2 ca./HH	3.3 ca./HH	3.6 ca./HH	3.8 ca./HH	1.6 ca./HH	1	1	1
Irradiation (kWh/m2/year)	1138	944	972	1056	1111	1111	1139	1090	1120	1085
Energy Hot Water (kWh/yr)	1306	2417	2417	1389	1917	2250	833	1929	2289	3286
Energy Hot Water (kWh/m2/yr)	466	650	902	505	871	804	595	386	305	219
(Collect. area / Storg. tank vol.) [m-1]	28.00	20.67	26.80	27.50	12.94	20.00	20.00	16.67	15.00	10.00
Solar fraction (SF) [%]	42	32	36	55	39	20	12	45	56	64
Collector loop efficiency [%]	40.97	68.82	92.77	47.83	78.42	72.33	52.26	35.39	27.25	20.19
Storage tank volume [litre]	100	180	100	100	170	140	70	300	500	1500
No. of storage tanks	one tank per collector	one tank per collector	one tank per collector	one tank per collector	one tank per collector	one tank per collector	one tank per collector	1	1	1
Collector orientation	South - elevation 40°	South - elevation 40°	South - elevation 40°	South - elevation 40°	South, 45°	South, 30°	South, 30°	45°/180°	25°/135°	30°/230°
Coll. loop flow rate [l/m2/s)]	0.0198	not measured	0.003	first 4 minutes 0.02 , then .01	not measured	not measured	not measured	not measured	not measured	not measured
Pumped, thermosyphon	pump control	thermosyphon	pump control (low flow)	pump control	integrated collector storage	integrated collector storage	integrated collector storage	n/a	n/a	n/a
Freeze protection	drain back	glycol	drain back	drain back	drain back	drain back	drain back	n/a	n/a	n/a
Auxiliary fuel type	Electricity	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	n/a	n/a	n/a
Year of installation	1991	1993	1994	1994	1996	1996	1996	n/a	n/a	n/a
Data on usage patterns	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Installed system costs	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	average installed system costs for individually installed solar systems in existing buildings were 5.000 to 6.000 Fl	n/a	n/a	n/a
Maintenance costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
How is SF calculated	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar energy effectively added to water/total energy consumption for hot water	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)
Any other information									(preheating), heater integrated in the solar tank	space heating, heater integrated in the solar tank

ASH - PERFORMANCE OF ACTIVE SOLAR HEATING IN NORTHERN EUROPE

	41	42	43	44	45	46	47	48	49	50
Country	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Sweden**
Data from	Chalmers University	Chalmers University	Chalmers University	Chalmers University	Chalmers University	Chalmers University	Chalmers University	Chalmers University	Chalmers University	Chalmers University
System Reference	TT14	TT19	Särö	Lunden	S9	S13	S3	S14	BS5	BS6
Manufacturer	Tekno Term ST	Tekno Term IT	Teckno Term AB	Teckno Term AB/ Derome Trä AB	Solsam HT3	Solsam HT2	Solsam HT2	Solsam HT2	Lesol 3	Lesol 3
Collector type	Flat plate	Flat plate	Flat Plate - Teckno Term with acrylic cover	Flat Plate	Flat plate	Flat plate	Flat plate, on Façade	Flat plate	Flat plate	Flat plate
Collector area [m2]	10	15	740	205	5.4	1.9	11.5	15.3	5.2	10.4
New build/Retrofit	Retrofit	New build	New build	New build	New build	New build	Retrofit	New build	New build	New build
Domestic/Single/Multiple	Domest./Singl.fam.(4Pers.	Domest./Singl.fam.(4Pers.	Domestic/ Multi family	Domestic/ Multi family	Domest./Singl.fam.(4Pers.	Domest./Singl.fam.(3Pers.	Domest./Singl.fam.(4Pers.	Domest./Singl.fam.(2Pers.	Domest./Singl.fam.(3Pers.	Domest./Singl.fam.(5Pers.
Single/Multiple installation	Single	Single			Single	Single	Single	Single	Single	Single
No.HH/Flats/ca.	1	1	48 apartments	36 apartments	1	1	1	1	1	1
Irradiation (kWh/m2/year)	1080	1098	1075	1107	1132	1134	625	1133	1110	1137
Energy Hot Water (kWh/yr)	2796	2333	384800	43100	1488	767	1026	2345	1710	3510
Energy Hot Water (kWh/m2/yr)	280	156	520	210	276	404	89	153	329	338
(Collect. area / Storg. tank vol.) [m-1]	5.00	5.56	1.16	11.39	18.00	6.33	4.18	20.40	10.40	13.00
Solar fraction (SF) [%]	61	49	26	62	35	23	23	79	50	65
Collector loop efficiency [%]	25.89	14.17	12.40	23.00	24.34	35.60	14.27	13.53	29.63	29.68
Storage tank volume [litre]	2000	2700	640000	18000	300	300	2750	750	500	800
No. of storage tanks	1	1	1	1	1	1	2 * 750	1	1	1
Collector orientation	47.5°/180°	27°/225°	South - South East 25° from south	South - South East 25° from south	30°/160°	27°/185°	90°/190°	30°/180°	30°/210°	27°/175°
Coll. loop flow rate [l/m2/s)]	not measured	not measured	0.004418919	0.01595122	not measured	not measured	not measured	not measured	not measured	not measured
Pumped, thermosyphon	n/a	n/a	Pumped	Pumped	n/a	n/a	n/a	n/a	n/a	n/a
Freeze protection	n/a	n/a	Propylene glycol	Propylene glycol	n/a	n/a	n/a	n/a	n/a	n/a
Auxiliary fuel type	n/a	n/a	Oil	Oil/ wood chips	n/a	n/a	n/a	n/a	n/a	n/a
Year of installation	n/a	n/a	1989	1995	n/a	n/a	n/a	n/a	n/a	n/a
Data on usage patterns	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Installed system costs	n/a	n/a	0.129 Million Euros	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Maintenance costs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
How is SF calculated	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)	Total contribution of solar collectors = 143 MWh - however with all losses only = 98.5 MWh: SF = 98.5/384.8 = 26%	26.6(MWh/6month) / 43.1(MWh/6month)	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)	solar contribution divided with total hot water use (including losses)
Any other information	space heating, heater integrated in the solar tank	space heating, heater integrated in the solar tank	Also used for space heating.	Energy hot water and Irradiation in 6 month base, calculated for one year; roof inclination at 22 degrees; data monitored from July - Dec			Flat plate on Façade; space heating, heater integrated in additional tank	space heating, heater integrated in the solar tank	heater integrated in the solar tank	(preheating), heater integrated in the solar tank