SMALL LOW FLOW SOLAR HEATING SYSTEMS

EXPERIENCE FROM PRACTICE

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Thermal Insulation Laboratory
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Three Solar Collector Manufacturers have participated:

Batec
Aidt Miljø
Arcon Solvarme

The following plumber firms have participated:

Poul Børgesen, Slangerup
Smedegården Svantevit, Ringe
Kalvehave El-Service, Kalvehave
Skørping Installationsforretning, Skørping

A sincere aknowledgement to the nine owners of the solar heating systems. They read the meters of their solar heating systems which they placed at the project's disposal. Without their obliging approach this project would never have been accomplished.

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1. INTRODUCTION

Experimental laboratory investigations, carried out during 1987 and 1988, showed that the thermal performance from solar heating systems with small volume flow rates is about 20% higher than the thermal performance from traditional solar heating systems [1], [2], [3] and [4].

The aim of the project was to investigate if the promising results from the laboratory systems with small volume flow rates would keep in practice. It was investigated whether the manufacturers' solar heating systems for domestic hot water supply were as efficient and attractive as expected, and whether the systems would work in practice without any operation problems. The three solar collector manufacturers: Batec, Aidt Miljø and Arcon Solvarme participated in the project. Each manufacturer built three small test systems at three different consumers. Nine systems were consequently built, and they were followed by means of energy meters, water meters and hour counters.

2. THE TEST SYSTEMS

The nine test systems were built in the period May 1989 - February 1991, see Table 1. The test systems are of different design. The systems are for instance equipped with solar collectors of different types, and have different areas, orientations and tilts.

In the Batec systems is used the solar collector element BA22 SELEKTIV with a transparent area of 2.16 m² and the efficiency:

$$\eta = 0.77 - 5.0 \cdot \frac{T_m - T_l}{E} - 0.007 \cdot \frac{(T_m - T_l)^2}{E}$$

In the Arcon systems is used the solar collector element S-250 with a transparent area of 2.51 m² and the efficiency:

$$\eta = 0.68 - 1.9 \cdot \frac{T_m - T_l}{E} - 0.023 \cdot \frac{(T_m - T_l)^2}{E}$$

In two of the Aidt Miljø systems is used the solar collector element LF4 with a transparent area of 3.84 m² and the efficiency:

$$\eta = 0.74 - 5.4 \cdot \frac{T_m - T_l}{E} - 0.018 \cdot \frac{(T_m - T_l)^2}{E}$$

In the third Aidt Miljø system is used the solar collector element LF5 with a transparent area of 5.07 m² and the efficiency:

$$\eta = 0.74 - 5.1 \cdot \frac{T_m - T_l}{E} - 0.018 \cdot \frac{(T_m - T_l)^2}{E}$$

T_m is the solar collector's mean temperature of the fluid, °C
T_l is the air temperature, °C
E *is the solar irradiance, W/m²*

In eight of the systems are used vertical mantle tanks, where the solar collector fluid is supplied in the top of the mantle and returned to the solar collector from the bottom of the mantle. The top of the tank is heated by means of an electric heating element and/or a heat exchanger spiral or an extra mantle around the top of the hot water tank. This is the reason why hot water can be tapped from the tanks even in periods with very little sun.

In the ninth system, in Svenstrup, a horizontal mantle tank is used. In this system is used an external heat exchanger placed under the tank to transfer the heat from the solar collector loop to the domestic water. The cold domestic water is led by natural convection from the bottom of the storage tank down to the heat exchanger. Here the water is heated and conducted to the centre of the heat storage. By using the mantle as a heat exchanger, the heat storage can furthermore be heated by an oil burner.

In two of the systems the water can be heated after having left the storage tank, either by a separate electric heater or by an oil burner unit.

The domestic hot water systems in two of the systems are equipped with a circulation piping. Low flow solar heating systems are expected to have especially high thermal performances when the domestic water system is equipped with a circulation piping. The reason for these great expectations is the fact that the high temperatures which are reached in the top of the tank of the low flow system correspond very well with the relatively high temperatures that are necessary to cover the heat loss of the circulation piping.

The storage tank of the system in Hadsten is placed in an unheated barn, and the storage tank of the system in Terndrup is placed in an uninsulated loft. The remaining systems' storage tanks are placed in heated rooms. Figure 1 shows the location of the systems. Furthermore is shown the location of the meteorological stations where the weather data are measured.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Batec	Gentofte	May 89	7 April 90 - Sept 90:8 Oct. 91 - Nov. 91:8 Dec. 91:4	8.64 m²	400 l	3° to the west	30°	oil burner/ natural gas burner electric heating	no	yes
Batec	Vindeby Strandvej Svendborg	June 89	6	6.48 m²	300 l	0°	45°	oil burner	no	no
Batec	Dannebrogsvej Svendborg	June 89	5 July 90 - Sept 90:6 May 91 - Dec. 91:6	6.48 m²	300 l	45° to the west	45°	oil burner electric heating	no	no
Aidt Miljø	Hørsholm	Aug. 89	4	3.84 m²	215 l	0°	26°	electric heating	no	no
Aidt Miljø	Hadsten	Sept. 89	2	3.84 m²	215 l from Feb. 91:280 l	22° to the west	45°	oil burner electric heating	no	yes
Aidt Miljø	Brædstrup	Febr. 90	2	5.07 m²	215 l from Sept. 91:280 l	22° to the west	40°	district heating	no	no
Arcon Solvarme	Kalvehave	Aug. 90	3	2.51 m²	200 l	0°	47°	oil burner electric heating	no	no
Arcon Solvarme	Terndrup	Jan. 91	5	2.51 m²	200 l	0°	45°	electric heating	yes, by an oil burner	no
Arcon Solvarme	Svenstrup	Febr. 91	4	2.51 m²	200 l	0°	45°	oil burner	yes, electrically	no

1. System 2. Locality 3. Date of installation 4. Number of occupants 5. Solar collector area 6. Storage volume

7. Solar collector orientation from south 8. Solar collector tilt from horizontal 9. Auxiliary energy sources for heating the top of the tank

10. Is the water heated after leaving the hot water tank of the system ? 11. Circulation piping ?

Table 1. The nine test systems.

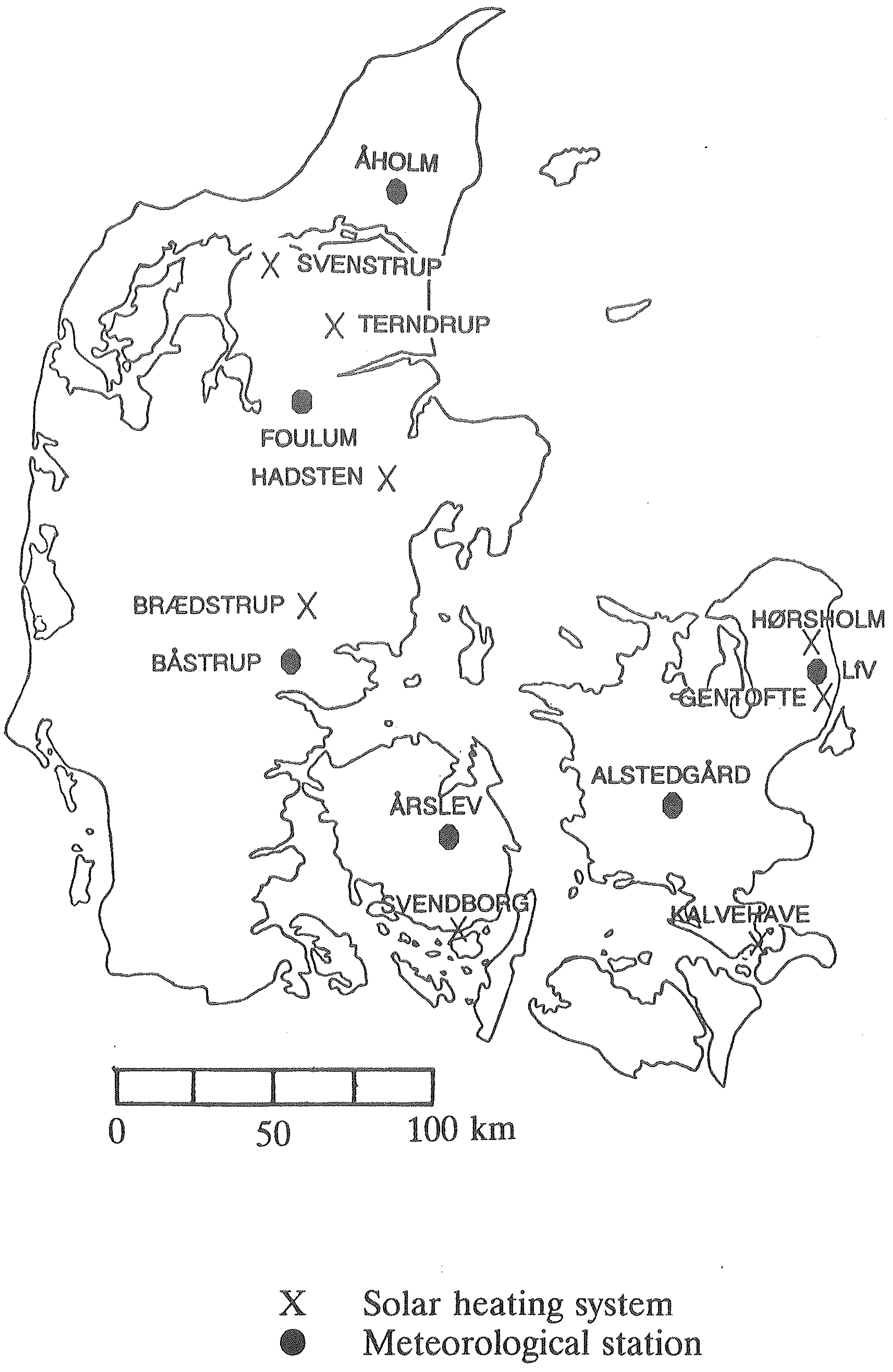


Fig. 1. Location of test systems and meteorological stations

3. MEASURING SYSTEM

The measuring equipment which was used in the nine systems is shown schematically in Figure 2. All the systems are equipped with at least one energy meter of the type Clorius Combimeter, either type EV50 or 1,5EP.

By means of this energy meter the hot water consumption and the amount of energy tapped from the heat storage of the system are measured. The meter consists of a water meter to measure the volume of the flowing water and of two temperature sensors. The cold temperature sensor is placed at the inlet of the cold water to the storage tank. The warm temperature sensor is placed at the outlet of the hot water from the storage tank. The meter is equipped with an electronic unit, which by the help of the measured quantities calculates the amount of energy. The amount of energy and the volume of water can be read on a special unit.

Systems, whose storage tanks have the possibility of post-heating in the form of a heat exchanger, a mantle or a heat exchanger spiral connected to a boiler or to a district heating network, are equipped with one more energy meter: Clorius Combimeter type EV50 or 1,5 EP. The amount of energy supplied to the storage from the boiler or from the district heating network is measured by means of this energy meter.

Systems with a circulation piping are furthermore equipped with an energy meter: Clorius Combimeter type EV50 or 1,5EP which measures the heat loss of the circulation piping.

Systems with post-heating in the form of an electric heating element placed in the solar storage tank are equipped with a kWh-meter to record the energy consumption of the electric heating element.

The water in all the storage tanks of the systems can be post-heated by means of one or more auxiliary energy source(s). The net utilized solar energy of the solar heating system is determined as the energy amount tapped from the storage tank minus the energy amount supplied to the storage tank from the auxiliary energy source(s). In the tables with measured performances, the net utilized solar energy of the system including an estimated heat loss from the storage tank is furthermore indicated.

The energy consumption for the domestic hot water supply is equal to the energy amount tapped from the storage tank if the domestic water is not heated after having passed the storage tank. Besides, in the tables, the solar fractions of the systems are indicated. The solar fraction is indicated without the heat loss of the storage tank as well as including an estimated heat loss from the storage tank. In the first case, the solar fraction is defined as the ratio between the net utilized solar energy and the tapped energy amount from the storage tank. In the second case, the solar fraction is defined as the ratio between the net utilized solar energy including an estimated heat loss from the heat storage and energy tapped from the storage tank including an estimated heat loss from the storage tank. In two systems, those in Terndrup and in Svenstrup, the domestic water can be heated after it has left the storage tank. For these two systems, the total amount of energy for domestic hot water supply is not measured, and the solar fractions are therefore not determined for these systems.

Finally, the circulation pump of the solar collector loop is equipped with an hour counter which registers the operation hours of the solar collector.

Each system is then equipped with so many energy meters that it is possible to determine the net utilized solar energy of the solar heating system. The budget of the project did not permit the solar collector loops to be equipped with energy meters. Therefore the energy from the storage tank have to be estimated.

It should be noted that the domestic hot water consumption in sunny periods with very high storage temperatures is higher than the measured consumption since the hot water is mixed with cold water in these periods.

There are two types of energy meters, one with the cold sensor integrated in the water meter, and one with two loose sensors. The water meter, when possible, is installed on the cold side to prevent internal circulation through the meter, and erroneous measuring which this might cause, see [5]. After installation the energy meters are checked by ISS Clorius International A/S. The accuracy of the meters is stated to be better than 2% at powers between 1 and 50 kW, and better than 5% at powers between 0.5 and 1 kW, which is quite satisfactory.

When small amounts of hot water are tapped, the inertia of the temperature sensors causes the measured tapped amount of energy to be somewhat smaller than the actual tapped amount of energy. However, it is estimated that this systematic erroneous measuring has only a limited influence on the measured system performance.

The kWh-meters applied are inspected at the Laboratory. The accuracy is better than 4%, which is satisfactory.

All the meters are read once a week by the occupants, and a table with the read values are sent to the Laboratory once a month.

For the evaluation of the system performances were applied weather data measured by the Danish Meteorological Institute for the meteorological station which is nearest to the relevant system, see Fig. 1.

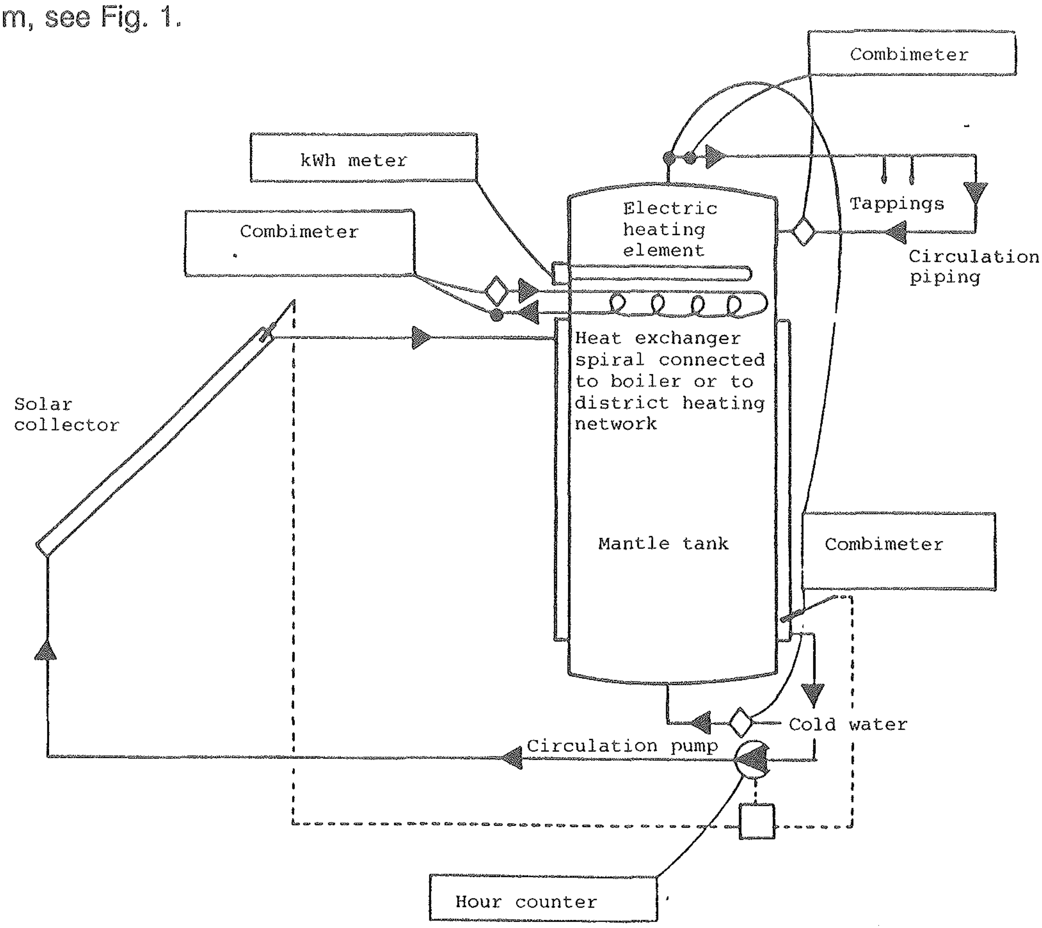


Fig. 2. Measurement equipment for the solar heating systems.

4. MEASUREMENTS

Most of the test systems have worked without major problems since the installation. Two of the systems, the Batec system in Gentofte and the Arcon system in Kalvehave, have had special problems. The problems in Gentofte concerned the control system and the placement and design of the connections of the circulation piping to the hot water tank. The system has been changed several times since the installation. The last change took place in May 1990. The problems of the Gentofte system are described in details in [6].

In section 4.1 the general experience from the systems are presented, and in section 4.2 the experience from the Kalvehave system is described. The results of the measurements are given in section 4.3, and an evaluation of the measured thermal performances is given in section 4.4.

4.1 Operation Experience in General

In two of the systems boiling occurred in the solar collector loop in sunny periods with very modest hot water consumption. The problem was solved by using step 2 of the circulation pump during summer holidays, instead of step 1 which is the one normally used. The volume flow rate in the solar collector loop was thus increased, and the risk of boiling was reduced.

In two of the systems, the one-way valves used in the solar collector loop were not functioning. Consequently thermosyphoning circulation occurred in the solar collector loop, resulting in a substantially increased heat loss from the storage, and a reduction of the system performance. The one-way valves have been replaced, and since then there have not been any problems of thermosyphoning circulation in the solar collector loops.

The heat losses from the upper part of the hot water tanks of some of the systems are relatively large. This is rather unfortunate as large heat losses from the top of the hot water tank substantially reduce the performances of the solar heating systems, as described in [7].

The cause of the large heat losses is an inappropriate design of the upper parts of the heat storages, especially as regards pipe connections. An inappropriate piping outside the storage might furthermore noticeably increase the heat loss from the storage.

Any pipe connection in the top of the tank will cause an increased heat loss. If the pipe is not turned downwards immediately outside the tank, the water in the pipe will always by natural convection keep warm a bigger or smaller part of the pipe, resulting in an increased heat loss.

The pipe might be a part of a pipe loop through which water is circulating either to heat the tank, or to tap heat from the tank. In such pipe loops, if the piping is inappropriate, there is a risk that water by thermosyphoning circulates in the loop in periods when it is not intended. Large amounts of energy can be lost in this way.

The problem of large heat losses from the storage is not especially linked with low flow solar heating systems. Systems with combi-tanks in the top of which the necessary post-heating of the solar heated water is done, are especially exposed to this problem [8].

If possible all pipes ought to be connected to the bottom of the storage tank. Furthermore, the piping should be designed in such a way that the possibility of a driving force, which can result in thermosyphoning water in pipe loops, is reduced to a minimum. This can be ensured, for instance, by thorough insulation of all parts of the pipe loops. Furthermore, well functioning check valves ought to be installed in the pipe loops.

In some of the storage tanks a large part of the storage can be heated by the auxiliary energy source, the electric heating element or the heat exchanger spiral being placed relatively low in the tank. This is especially inappropriate as the performance of the solar heating system is strongly reduced when the water volume, heated by the auxiliary energy source, is increased.

It is therefore important to place the electric heating element and the heat exchanger spiral so high in the tank that the auxiliary energy sources do not heat more water than necessary for the desired comfort.

Besides, in some of the storage tanks, the control of the heat supply from the auxiliary energy source was defective. In these systems the water was heated to a higher temperature than the desired tap temperature of the auxiliary energy source resulting in a reduced performance of the solar heating system. It is therefore important that the control system ensures that the domestic water is only heated to the desired tap temperature of the auxiliary energy source. This problem was solved by changing the control systems of the problematic systems during the measuring period.

For long periods the performances of the two solar heating systems with circulation piping were very small. The reason for these small performances was the fact that the water which is led back to the storage tank from the circulation piping causes a mixing in the tank. The mixing results in a deterioration of the stratification of the storage tank and a substantial reduction of the system performance. It is therefore important that the storage tank is designed in such a way that the water is slowly supplied to the tank at the right temperature level.

The problem was solved by installing a pipe throughout the height of the hot water tank. The pipe is connected to the return pipe of the circulation piping. The pipe is supplied with many holes throughout all its length. In this way the pipe ensures that the water from the circulation piping without any vigorous mixing is supplied to the hot water tank at the level which has the same temperature as the returned water. In this way the stratification of the storage is retained to a certain extent.

4.2 Experience of Operation from the Kalvehave System

Fig. 3 shows a diagram of the heat storage of the system and the applied measuring equipment. The heat storage is a 200 l mantle tank with a heat exchanger spiral integrated in the top of the heat storage tank.

The heat exchanger spiral is connected to an oil burner. The upper part of the heat storage tank can also be heated electrically.

The solar collector of the system is an Arcon S-250 solar collector element mounted at the top of a south facing roof, in this way the shadows from the surroundings will never reach the solar collector, see Fig. 4.

In the beginning of the system's lifetime the performance was unsatisfactorily low. Therefore investigations were initiated to elucidate the causes of the low performances. The results of these investigations will be dealt with below.

The operation time for the circulation pump was **very** short in the beginning of the system's lifetime. That is why the mode of operation of the control system was checked.

The circulation pump is controlled by an Arcon TC-S3 differential control with one sensor placed in the solar collector and one sensor placed in thermal contact with the mantle under the insulation on a level with the outlet stub at the lowest part of the mantle. The start difference can be adjusted to a quantity between 2 K and 10 K. The adjustment of the stop differential temperature is fixed to 1.5 K.

The system was inspected on the 15th of April 1991, a day of clear sunshine without any clouds on the sky. It was demonstrated that the circulation pump was functioning for a short period followed by a long period without functioning.

This pattern is repeated throughout all the day. The outlet temperature of the solar collector was therefore measured and compared to the temperature which the temperature sensor of the control system records in the solar collector. It appeared that the outlet temperature from the solar collector in some periods was up to 40 K higher than the one recorded by the temperature sensor of the control system. This results in the on/off operation of the pump, a short time of operation for the pump and a low system performance.

The cause of the erroneous measurement is the temperature sensor's bad placing in the solar collector. The sensor is placed in a sensor pipe in the upper part of the solar collector. Figure 5 shows the outlet pipe from the solar collector with the temperature sensor placed in the sensor pipe, which is in contact with the outlet pipe. Figure 6 shows the temperature sensor outside the sensor pipe.

The sensor pipe is too short to completely place the temperature sensor inside the solar collector. This can be seen in Fig. 7 where the temperature sensor is placed next to the sensor pipe. Only somewhat more than half of the temperature sensor is placed inside the solar collector. This placing causes the recorded temperature to be **much** lower than the temperature of the solar collector fluid. The missing insulation of the outlet pipe and the sensor pipe outside contributes to the big temperature difference. Nevertheless, it is estimated that a careful insulation work cannot solve the problem.

It was decided temporarily to place the temperature sensor loosely on top of the absorber as shown in Fig. 8. This placing is definitely the best placing up till now.

The 28th of August 1991 the temperature sensor was substituted by a smaller temperature sensor which was placed in the solar collector fluid in the very solar collector. The control problems were accordingly solved.

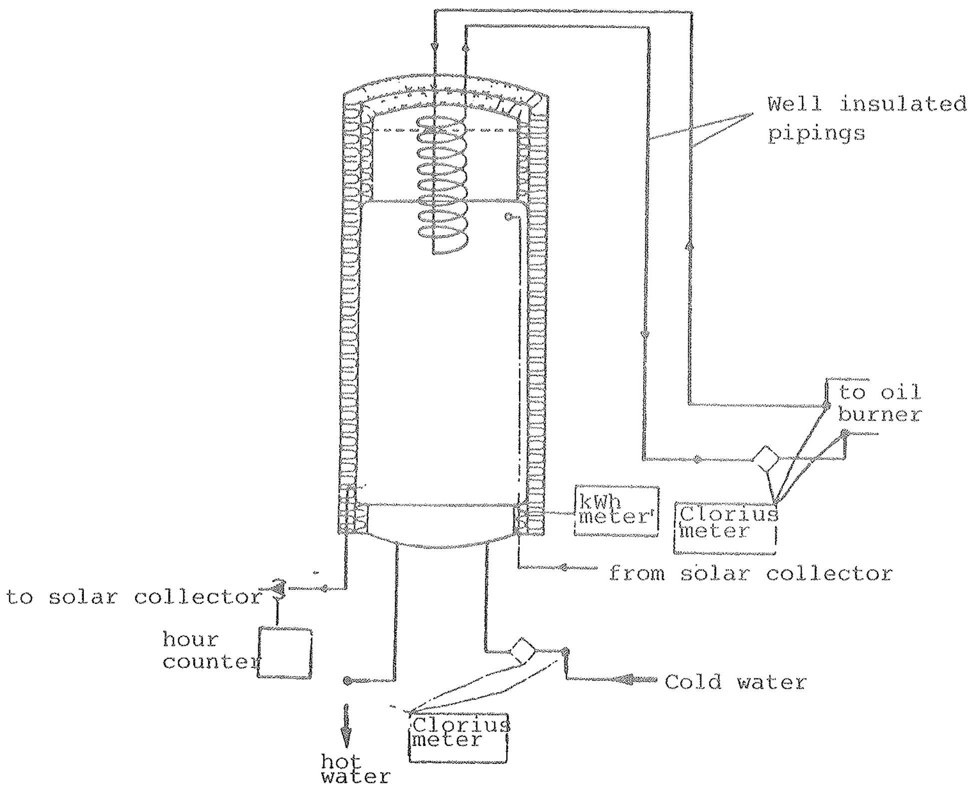


Fig. 3. Diagram of the heat storage and measuring equipment.

Fig. 4. The solar collector element of the system.

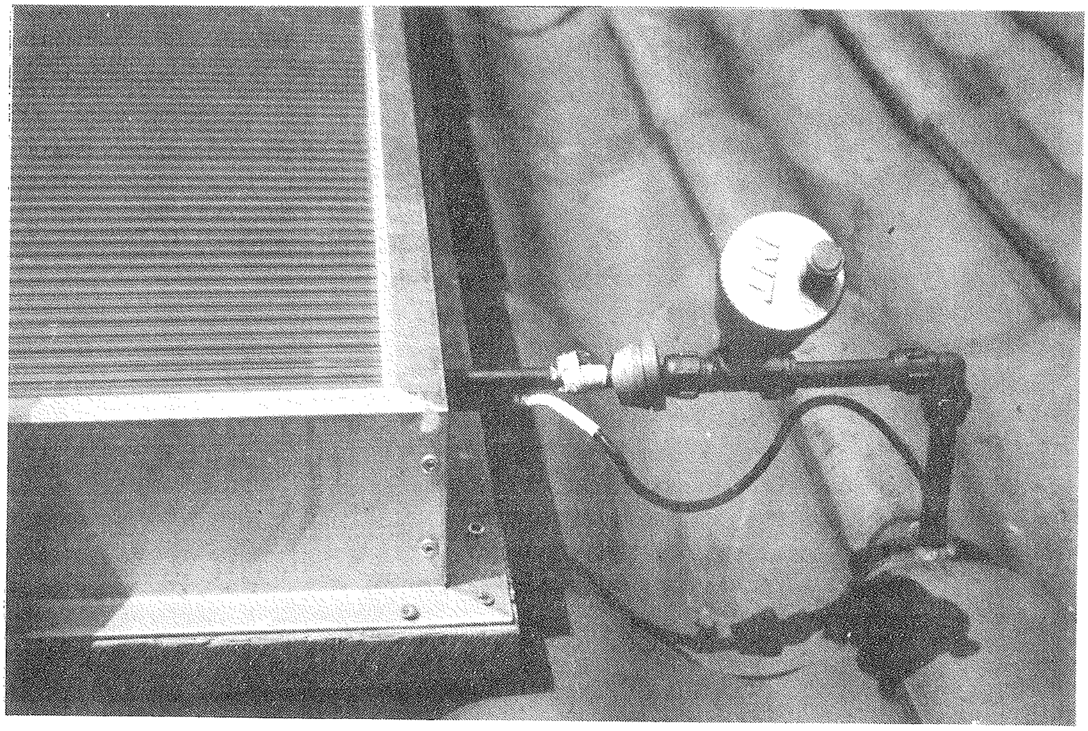


Fig. 5. Placing of the temperature sensor of the control system in the solar collector.

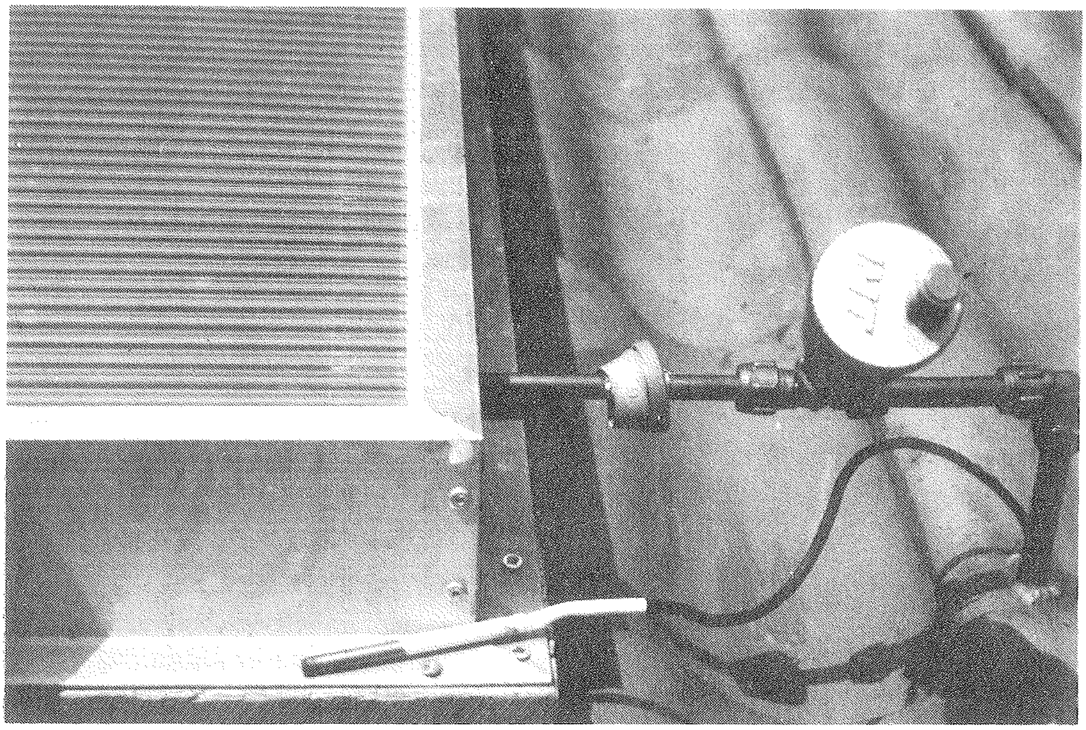


Fig. 6. The temperature sensor of the control system next to the solar collector.

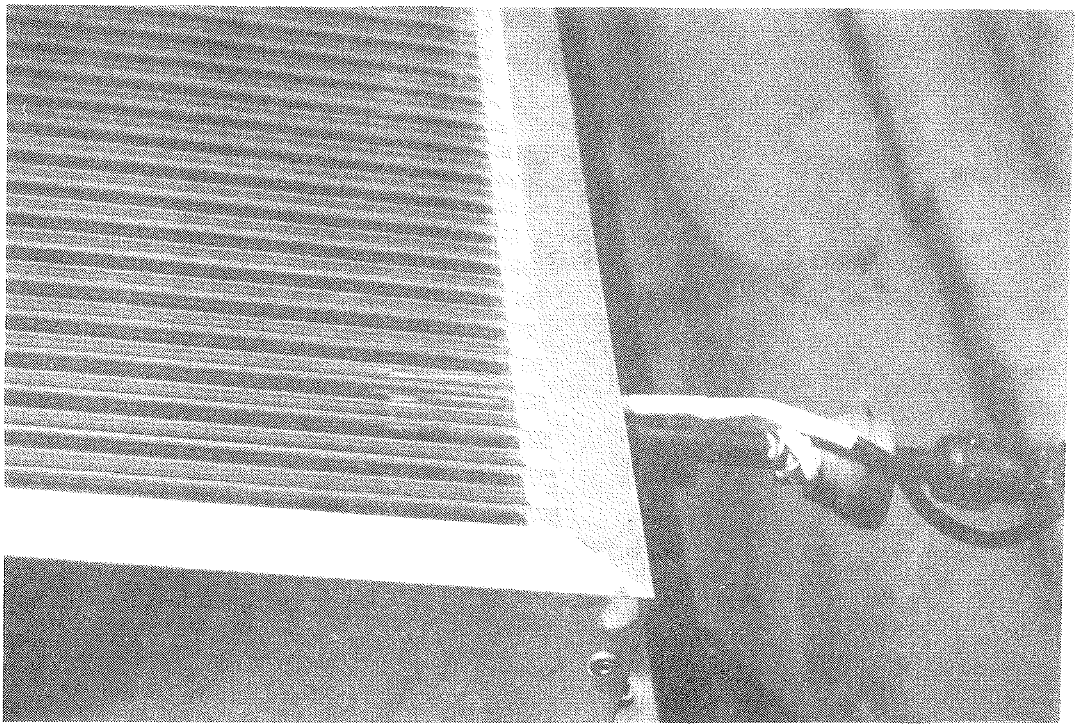


Fig. 7. The temperature sensor placed next to the sensor pipe.

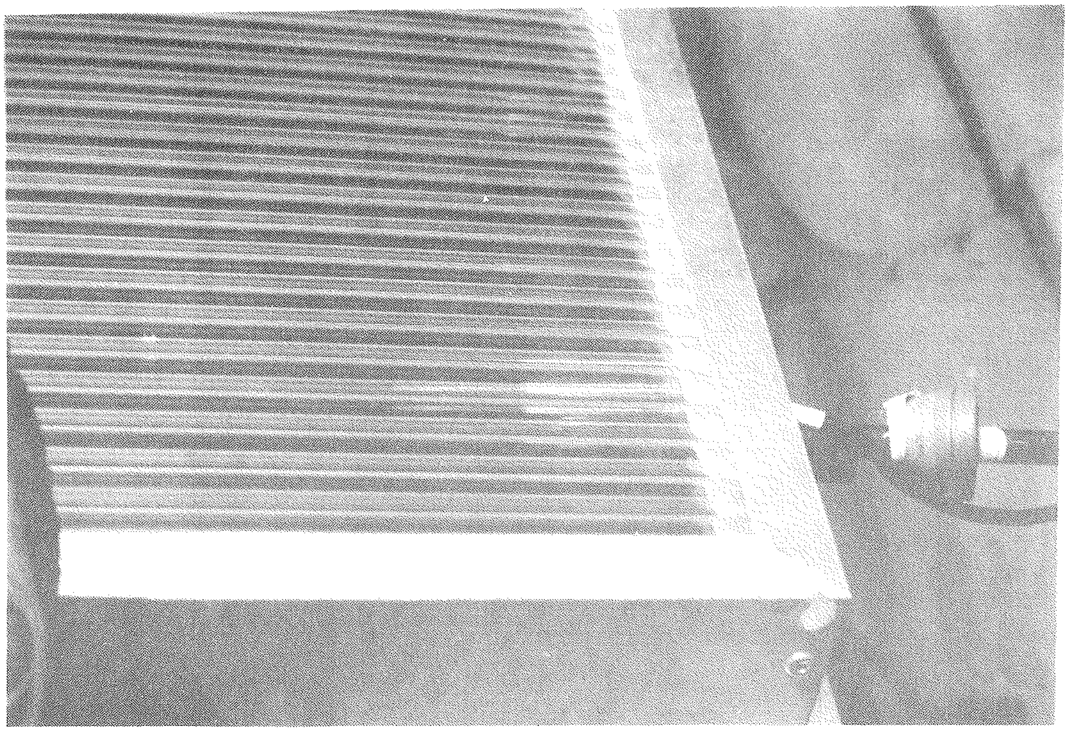


Fig. 8. The temperature sensor placed on top of the absorber.

It was also stated that the heat loss from the storage was especially high because of the missing or insufficient insulation of the pipes connected to the storage tank. This substantially reduced the system performance. A considerable part of the pipe loop between the heat exchanger spiral and the oil burner was for instance not insulated. Besides, the hot water pipe from the bottom of the storage tank was uninsulated. In late April 1991 the above-mentioned conditions were improved by means of a careful insulation work. However, it should be noticed that the heat loss of the storage tank still remains unsatisfactorily high because of the pipe connections in the top of the tank.

4.3 Measurement Results

The thermal performances of the solar heating systems depend primarily of the amount of the hot water consumption. Below is indicated the measured consumption of hot water as the amount of water passing through the hot water tanks of the solar collector systems. The actual hot water consumption has therefore, in summer periods, been somewhat higher than indicated here as the solar heated water in these periods is mixed with cold water to prevent the tap temperature from being too high.

Table 2 shows the measured mean hot water consumption for the nine systems for the parts of the period 1989-1991 in which the measurements were carried out. Figures 9 and 10 show the measured mean hot water consumption for the nine systems, per m^2 of solar collector and per occupant respectively. The consumption varies highly from one system to another. A well dimensioned solar heating system for domestic hot water supply has in Denmark a hot water consumption of 50 l/day per m^2 solar collector. All nine systems are therefore oversized. Relatively small system performances per m^2 of solar collectors are therefore to be expected.

The daily hot water consumption per occupant varies **very much** from one system to another. The consumption is especially high in houses with few occupants, each household having a certain basic consumption of hot water. For all the systems, the mean hot water consumption was found to be 38 l/day per occupant.

The variation of the hot water consumption in the course of the year naturally also influences the system performance. Fig. 11 shows the daily mean hot water consumption per occupant for the nine systems for each month of the measuring period. The variations are especially great for houses with few occupants. Furthermore, in many cases the consumption is low in July because of the summer holidays. This low consumption will naturally result in a reduced system performance.

Fig. 12 shows the daily mean hot water consumption per occupant throughout all the months of the year on the basis of measurements for all nine systems during the entire measuring period. The variations are relatively small, however, the consumption is especially low in July because of the summer holidays. In this figure the consumption is greater than the above-mentioned mean hot water consumption of 38 l/day per occupant. This is due to the fact that all measured monthly consumption quantities in this figure are weighted equally. Consequently, the systems which early in the course of the project were put into operation count much more than the newest systems. It is exactly the first established systems that have the highest consumption of hot water per occupant.

System / Period	Batec Gentofte 8.64 m² 5-8 occupants	Batec Vindeby Strand-vej Svendborg 6.48 m² 6 occupants	Batec Svendborg 6.48 m² 5-6 occupants	Aidt Miljø Hørsholm 3.84 m² 4 occupants	Aidt Miljø Hadsten 3.84 m² 2 occupants	Aidt Miljø Brædstrup 5.07 m² 2 occupants	Arcon Solvarme Kalvehave 2.51 m² 3 occupants	Arcon Solvarme Terndrup 2.51 m² 5 occupants	Arcon Solvarme Svenstrup 2.51 m² 4 occupants
1989	319 l/day 37 l/day m² 46 l/day occup.	154 l/day 24 l/day m² 26 l/day occup.	188 l/day 29 l/day m² 38 l/day occup.	174 l/day 45 l/day m² 44 l/day occup.	178 l/day 46 l/day m² 89 l/day occup.				
1990	364 l/day 42 l/day m² 49 l/day occup.	182 l/day 28 l/day m² 30 l/day occup.	199 l/day 31 l/day m² 38 l/day occup.	169 l/day 44 l/day m² 42 l/day occup.	139 l/day 36 l/day m² 69 l/day occup.	140 l/day 28 l/day m² 70 l/day occup.	93 l/day 37 l/day m² 31 l/day occup.		
1991	308 l/day 36 l/day m² 44 l/day occup.	190 l/day 29 l/day m² 32 l/day occup.	224 l/day 35 l/day m² 40 l/day occup.	171 l/day 45 l/day m² 43 l/day occup.	145 l/day 38 l/day m² 73 l/day occup.	98 l/day 19 l/day m² 49 l/day occup.	105 l/day 42 l/day m² 35 l/day occup.	118 l/day 47 l/day m² 24 l/day occup.	101 l/day 40 l/day m² 25 l/day occup.
Total	332 l/day 38 l/day m² 46 l/day occup.	180 l/day 28 l/day m² 30 l/day occup.	207 l/day 32 l/day m² 39 l/day occup.	171 l/day 44 l/day m² 43 l/day occup.	146 l/day 38 l/day m² 73 l/day occup.	121 l/day 24 l/day m² 61 l/day occup.	102 l/day 41 l/day m² 34 l/day occup.	118 l/day 47 l/day m² 24 l/day occup.	101 l/day 40 l/day m² 25 l/day occup.

Table 2. Measured average hot water consumption.

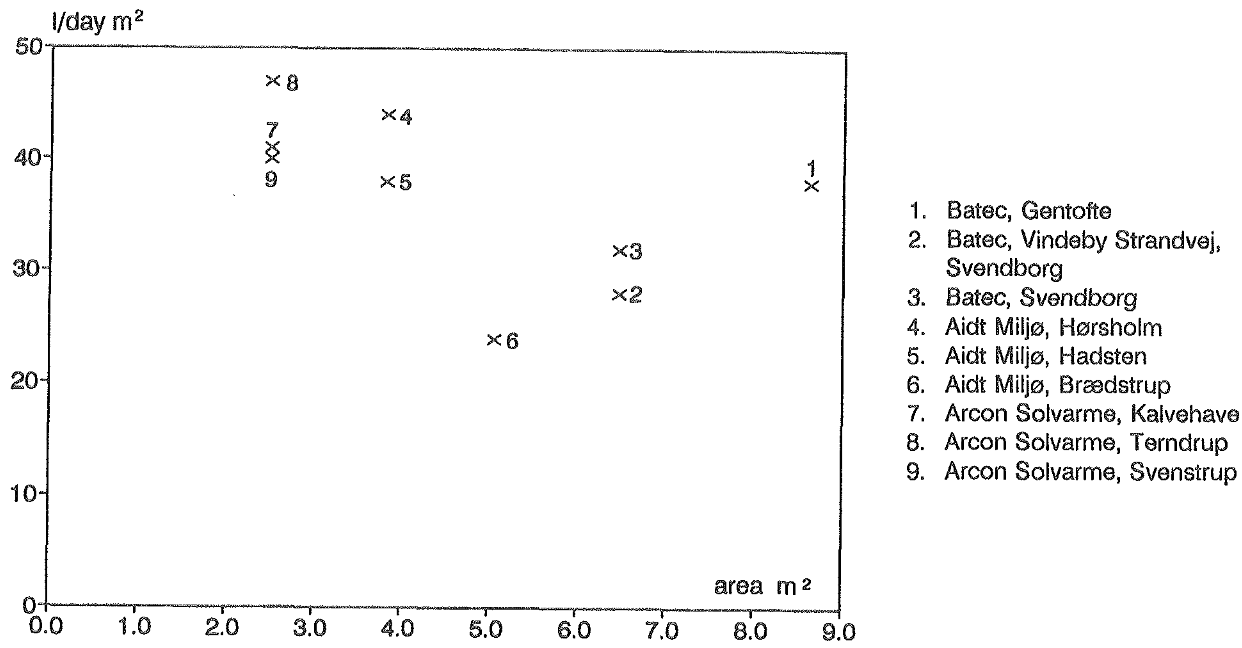


Fig. 9. Measured mean consumption of hot water per m² solar collector for the nine test systems.

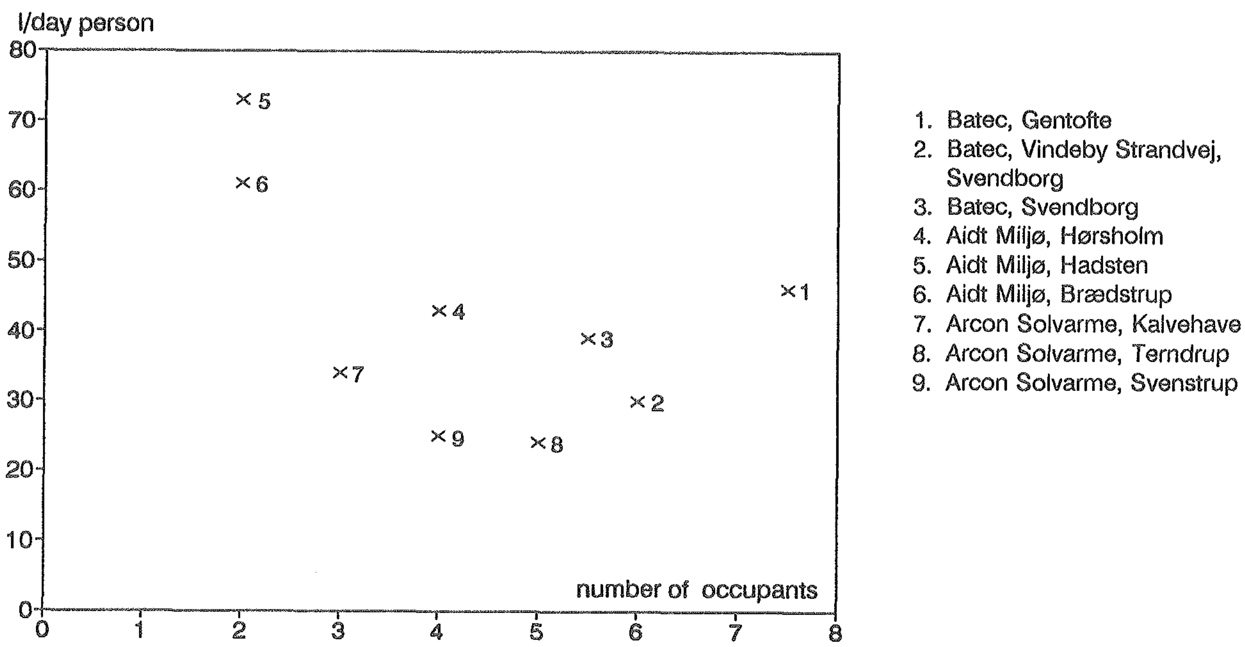


Fig. 10. Measured mean consumption of hot water per occupant for the nine test systems.

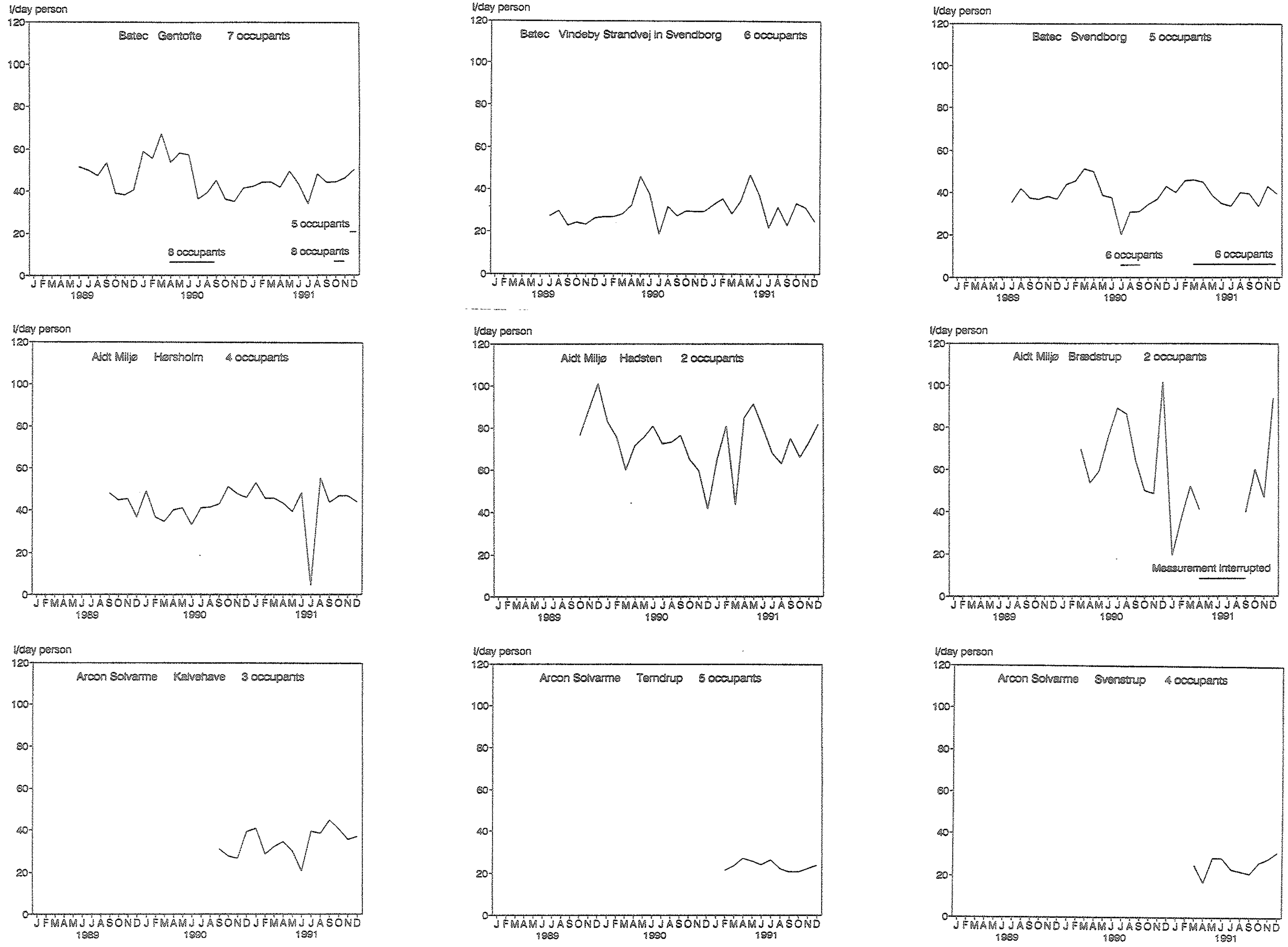


Fig. 11. Measured mean consumption of hot water per occupant for the nine test systems.

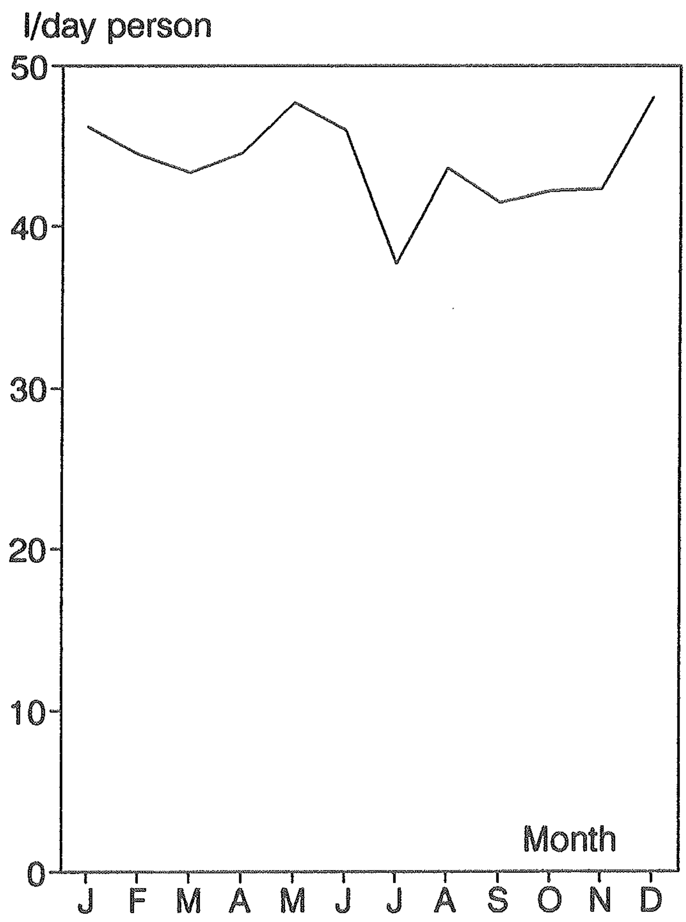


Fig. 12. Measured mean hot water consumption per occupant during the year for all nine systems in the entire measuring period.

Obviously, the performances of the solar heating systems also very much depend on the solar radiation. The measured total horizontal radiation at the meteorological stations in periods when the systems near the meteorological stations have been in operation appears from Table 3.

At the estimation of the thermal performances, in the following the solar radiation of a specific system is considered to be equal to the solar radiation of the meteorological station nearest to this system. However, for the system in Svenstrup, mean values of the solar radiation in Åholm and Foulum were used.

On the basis of the measured weather data and of the orientation and tilt of the solar collectors the amount of the total solar radiation on the solar collectors is determined by means of the program developed in [9], for each single month of the measuring period.

The "measured" solar radiations on the solar collectors determined in this way are given in Table 4. The quantities from the Danish Test Reference Year are also given in this table.

The measured quantities for the nine systems are shown in Tables 5-13. Measured mean hot water consumption and operation hours for the circulation pumps, as well as the amounts of energy tapped from the hot water tank of the system and supplied from the auxiliary energy source(s) are indicated. Furthermore, the net utilized solar energy of the solar heating system defined as energy tapped from the storage minus energy supplied to the storage from the auxiliary energy source(s) is indicated. Furthermore, the performance of the solar heating system including an estimated heat loss from the storage is indicated. This heat loss from the storage is estimated, for the sake of clearness, to be 2 kWh/day without regard to the placing, the size and the insulation condition of the storage. The performance of the solar heating system per m^2 of solar collector is also indicated, exclusively the heat loss of the storage as well including the estimated heat loss. If it was possible, on the basis of the measurements, to determine the solar fraction of the system, this one is moreover indicated without the storage heat loss as well as including the estimated heat loss from the heat storage. The definition of these quantities is indicated in section 3.

In one of the systems the meters were broken for a couple of months, and the circulation pump was turned off for a month, in another system the solar collector was emptied of fluid for a couple of months, and in a third one the meters were not read for four months. Finally, it should be noted that the Batec system in Svendborg in July 1991 was modified so that after that heat can be tapped from the storage for space heating. An extra energy meter was installed to make it possible to measure this amount of heat too. Apart from this, the measurements were carried out as planned. The measurement results are comprised in Table 14.

Period	Total horizontal radiation, kWh/m²						
	Thermal Insulation Laboratory	Alstedgård	Årslev	Båstrup	Foulum	Åholm	Danish Test Reference Year
July 89	167		151				161
August	124		114				135
Sept.	86		81				83
October	41		38		46		44
November	21		25		23		19
December	11		11		12		12
January 90	10		10		7		13
February	29		31		29		33
March	71		70	68	68		59
April	130		130	125	121		119
May	157		186	178	166		155
June	144		140	135	147		186
July	167		173	166	171		161
August	137		141	135	140		135
Sept.	73	78	78	71	73		83
October	40	40	44	42	43		44
November	20	18	20	20	23		19
December	10	10	10	9	11		12
January 91	17	17	17	17	18		13
February	27	32	33	32	33		33
March	60	57	58	55	53	50	59
April	101	97	105	102	103	101	119
May	160	148	168	165	168	157	155
June	112	120	134	133	132	125	186
July	164	159	179	175	164	160	161
August	131	129	134	132	127	123	135
Sept.	89	81	88	88	92	86	83
October	47	46	47	45	49	42	44
November	17	18	20	18	20	16	19
December	10	10	11	11	12	8	12
1990	988	-	1033	-	999	-	1018
1991	935	914	994	973	971	-	1018

Table 3. Measured total horizontal radiation at the meteorological stations.

Period	Total solar radiation on the solar collector, kWh/m²																	
	1		2		3		4		5		6		7		8		9	
	measured	TRY	measured	TRY	measured	TRY	measured	TRY	measured	TRY	measured	TRY	measured	TRY	measured	TRY	measured	TRY
July 89			147	156	146	154												
Aug.			126	149	119	141												
Sept.	107	104	104	107	92	95	104	101										
Oct.	59	63	59	68	50	58	57	61	67	64								
Nov.	37	34	51	39	41	31	35	32	43	36								
Dec.	26	28	32	34	24	26	24	26	32	32								
Jan. 90	18	23	21	27	16	21	17	22	14	24								
Febr.	45	52	54	58	44	47	43	49	50	53								
March	87	72	88	74	76	64	85	71	80	69	80	69						
April	148	135	145	133	135	123	145	133	140	128	136	129						
May	166	164	186	156	184	154	164	163	164	154	180	157						
June	146	188	133	176	129	171	146	188	136	172	129	177						
July	172	165	168	156	166	154	171	164	164	154	163	158						
Aug.	155	152	156	149	148	141	152	150	151	145	147	147						
Sept.	91	104	100	107	89	95	89	101	89	101	86	101	98	105				
Oct.	58	63	68	68	58	58	55	61	63	64	61	63	62	68				
Nov.	35	34	40	39	33	31	33	32	43	36	36	35	36	39				
Dec.	24	28	29	34	22	26	22	26	29	32	23	30	29	35				
Jan. 91	31	23	36	27	28	21	29	22	35	24	32	24	36	27				
Febr.	42	52	57	58	47	47	40	49	53	53	50	52	55	57	56	57		
March	74	72	73	74	63	64	72	71	62	69	65	69	71	73	66	73	64	73
April	115	135	117	133	109	123	113	133	111	128	111	129	106	130	114	131	112	131
May	169	164	168	156	167	154	167	163	166	154	167	157	144	152	166	153	160	153
June	114	188	127	176	124	171	113	188	122	172	127	177	111	171	123	174	120	174
July	168	165	174	156	172	154	167	164	157	154	172	158	150	152	157	154	155	154
Aug.	147	152	148	149	140	141	146	150	137	145	144	147	140	146	138	147	136	147
Sept.	112	104	113	107	100	95	108	101	112	101	107	101	102	105	116	105	112	105
Oct.	67	63	73	68	62	58	65	61	71	64	64	63	71	68	75	67	69	67
Nov.	30	34	41	39	33	31	28	32	38	36	33	35	37	39	40	38	36	38
Dec.	24	28	32	34	24	26	22	26	32	32	27	30	29	35	34	34	28	34
1990	1145	1180	1188	1175	1100	1086	1122	1158	1123	1132								
1991	1093	1180	1159	1175	1069	1086	1070	1158	1096	1132	1099	1142	1052	1153				

1. Batec, Gentofte 2. Batec, Vindeby Strandvej, Svendborg 3. Batec, Svendborg 4. Aidt Miljø, Hørsholm 5. Aidt Miljø, Hadsten 6. Aidt Miljø, Brædstrup
7. Arcon Solvarme, Kalvehave 8. Arcon Solvarme, Terndrup 9. Arcon Solvarme, Svenstrup

Table 4. Total solar radiation on the solar collector for the nine test systems - measured quantities stressed and quantities from the Danish Test Reference Year (TRY).

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank *	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
Batec	June 1989	360	42	10.8	408	218	0	190	250	22	29	47	53
	July	348	40	6.7	394	503	0	-109	-47	-13	-5	< 0	< 0
8.64 m²	August	330	38	7.5	381	375	0	6	68	1	8	2	15
	September	374	43	5.8	441	470	96	-125	-65	-14	-8	< 0	< 0
Gentofte	October	272	31	1.9	491	0	958	-467	-405	-54	-47	< 0	< 0
	November	267	31	1.0	482	0	934	-452	-392	-52	-45	< 0	< 0
7 occupants	December	282	33	0.5	554	0	1017	-463	-401	-54	-46	< 0	< 0
	January 1990	412	48	0.3	621	153	1185	-717	-655	-83	-76	< 0	< 0
From April 1990	February	388	45	2.0	861	0	963	-102	-46	-12	-5	< 0	< 0
to Sept. 1990 and	March	470	54	3.4	297	0	835	62	124	7	14	7	13
	April	429	50	7.0	831	0	509	322	382	37	44	39	43
from Oct. 1991	May	464	54	7.9	775	198	33	544	606	63	70	70	72
to November 1991	June	456	53	6.6	697	293	1	403	463	47	54	58	61
	July	290	34	6.2	544	116	0	428	490	50	57	79	81
8 occupants	August	312	36	6.0	537	154	1	382	444	44	51	71	74
	September	358	41	3.6	653	173	309	171	231	20	27	26	32
	October	254	29	2.3	628	0	609	19	81	2	9	3	12
December 1991:	November	245	28	0.8	635	0	666	-31	29	-4	3	< 0	4
	December	289	33	0.6	733	0	799	-66	-4	-8	0	< 0	< 0
5 occupants	January 1991	295	34	1.1	732	0	763	-31	31	-4	4	< 0	0
	February	307	36	1.1	705	0	746	-41	15	-5	2	< 0	0
	March	309	36	2.8	734	0	657	77	139	9	16	1	17
	April	291	34	4.6	690	0	489	201	261	23	30	29	35
	May	344	40	6.2	759	31	347	381	443	44	51	50	54
	June	302	35	4.0	469	260	0	209	269	24	31	45	51
	July	237	27	6.3	491	140	0	351	413	41	48	71	75
	August	335	39	6.6	570	161	0	409	471	47	55	72	75
	September	308	36	4.7	633	53	386	194	254	22	29	31	37
	October	353	41	2.5	758	0	765	- 7	55	-1	6	< 0	7
	November	368	43	0.7	773	0	840	-67	-7	-8	-1	< 0	< 0
	December	251	29	0.2	689	0	789	-100	-38	-12	-4	< 0	< 0

* Inclusive circulation piping heat loss, from February 1990.

Table 5. Measured hot water consumption and thermal performances for the Batec system in Gentofte.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
	July 1989	163	25	6.7	191	0	0	191	253	29	39	100	100
Batec	August	178	28	6.5	228	0	0	228	290	35	45	100	100
	September	137	21	5.8	213	0	0	213	273	33	42	100	100
6.48 m²	October	145	22	3.8	193	0	76	117	179	18	28	61	70
	November	140	22	3.3	203	0	152	51	111	8	17	25	42
	December	158	24	1.7	269	0	357	-88	-26	-14	-4	< 0	< 0
Vindeby	January 1990	161	25	1.1	273	0	313	-40	22	-6	3	< 0	7
Strandvej	February	161	25	3.5	234	0	189	45	101	7	16	19	35
Svendborg	March	169	26	4.7	273	0	113	160	222	25	34	59	66
	April	193	30	7.0	337	0	28	309	369	48	57	92	93
6 occupants	May	275	42	7.9	576	0	1	575	637	89	98	100	100
	June	225	35	7.3	366	0	37	329	389	51	60	90	91
	July	113	17	5.6	197	0	1	196	258	30	40	99	100
	August	190	29	7.2	306	0	0	306	368	47	57	100	100
	September	164	25	5.2	234	0	38	196	256	30	40	84	87
	October	178	28	4.4	261	0	155	106	168	16	26	41	52
	November - December *	177	27	-	715	0	777	-	-	-	-	-	-
	January 1991	196	30	2.9	334	0	309	25	87	4	13	7	22
	February	211	33	3.2	314	0	271	43	99	7	15	14	27
	March	170	26	6.1	275	0	156	119	181	18	28	43	54
	April	206	32	8.2	318	0	113	205	265	32	41	64	70
	May	281	43	8.1	502	0	60	442	504	68	78	88	89
	June	224	35	8.6	272	0	50	222	282	34	44	82	85
	July	130	20	8.2	209	0	24	185	247	29	38	89	91
	August	189	29	7.2	269	0	0	269	331	42	51	100	100
	September	137	21	5.9	257	0	0	257	317	40	49	100	100
	October	199	31	4.3	260	0	92	168	230	26	35	65	71
	November	188	29	2.8	257	0	159	98	158	15	24	38	50
	December	148	23	1.2	220	0	188	32	94	5	15	15	33

* System out of operation. Solar collector fluid drained from the system.

Table 6. Measured hot water consumption and thermal performances for the Batec system on Vindeby Strandvej in Svendborg.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
	July 1989	176	27	6.9	235	12	0	223	285	34	44	95	96
	August	208	32	7.0	247	30	10	208	270	32	42	84	87
Batec	September	187	29	6.8	239	17	3	219	279	34	43	92	93
6.48 m²	October	183	28	4.2	257	0	182	75	137	12	21	29	43
	November	190	29	2.8	273	0	224	49	109	8	17	18	33
	December	184	28	1.5	280	0	283	-3	59	0	9	< 0	17
Svendborg	January 1990	218	34	1.0	325	0	331	-6	56	-1	9	< 0	14
	February	226	35	3.3	304	0	262	42	98	6	15	14	27
5 occupants	March	255	39	4.7	385	19	231	135	197	21	30	35	44
	April	249	38	6.9	352	0	115	237	297	37	46	67	72
from July 1990 to	May	193	30	7.7	285	8	33	244	306	38	47	86	88
September 1990	June	188	29	7.1	230	28	0	202	262	31	40	88	90
	July	122	19	7.2	190	7	0	183	245	28	38	96	97
and from	August	184	28	7.5	266	18	0	248	310	38	48	93	95
	September	186	29	5.9	240	28	78	134	194	21	30	56	65
May 1991 to	October	172	27	4.3	218	0	160	58	120	9	19	27	43
December 1991:	November x	184	28	-	224	0	284	-	-	-	-	-	-
	December	214	33	0.6	302	0	255	47	109	7	17	16	30
6 occupants	January 1991	200	31	1.7	272	0	*	*	*	*	*	*	*
	February	227	35	2.0	298	0	*	*	*	*	*	*	*
	March	229	35	4.8	302	0	209	93	155	14	24	31	43
	April	224	35	6.5	296	3	98	195	255	30	39	66	72
	May	231	36	7.4	323	29	44	250	312	39	48	77	81
	June	209	32	8.1	270	62	0	208	268	32	41	77	81
	July ▲	201	31	7.7	291	25	0	266	328	41	51	91	93
	August	239	37	7.5	333	32	0	301	363	46	56	-	-
	September	235	36	5.4	287	0	92	195	255	30	39	-	-
	October	200	31	3.5	241	0	153	88	150	14	23	-	-
	November	257	40	1.8	318	0	270	48	108	7	17	-	-
	December	235	36	1.0	311	0	279	32	94	5	15	-	-

x Circulation pump turned off for some part of the period.

* Clorius meter broken !

▲ In July 1991 the system was modified, after this heat could also be tapped from the tank for space heating.

Table 7. Measured hot water consumption and thermal performances for the Batec system in Svendborg.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
	Sept. 1989	192	50	5.8	195	90	0	105	165	27	43	54	65
Aidt Miljø	October	179	47	2.4	245	214	0	31	93	8	24	13	30
3.84 m²	November	181	47	1.1	267	226	0	41	101	11	26	15	31
	December	146	38	0.3	226	216	0	10	72	3	19	4	25
	January 1990	196	51	0.2	335	304	0	31	93	8	24	9	23
Hørsholm	February	146	38	1.2	254	200	0	54	110	14	29	21	35
	March	138	36	3.2	261	172	0	89	151	23	39	34	47
	April	160	42	5.2	278	127	0	151	211	39	55	54	62
4 occupants	May	164	43	7.2	287	97	0	190	252	49	66	66	72
	June	132	34	6.7	208	78	0	130	190	34	49	63	71
	July	164	43	7.0	257	93	0	164	226	43	59	64	71
	August	165	43	7.0	245	84	0	161	223	42	58	66	73
	September	171	45	4.2	273	148	0	125	185	33	48	46	56
	October	204	53	2.8	353	243	0	110	172	29	45	31	41
	November	191	50	1.3	354	266	0	88	148	23	39	25	36
	December	184	48	0.4	352	284	0	68	130	18	34	19	31
	January 1991	212	55	0.5	422	331	0	91	153	24	40	22	32
	February	183	48	0.6	344	269	0	75	131	20	34	22	33
	March	183	48	2.5	365	243	0	122	184	32	48	33	43
	April	173	45	4.0	322	177	0	145	205	38	53	45	54
	May	157	41	6.1	276	108	0	168	230	44	60	61	68
	June	193	50	6.5	327	136	0	191	251	50	65	58	65
	July	18	5	4.7	32	31	0	1	63	0	16	3	17
	August	221	58	6.8	346	127	0	219	281	57	73	63	69
	September	174	45	5.1	280	134	0	146	206	38	54	52	61
	Oct. - Nov.	187	49	1.2	698	502	0	196	318	51	83	28	39
	December	175	46	0.1	356	288	0	68	130	18	34	19	31

Table 8. Measured hot water consumption and thermal performances for the Aidt Miljø system in Hørsholm.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank *	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl.. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
	October 1989	153	40	4.6	281	20	387	-126	-64	-	-	< 0	< 0
	November	178	46	1.3	276	0	345	-69	- 9	-	-	< 0	< 0
Aidt Miljø	December	202	53	1.1	284	0	358	-74	-12	-	-	< 0	< 0
	January 1990	166	43	0.8	283	0	364	-81	-19	-	-	< 0	< 0
3.84 m²	February	151	39	3.5	251	138	155	-42	14	-11	4	< 0	5
	March	120	31	5.5	208	200	0	8	70	2	18	4	26
	April	143	37	8.9	192	85	0	107	167	28	43	56	66
Hadsten	May	151	39	9.6	191	47	0	144	206	38	54	75	81
	June	162	42	9.7	184	62	0	122	182	32	47	66	75
2 occupants	July	145	38	9.5	185	35	0	150	212	39	55	81	86
	August	146	38	8.3	190	45	0	145	207	38	54	76	82
	September	153	40	6.9	228	193	0	35	95	9	25	15	33
	October	130	34	4.8	238	214	0	24	86	6	22	10	29
	November	119	31	2.3	273	288	0	-15	45	- 4	12	< 0	4
	December	83	22	0.6	206	239	0	-33	29	- 9	8	< 0	3
	January 1991	130	34	1.5	309	341	3	-32	30	- 8	8	< 0	8
	February	162	42	3.0	257	268	0	-11	45	- 3	12	< 0	14
	March	87	23	4.1	152	161	0	- 9	53	- 2	14	< 0	26
	April	170	44	7.5	221	124	0	97	157	25	41	44	56
	May	183	48	6.9	245	92	0	153	215	40	56	62	70
	June	161	42	6.1	177	92	0	85	145	22	38	48	61
	July	136	35	7.1	188	40	0	148	210	39	55	79	84
	August	126	33	7.9	176	42	0	134	196	35	51	76	82
	September	150	39	6.4	196	101	0	95	155	25	40	48	61
	October	132	34	4.5	196	156	0	40	102	10	27	20	40
	November	145	38	1.8	242	31	314	-103	-43	-27	-11	< 0	< 0
	December	164	43	1.3	286	0	370	- 84	-22	-22	- 6	< 0	< 0

* Inclusive circulation piping heat losses.

Table 9. Measured hot water consumption and thermal performances for the Aidt Miljø system in Hadsten.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	district heating network	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
	March 1990	139	36	2.4	150	0	122	28	90	7	23	19	43
Aidt Miljø	April	107	28	3.6	136	0	98	38	98	10	26	28	50
	May	118	-	6.4	150	0	62	88	150	-	-	59	71
3.84 m²	June	150	30	7.3	184	0	79	105	165	21	33	57	68
	July	178	35	7.3	193	0	119	74	136	15	27	38	53
	August	173	34	7.1	199	0	82	117	179	23	35	59	69
from 17.6.1990	September	128	25	2.9	145	0	120	25	85	5	17	17	41
5.07 m²	October	100	20	2.8	126	0	103	23	85	5	17	18	45
	November	97	19	1.6	140	0	153	-13	47	- 3	9	-	5
	December	203	40	0.6	355	0	426	-71	-9	-14	- 2	-	-
Brædstrup	January 1991	39	8	1.1	111	0	175	-64	-2	-13	0	-	0
	February	74	15	1.3	117	0	171	-54	2	-11	0	-	1
2 occupants	March	104	21	2.5	144	0	112	32	94	6	19	22	46
	April	82	16	4.8	112	0	70	42	102	8	20	38	59
	September	79	16	3.9	89	0	15	74	134	15	26	83	90
	October	120	23	2.2	132	0	94	38	100	7	20	29	52
	November	93	18	1.0	104	0	110	- 6	54	-1	11	-	33
	December	188	37	0.6	239	0	280	-41	21	-8	4	-	7

No measurements were carried out from May 1991 - August 1991

Table 10. Measured hot water consumption and thermal performances for the Aidt Miljø system in Brædstrup.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector		Solar fraction	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²		%	
	Sept. 1990	93	37	1.9	89	0	66	23	83	9	33	26	56
Arcon Solvarme	October	83	33	1.4	74	0	57	17	79	7	31	23	58
	November	80	32	0.7	83	0	90	- 7	53	< 0	21	< 0	14
2.51 m²	December	117	47	1.3	125	0	142	-17	45	< 0	18	< 0	24
	January 1991	122	48	0.9	135	0	154	-19	43	< 0	17	< 0	9
Kalvehave	February	86	34	0.8	90	0	97	- 7	49	< 0	20	< 0	34
	March	96	38	1.6	86	0	105	-19	43	< 0	17	< 0	29
	April	103	41	5.6	85	0	102	-17	43	< 0	17	< 0	30
3 occupants	May	90	36	6.3	90	0	55	35	97	14	39	39	64
	June	62	25	5.8	77	86	15	-24	36	-10	14	< 0	10
	July	118	47	8.3	101	45	0	56	118	22	47	55	72
	August	115	46	7.9	90	20	3	67	129	27	51	14	85
	September	134	54	5.2	105	60	0	45	105	18	42	43	64
	October	121	48	3.9	95	0	100	- 5	57	- 2	23	< 0	36
	November	106	42	1.4	86	0	119	-33	27	-13	11	< 0	18
	December	110	44	1.0	97	0	*	*	*	*	*	*	*

* Inspection of energy meter and measurement method.

Table 11. Measured hot water consumption and thermal performances for the Arcon Solvarme system in Kalvehave.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²	
	February 1991	108	43	2.8	51	32	0	19	75	8	30
Arcon Solvarme	March	118	47	4.9	70	27	0	43	105	17	42
	April	136	54	6.6	122	3	0	119	179	47	71
2.51 m²	May	129	51	7.7	149	4	0	145	207	58	82
	June	121	48	8.4	102	0	0	102	162	41	65
Terndrup	July	132	53	9.2	151	1	0	150	212	60	84
	August	111	44	8.5	125	0	0	125	187	50	75
5 occupants	September	104	41	6.4	98	0	0	98	158	39	63
	October	104	41	5.2	61	6	0	55	117	22	47
	November	111	44	2.9	52	28	0	24	84	10	33
	December	119	47	2.7	58	46	0	12	74	5	29

Table 12. Measured hot water consumption and thermal performances for the Arcon Solvarme system in Terndrup.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply from:		Utilized solar energy:		Utilized solar energy per m² solar collector	
						electric heating element	oil burner	excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh		kWh		kWh/m²	
	March 1991	101	40	2.5	78	0	134	-56	6	-22	2
Arcon Solvarme	April	68	27	4.2	87	0	92	- 5	55	- 2	22
	May	114	46	9.0	159	0	70	89	151	35	60
2.51 m²	June	114	45	12.8	94	0	45	49	109	20	43
	July	93	37	13.8	93	0	0	93	155	37	62
Svenstrup	August	89	36	12.5	82	0	14	68	130	27	52
	September	85	34	9.9	75	0	32	43	103	17	41
4 occupants	October	105	42	4.8	133	0	192	-59	3	-23	1
	November	112	45	2.5	151	0	210	-60	0	-24	0
	December	125	50	1.9	178	0	257	-79	-17	-31	-7

Table 13. Measured hot water consumption and thermal performances for the Arcon Solvarme system in Svenstrup.

System	Period	Hot water consumption		Average operation time for circulation pump	Energy tapped from the tank	Energy supply to the tank from auxiliary energy source(s)	Net utilized solar energy		Net utilized solar energy per m² solar collector		Solar fraction	
							excl. heat loss	incl. estimated heat loss	excl. heat loss	incl. heat loss	excl. heat loss	incl. heat loss
		l/day	l/m²day	h/day	kWh	kWh	kWh		kWh/m²		%	
Batec, Gentofte 8.64 m²	June-Dec. 1989	319	37	4.9	3151	4571	-1420	-992	-164	-115	-	-
	1990	364	42	3.9	8412	6997	1415	2145	164	248	17	23
	1991	308	36	3.4	8003	6427	1576	2306	182	267	20	26
Batec, Vindeby Strandvej, Svendborg 6.48 m²	July-Dec. 1989	154	24	4.6	1297	585	712	1080	110	167	55	65
	Jan-Oct. 1990*	182	28	5.4	3057	875	2182	2790	337	431	71	76
	1991	190	29	5.6	3487	1422	2065	2795	319	431	59	66
Batec, Svendborg 6.48 m²	July-Dec. 1989	188	29	4.9	1531	761	770	1138	119	176	50	60
	Jan-Oct and Dec.1990**	199	31	5.1	3097	1573	1524	2194	235	339	49	58
	Mar.-Dec. 1991***	224	35	4.8	2972	1296	1676	2288	259	353	56	64
Aidt Miljø Hørsholm 3.84 m²	Sept-Dec. 1989	174	45	2.4	933	746	187	431	49	112	20	37
	1990	169	44	3.9	3457	2096	1361	2091	354	545	39	50
	1991	171	45	3.3	3768	2346	1422	2152	370	560	38	48
Aidt Miljø Hadsten 3.84 m²	Oct.-Dec. 1989	177	46	2.4	841	1110	-269	-85	-70	-22	-	-
	1990	139	36	5.9	2629	2065	564	1294	147	337	21	39
	1991	145	38	4.9	2645	2135	510	1240	133	323	19	37
Aidt Miljø Brædstrup 5.07 m²	June-Dec. 1990	147	29	4.2	1342	1082	260	688	51	136	19	39
	Jan.-April and Sept.-Dec. 1991 ****	98	19	2.2	1048	1027	21	505	4	100	2	33
Arcon Solvarme Kalvehave 2.51 m²	Sept.-Dec. 1990	93	37	1.3	371	355	16	260	6	104	4	42
	Jan.-Nov. 1991 *****	105	42	4.1	1137	961	176	844	70	336	15	47
Arcon Solvarme Terndrup 2.51 m²	Febr.-Dec. 1991	118	47	6.0	1039	147	892	1560	355	622	-	-
Arcon Solvarme Svenstrup 2.51 m²	March-Dec. 1991	101	40	7.4	1130	1046	84	696	33	277	-	-

* system not in operation in November - December.
** system not in operation in November
*** meter broken in January - February.
**** no measurements carried out from May - August.
***** measurement method checked in December.

Table 14. Measured hot water consumption and thermal performances for the nine systems.

4.4 Estimation of the System Performances

To estimate whether the system performances are as high as can be expected, performance calculation for the systems with the weather data of the Danish Reference Year were carried out using the developed program in [9]. However, the system in Svenstrup was not taken into calculation as the program was not able to calculate with a mantle tank placed horizontally. The calculation program demands a thorough knowledge of the design of the systems. All the assumptions for the program are, however, not known with a too good accuracy. An example of this will be the size of the heat loss coefficient for the upper part of the heat storage. This size influences strongly the system performance. The calculated system performances are consequently determined with some uncertainty.

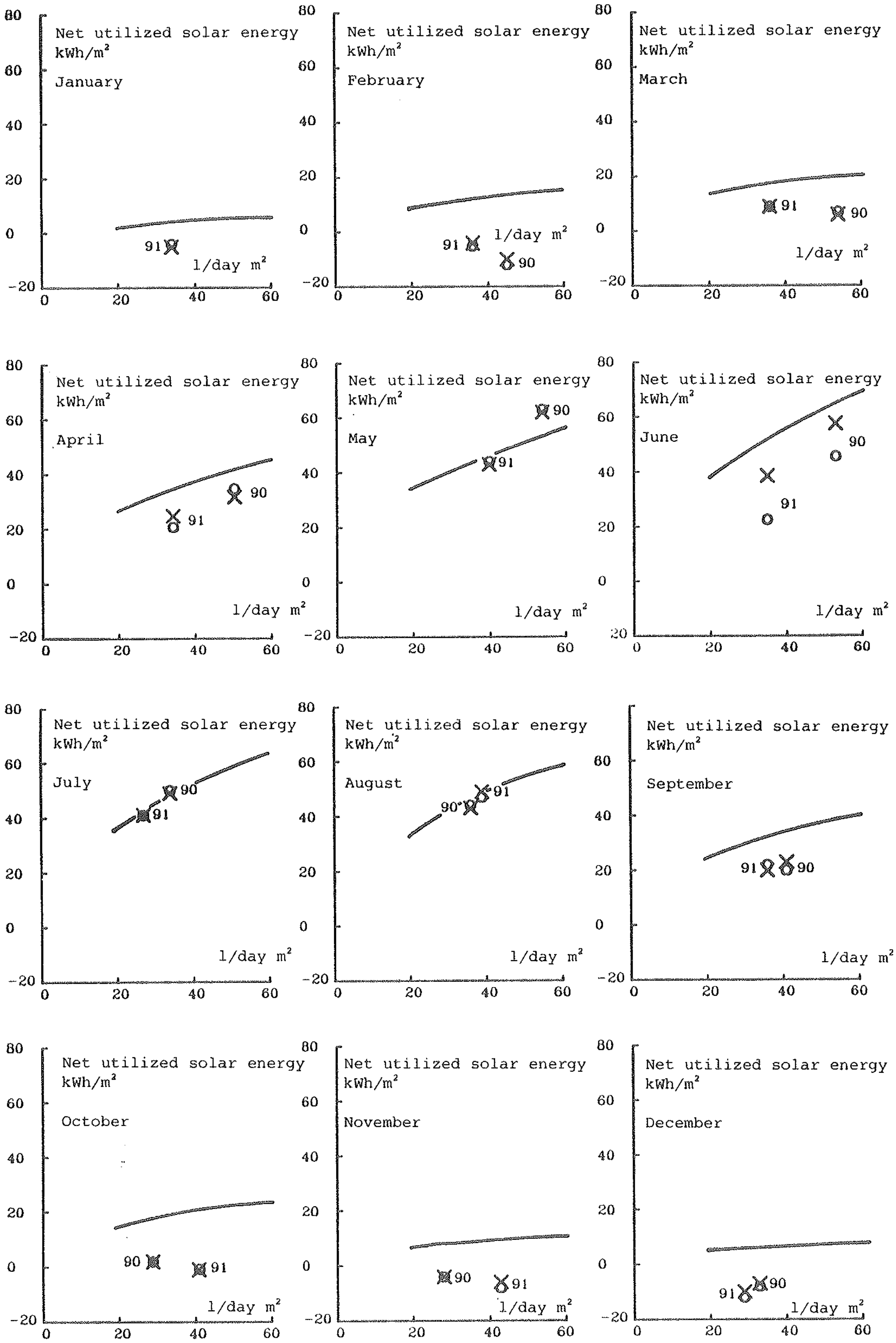
Another important calculation assumption will be the temperature level to which the auxiliary energy source(s) heats the top of the hot water tank. This temperature level is determined for each system by comparing measured amounts of tapped water and energy for a month with a solar fraction so low that the solar energy only contributed very little to the heating. The temperature levels determined in this way are given in Table 15.

System	Temperature of the water in the top of the tank heated by the auxiliary energy source(s)
Batec, Gentofte	42°C
Batec, Vindeby Strandvej, Svendborg	55°C in winter. In summer no back-up.
Batec, Svendborg	52°C
Aidt Miljø, Hørsholm	53°C
Aidt Miljø, Hadsten	59°C
Aidt Miljø, Brædstrup	40°C. However, in some periods 90°C because of erroneous control of the district heating supply.
Arcon Solvarme, Kalvehave	45°C. However, in some periods only 35°C
Arcon Solvarme, Terndrup	10°C
Arcon Solvarme, Svenstrup	32°C

Table 15. The temperatures to which the auxiliary energy source(s) heat the top of the storage tank.

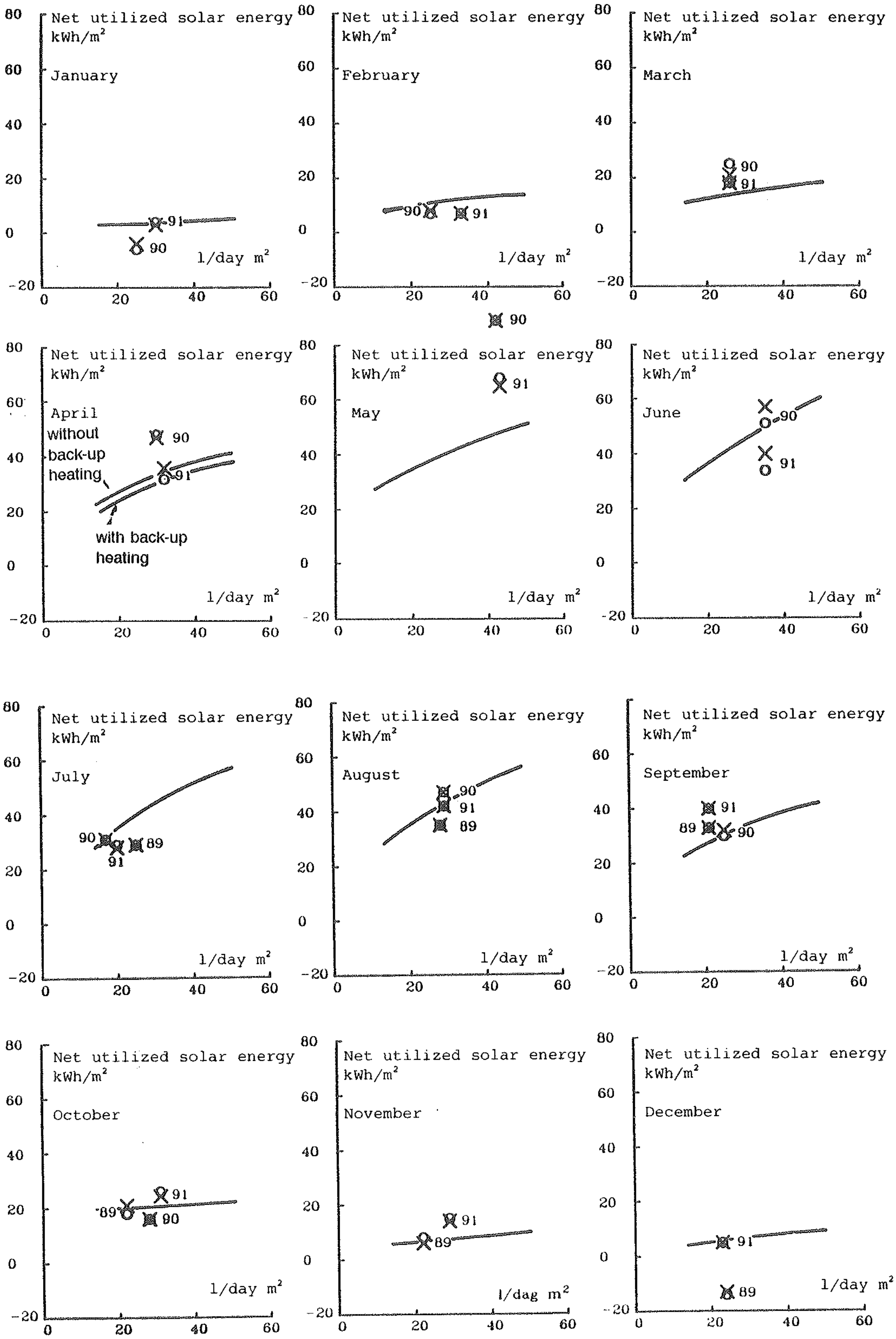
The performance calculations are carried out with different quantities of the daily hot water consumption. In all the calculations, a cold water temperature of 10°C is assumed. The calculated and the measured thermal performances are indicated as a function of the daily mean hot water consumption per m² of solar collector for each month in Figures 13-20.

It should be noted that the calculation program is not able to include a circulation piping into the calculations. Consequently, the system performances of the Gentofte and the Hadsten systems ought to be somewhat higher than the calculated quantities if the systems operate as projected.



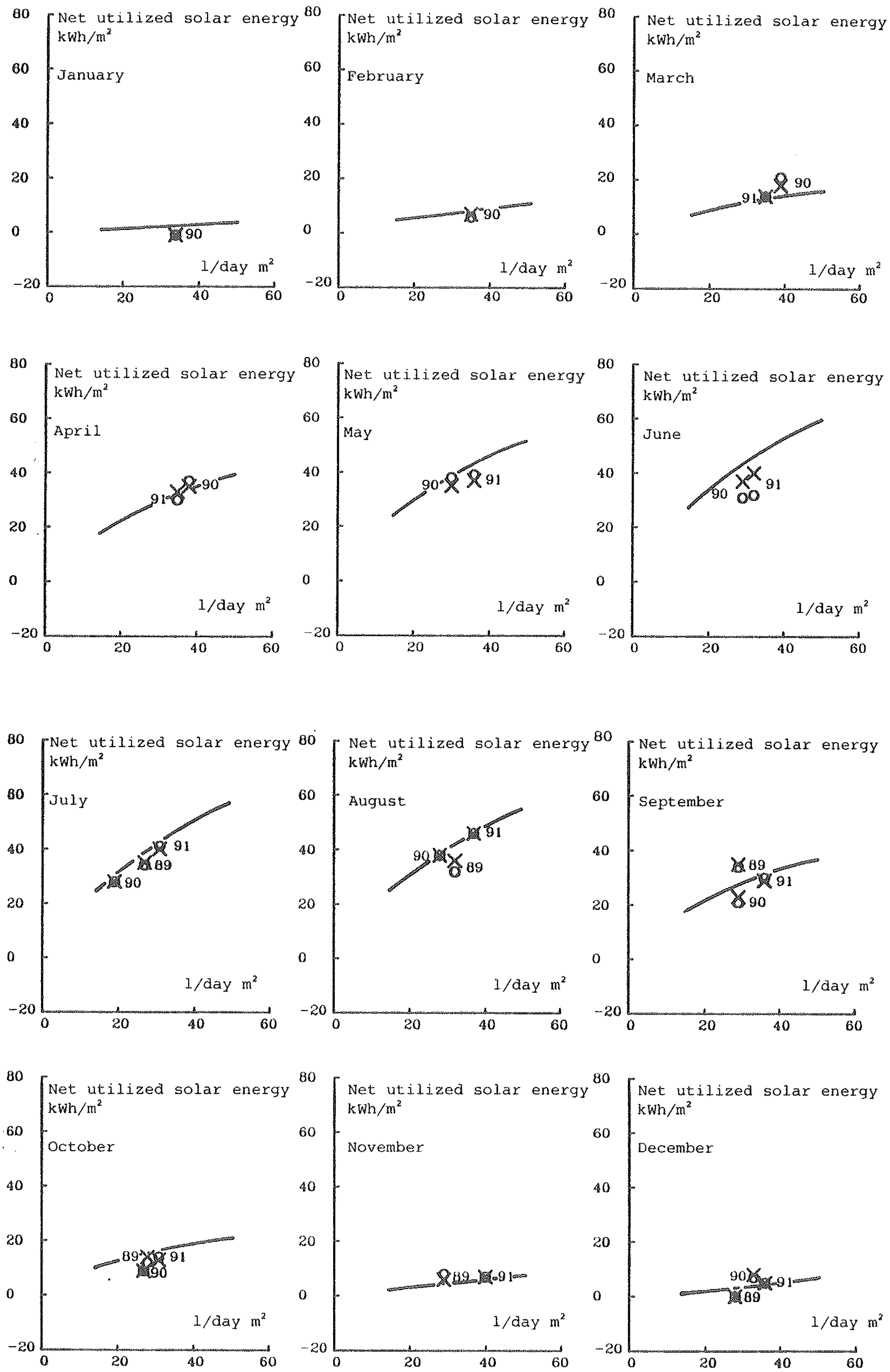
- Calculated thermal performance in the Danish Test Reference Year.
o Measured thermal performance.
x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 13. Calculated and measured thermal performances during the year for the Batec system in Gentofte.



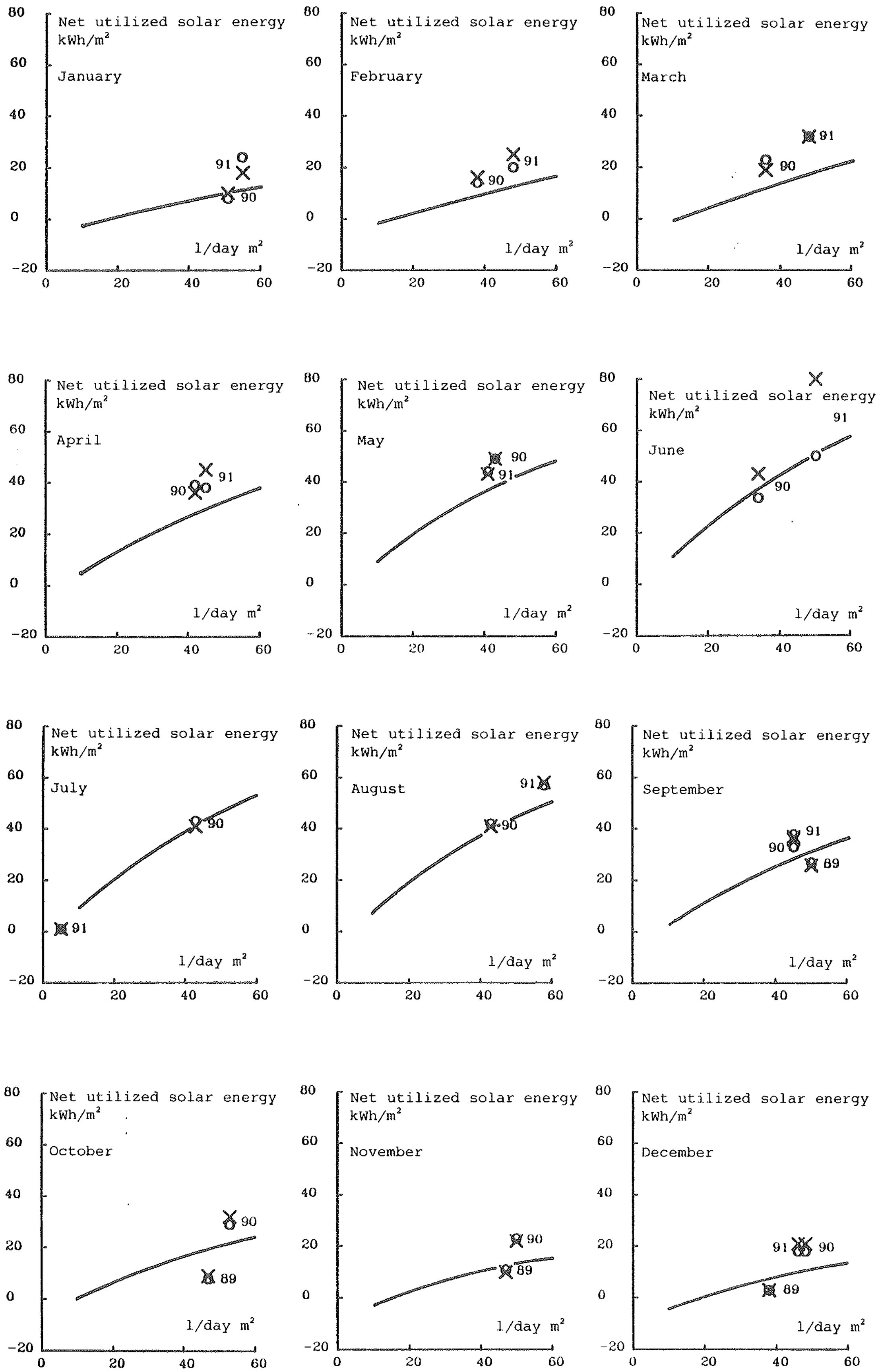
- Calculated thermal performance in the Danish Test Reference Year.
o Measured thermal performance.
x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 14. Calculated and measured thermal performance during the year for the Batec system at Vindeby Strandvej in Svendborg.



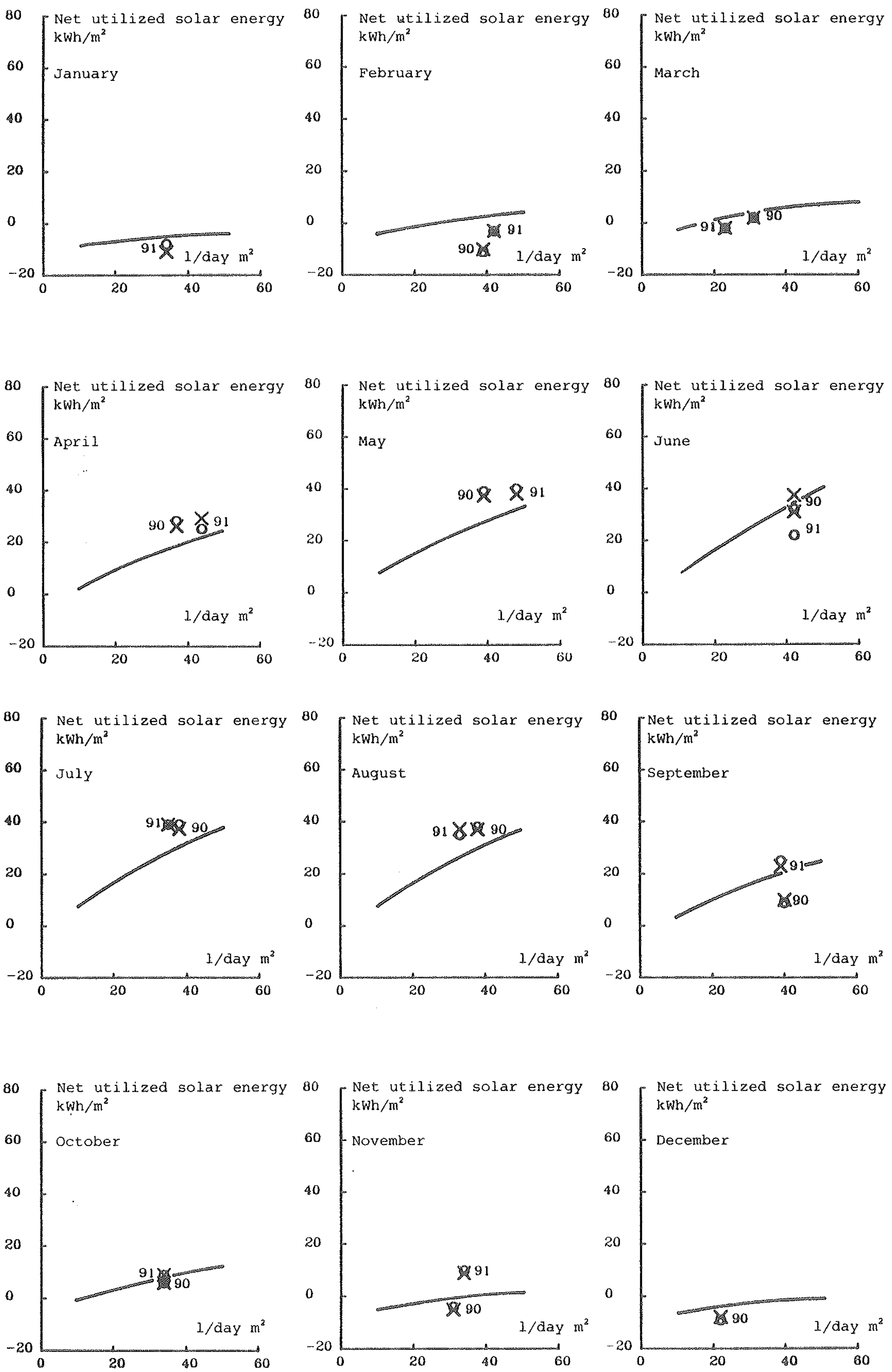
- Calculated thermal performance in the Danish Test Reference Year.
- o Measured thermal performance.
- x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 15. Calculated and measured thermal performances during the year for the Batec system in Svendborg.



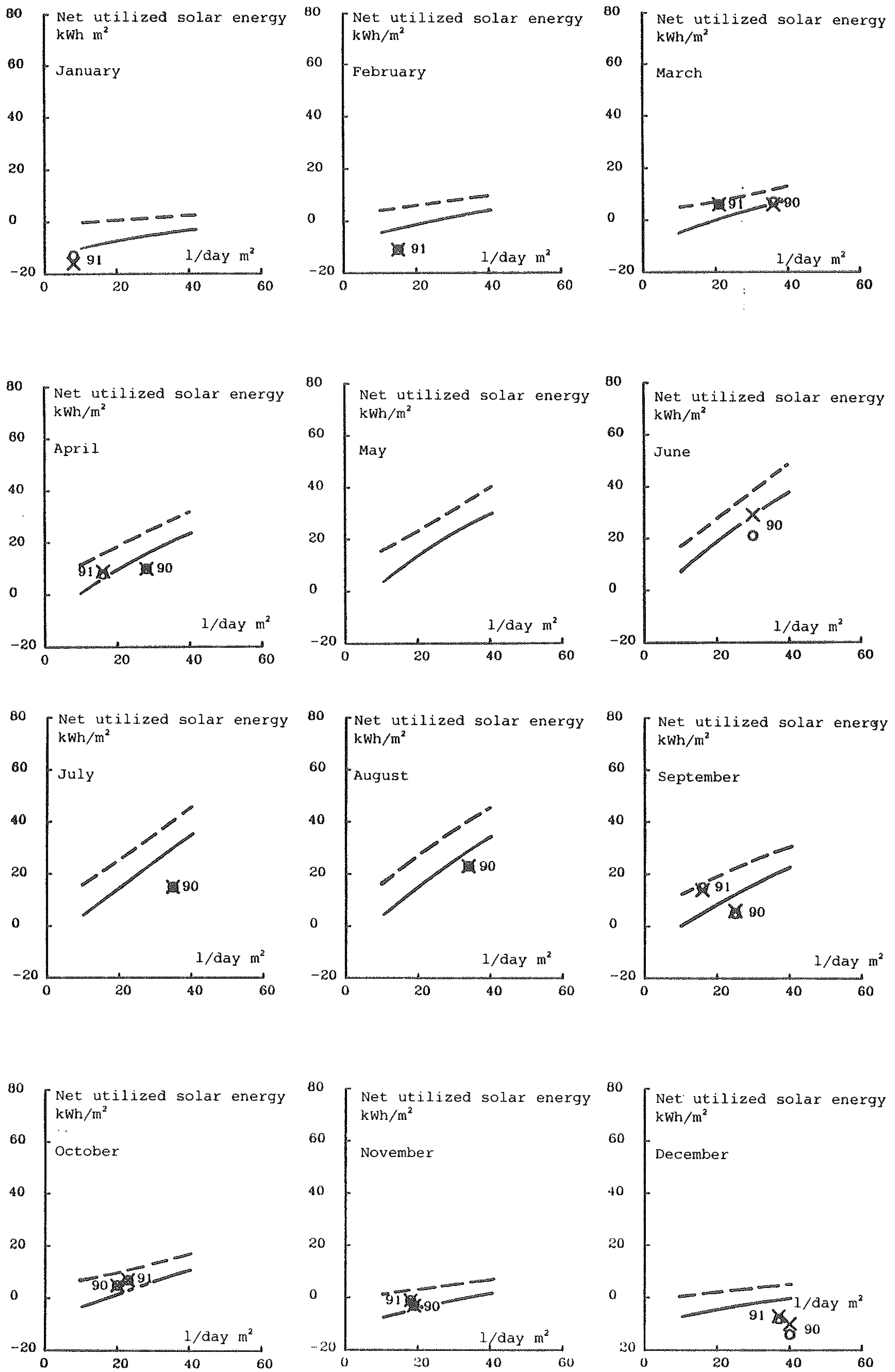
- Calculated thermal performance in the Danish Test Reference Year.
o Measured thermal performance.
x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 16. Calculated and measured thermal performances during the year for the Aidt Miljø system in Hørsholm.



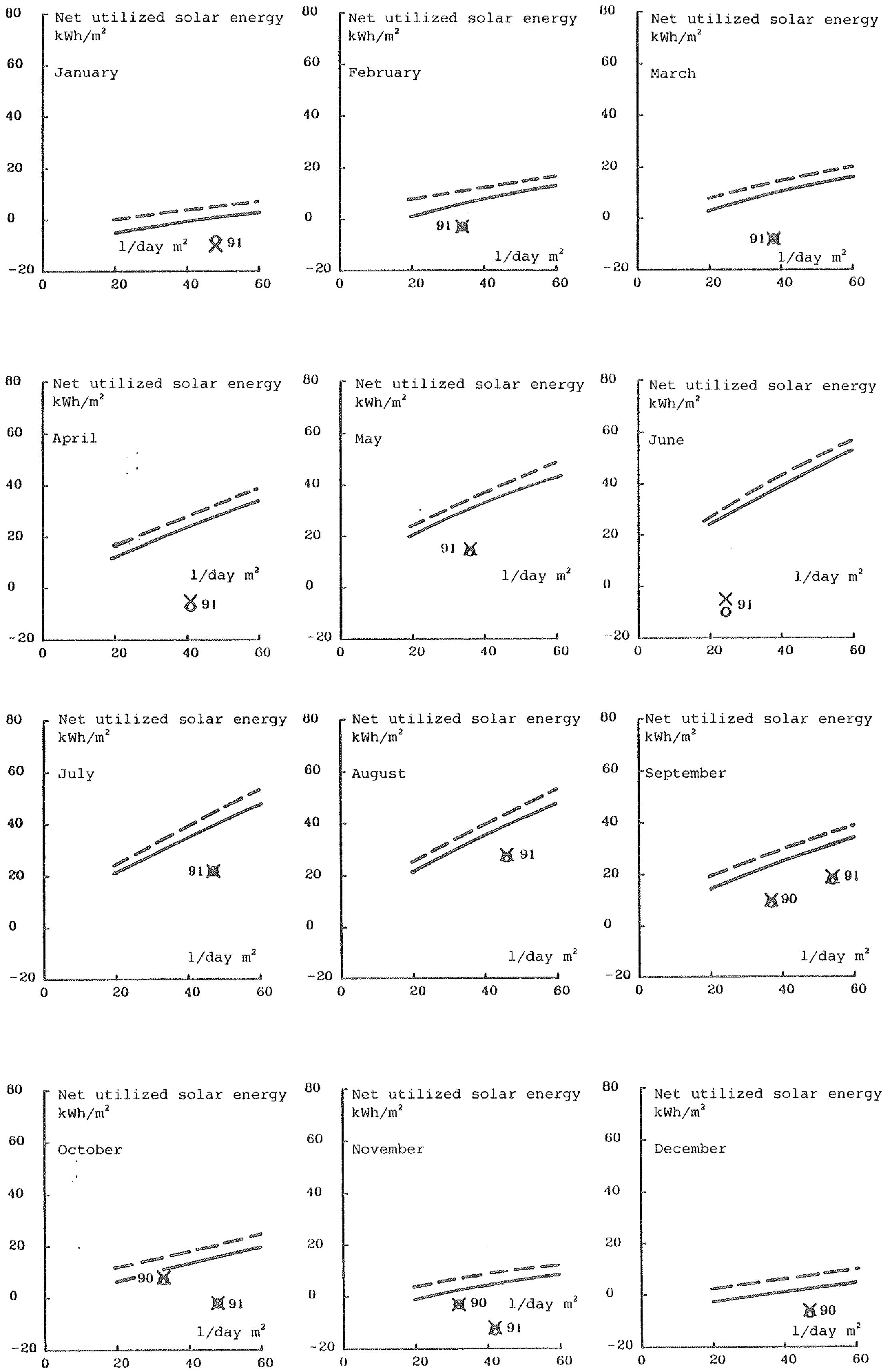
- Calculated thermal performance in the Danish Test Reference Year.
o Measured thermal performance.
x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 17. Calculated and measured thermal performances during the year for the Aidt Miljø system in Hadsten.



- - - Calculated thermal performance in the TRY with the top of the tank heated to 40°C by the district heating network.
—— Calculated thermal performance in the TRY with the top of the tank heated to 90°C by the district heating network.
o Measured thermal performance.
x "Measured" thermal performance in the TRY.

Fig. 18. Calculated and measured thermal performances during the year for the Aidt Miljø system in Brædstrup.



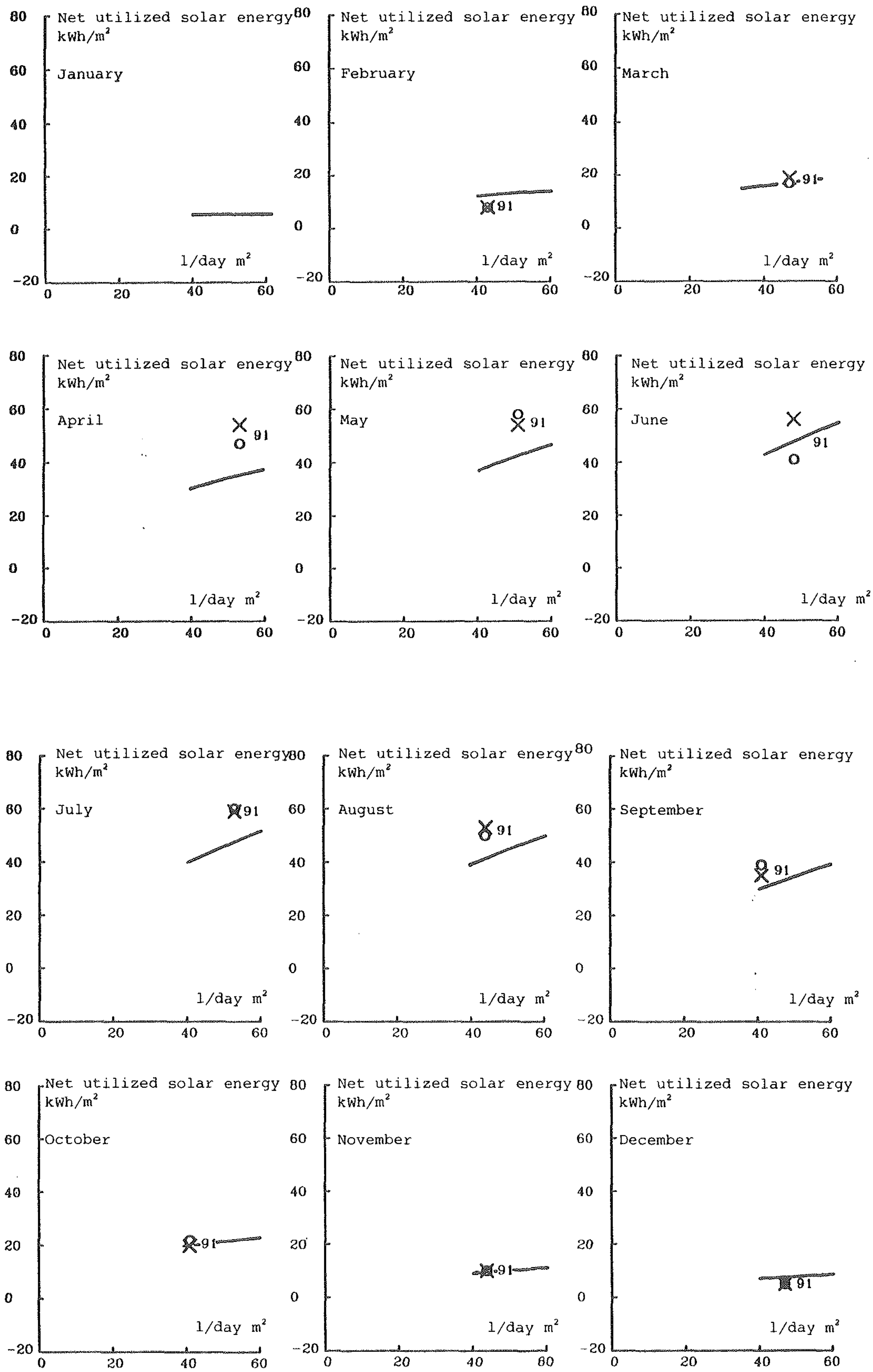
- - - Calculated thermal performance in the TRY with the top of the tank heated to 35° by the auxiliary energy source.

——— Calculated thermal performance in the TRY with the top of the tank heated to 45° by the auxiliary energy source.

o Measured thermal performance.

x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 19. Calculated and measured thermal performances during the year for the Arcon Solvarme system in Kalvehave.



- Calculated thermal performance in the Danish Test Reference Year.
o Measured thermal performance.
x "Measured" thermal performance in the Danish Test Reference Year.

Fig. 20. Calculated and measured thermal performances during the year for the Arcon Solvarme system in Terndrup.

In the figures the measured system performances are indicated for each month. On the basis of the calculations carried out in [10] and [11] a connection between the ratio between the actual solar radiation and the solar radiation of the Danish Test Reference Year, the solar fraction of the system and the ratio between the system performance with the actual solar radiation and the system performance in the Danish Test Reference Year has been established. On the basis of the actual solar radiation and the solar radiation of the Danish Test Reference Year from Table 4 it has in this way been possible to correct the measured system performance so that on the figures are also indicated "measured" system performances with weather data of the Danish Test Reference Year. These "measuring points" can be directly compared with the calculated system performances.

In Figures 21 and 22 calculated and measured yearly thermal performances are shown as a function of the daily mean hot water consumption per m² solar collector for the eight systems. Furthermore are shown the "measured" yearly thermal performances in the Danish Test Reference Year which are corrected for the actual solar radiation being different from that of the Danish Test Reference Year, as well as for the varying hot water consumption in the course of the year. These "measuring points" can then be directly compared with the calculated system performances. However, it should be mentioned that not all the measured yearly performances are for complete years. For instance, as for the system on Vindeby Strandvej in Svendborg, November and December 1990 are not included, while November 1990 and January and February 1991 are not included in the other system in Svendborg. As for the system in Brædstrup the periods January - May 1990 and May - August 1991 are not included, and as for the system in Kalvehave December 1991 is not included. Finally, January 1991 is not included as for the system in Terndrup. In these periods the measured performances are put equal to zero. These conditions ought to be taken into account in connection with the evaluation of the systems.

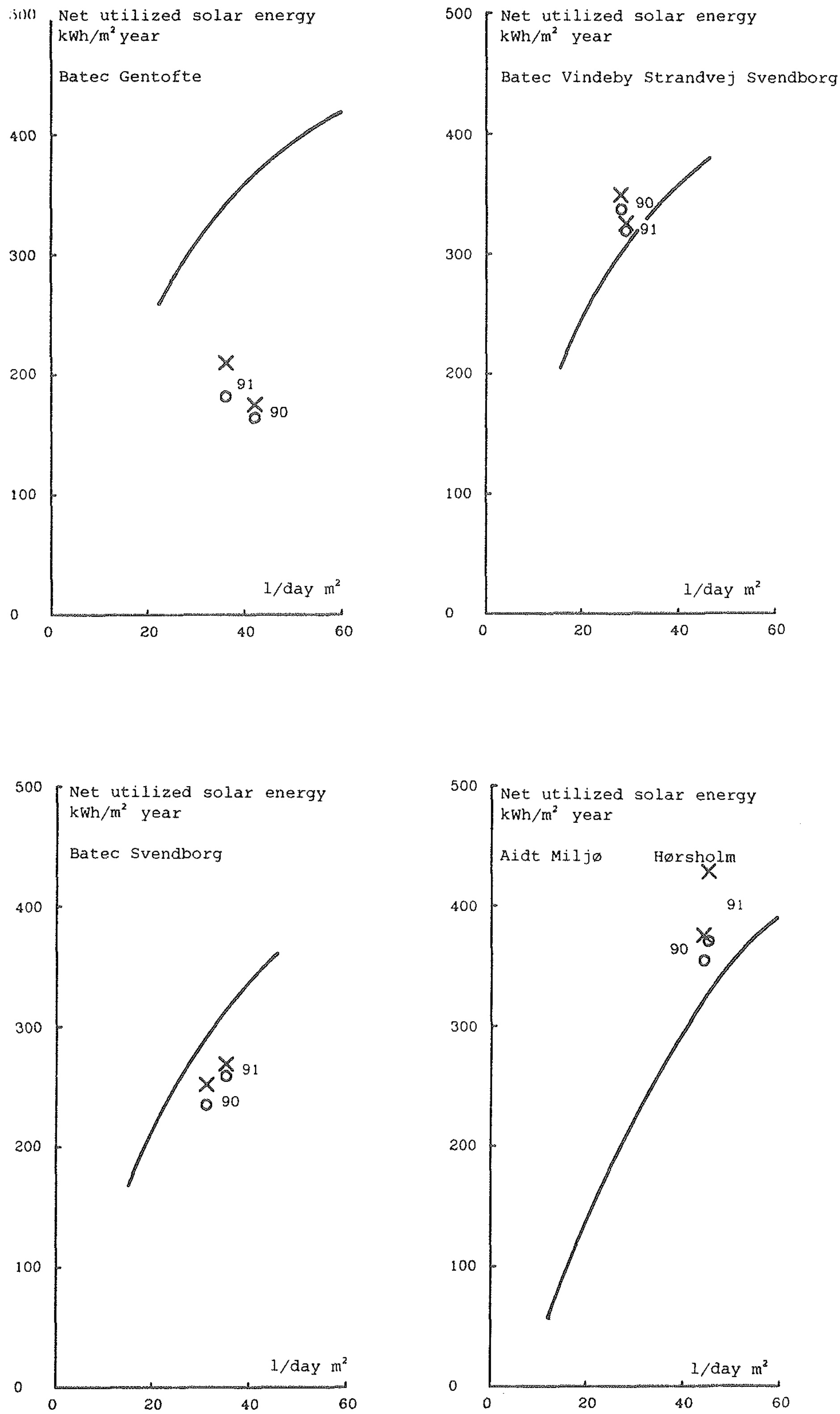
The system performances are evaluated below by means of the Figures 13-22.

As already mentioned the Gentofte system was rebuilt in May 1990, and only after that the system has operated as projected. In summer periods the measured performances have been close to the calculated performances. The measured performances in winter periods and by this the measured yearly performances too have been smaller than the calculated performances. The yearly performance for 1990 is especially small as the reconstruction did not occur before May 1990. The reason for the small performances in winter are the many shadows hitting the solar collector during the six winter months. It can therefore be concluded that the system after the reconstruction has lived up to the expectations. However, it should be noted that the circulation piping did not result in an increased system performance.

The system on Vindeby Strandvej in Svendborg has operated satisfactorily. In sunny periods the system has performed better than expected. The explanation is that the family to some extent has adapted their hot water consumption according to the heat amount in the hot water tank. Thus hot water consumption has been large in sunny periods and smaller in periods with very little sun.

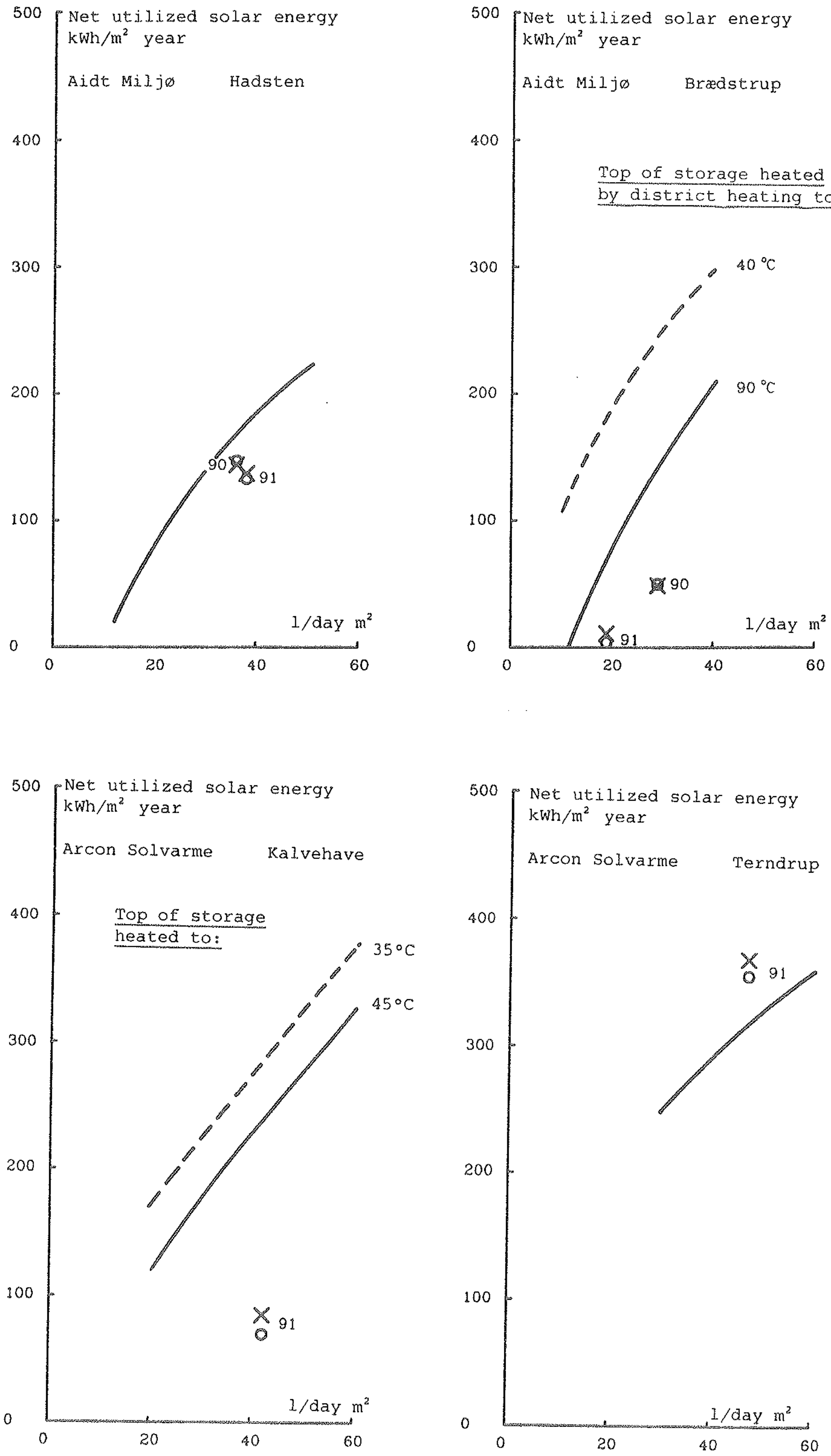
This resulted in especially high solar fractions of the system in summer. The yearly performance for 1990 in Figure 21 is calculated without the contribution for November and December as the system then was not in operation. It can be concluded that the system is functioning extremely well with high performances.

The measured performances of the other Svendborg system are somewhat smaller than the calculated performances. The yearly performance for 1990 is calculated without the contribution for November as the system was not operating in this month, and the yearly performance for 1991 is without the contribution for January and February as the meters were



- Calculated thermal performance in the Danish Test Reference Year.
- o Measured thermal performance.
- x "Measured" thermal performance corrected for weather and consumption variations.

Fig. 21. Calculated and measured thermal performances for the three Batec systems and the Aidt Miljø system in Hørsholm.



———	Calculated thermal performance in the Danish Test Reference Year.
o	Measured thermal performance
x	"Measured" thermal performance corrected for weather and consumption variations.

Fig. 22. Calculated and measured thermal performances for the Aidt Miljø systems in Hadsten and Brædstrup, and the Arcon Solvarme systems in Kalvehave and Terndrup.

Fig. 23. Solar collector and surroundings of the Svendborg system.

broken down at this period. The reason for the relatively low performances is primarily the shadows from the surroundings hitting the solar collectors in the afternoon. Fig. 23 shows the solar collectors in the afternoon. Figure 23 shows both the solar collectors and the building whose shadows hit the solar collectors in the afternoon. The relatively low performances are furthermore caused by a coat of dust covering the solar collectors, resulting in a reduced performance. The dust comes from the harbour of Svendborg where the handling of considerable amounts of corn gives a substantial dust problem. It can be concluded that the system functions satisfactorily.

The measured thermal performances of the Hørsholm system have in certain periods been higher than the calculated thermal performances. However, the difference is not so great that it cannot be explained by measurement inaccuracy, and uncertainty as regards calculation assumptions. It can be concluded that the system functions especially well with high thermal performances.

The measured performances of the Hadsten system came close to the calculated performances. The explanation of the relatively low performances is primarily the high temperatures to which the top is heated by the auxiliary energy source. Here too it should be noted that the circulation piping has not resulted in an increased performance. Finally, it should be noted that the system performances are especially low in the months when the oil burner is heating the top of the hot water tank. The heat is transferred from the oil burner loop to the hot water tank by means of a heat exchanger spiral placed at the top of the tank. The reason for the low performances is due to the fact that in periods when the boiler is off, heat is transferred from the hot water tank to the oil burner loop by means of the heat exchanger spiral. This "inverse" heat transfer is not taken into account at the design of the measuring system as the energy meter used cannot record negative energy amounts. The heat, which in this way is transferred from the tank to the oil burner loop, covers some of the heat loss from the heating system. The amount of heat which actually is supplied to the tank from the oil burner loop in these periods is then smaller than the measured quantities. The real performance of the solar heating system is therefore higher than the measured performance in these periods.

In the majority of the measuring period the performance of the Brædstrup system has been unsatisfactorily small. The low performances can be explained by a wrong control of the heat supply from the district heating network to the top of the hot water tank. The valve for interrupting the heat supply was not able to cut off fluid flow through the heat exchanger spiral in the upper part of the hot water tank. That is why the top of the hot water tank was heated to 90°C for long periods, and this caused an increased heat loss from the top of the storage tank. In September 1991 both the hot water storage and the defective valve were replaced. After this the top of the hot water tank was only heated to 40°C by means of the district heating network. The system seems to have functioned satisfactorily from then on.

As mentioned in section 4.2 the Kalvehave system has functioned very unsatisfactorily. The system was modified by the end of August 1991, but even after this the measured system performances have been low. The main reason for the low performances is the many pipe connections in the top of the heat storage. These pipe connections, as mentioned in section 4.1, cause substantial heat storage losses and low system performances. However, detailed investigations, which include measurements of different system temperatures and of the thermal performance of the solar collector, are necessary to fully elucidate the causes of the low system performances. The framework of this project as regards economy and time did not permit investigations of this kind.

The Terndrup system has functioned satisfactorily, its measured performances were somewhat higher than the calculated performances. The yearly performance is without contribution from January as the system did not get started until February 1991.

As already mentioned the performance of the Svenstrup system was not calculated. On the basis of Tables 13 and 14 it can be concluded that the measured performances are low. The reason for these low performances is a substantial heat loss from the hot water tank. Relatively great amounts of energy are probably lost to the oil burner loop by natural circulation backwards through the mantle. The amount of heat lost in this way, which was not measured, contributes to the reduction of the heat loss in the heating system. Therefore the real performances of the system are greater than indicated in the tables. Furthermore, in some periods without solar energy supply, heat is lost by natural circulation in the heat exchanger loop between the hot water tank and the solar collector loop. Besides, it is difficult to establish and maintain a temperature stratification in the hot water tank, a stratification which is important for the solar heating system, partly because the tank is situated horizontally and partly because the auxiliary energy source not only heats the upper part of the tank - the lower part of the tank too is somewhat heated by the auxiliary energy source. On the basis of the measurements the type of system with the horizontal mantle tank and an external heat exchanger for the heat transfer from the solar collector loop to the hot water tank cannot be recommended.

The measured yearly performances of the well functioning systems have been higher than earlier measured yearly performances of corresponding small traditional solar heating systems [5]. Furthermore, the measurements showed that small low flow solar heating systems are able to function without any operation problems and with performances as high as calculations show. Consequently, small low flow solar heating systems can also in practice perform about 10-20% better than traditional solar heating systems. However, the measurements also showed that it is most important - quite as for traditional solar heating systems - that the systems are dimensioned, designed and installed in the right way. At the design and the installation it is therefore important to take into account the operation experience mentioned in section 4.1.

As already mentioned, the introduction of a circulation piping has not resulted in the expected increased system performance. It is necessary to investigate the best design of a system with circulation piping to minimize mixing in the tank when the water returns to the tank from the circulation piping, and to establish and keep as well as possible the temperature stratification in the tank.

5. CONCLUSION

Nine small low flow solar heating systems for DHW supply were built by three solar collector manufacturers, and the operation of the systems have been followed since the installation.

The investigations showed that small low flow solar heating systems in practice can work without any operation problems and with remarkably high performances.

However, the investigations also showed that it is extremely important that the systems - as is also the case for traditional solar heating systems - are dimensioned, designed and installed in the right way. Only then the systems will be reliable, durable and efficient.

Besides the increased thermal performances, the use of the low flow principle makes it possible to reduce the price of the systems. Today low flow systems are only marketed by one Danish manufacturer. The experience from this project can therefore be of use in connection with the manufacturers' development work so that inexpensive, reliable, durable and efficient low flow solar heating systems can be developed and marketed.

SUMMARY

Nine small low flow solar heating systems for domestic hot water supply have been built by three producers of solar collectors. The operation of the systems have been followed since the installation.

The investigations showed that the promising results from laboratory experiments with small DHW low flow systems can be transferred to practice. Small DHW low flow systems can thus work without any problems with very high thermal performances.

However, the investigations also showed that it is essential to optimize, design and install the systems in the right way. Only in this way the systems will be reliable and durable with high thermal performances.

The design and control of the system should ensure that the heat loss from the heat storage is minimized and that the auxiliary energy source(s) only heat the needed volume of water to the required hot water temperature. Furthermore, thermosyphoning in the solar collector loop during nights and boiling in the solar collector during summer holidays should be avoided.

Furthermore, in systems with a circulation piping it is important that the water returning from the circulation piping enters the hot water tank without causing mixing inside the tank.

The low flow principle makes it possible both to increase the thermal performance and to decrease the costs of the solar heating systems. To day only one Danish manufacturer is producing low flow systems. The experience from this project can therefore be utilized in connection with the developing work of the other producers in such a way that inexpensive, reliable, durable marketed low flow systems with high thermal performances can be developed.

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