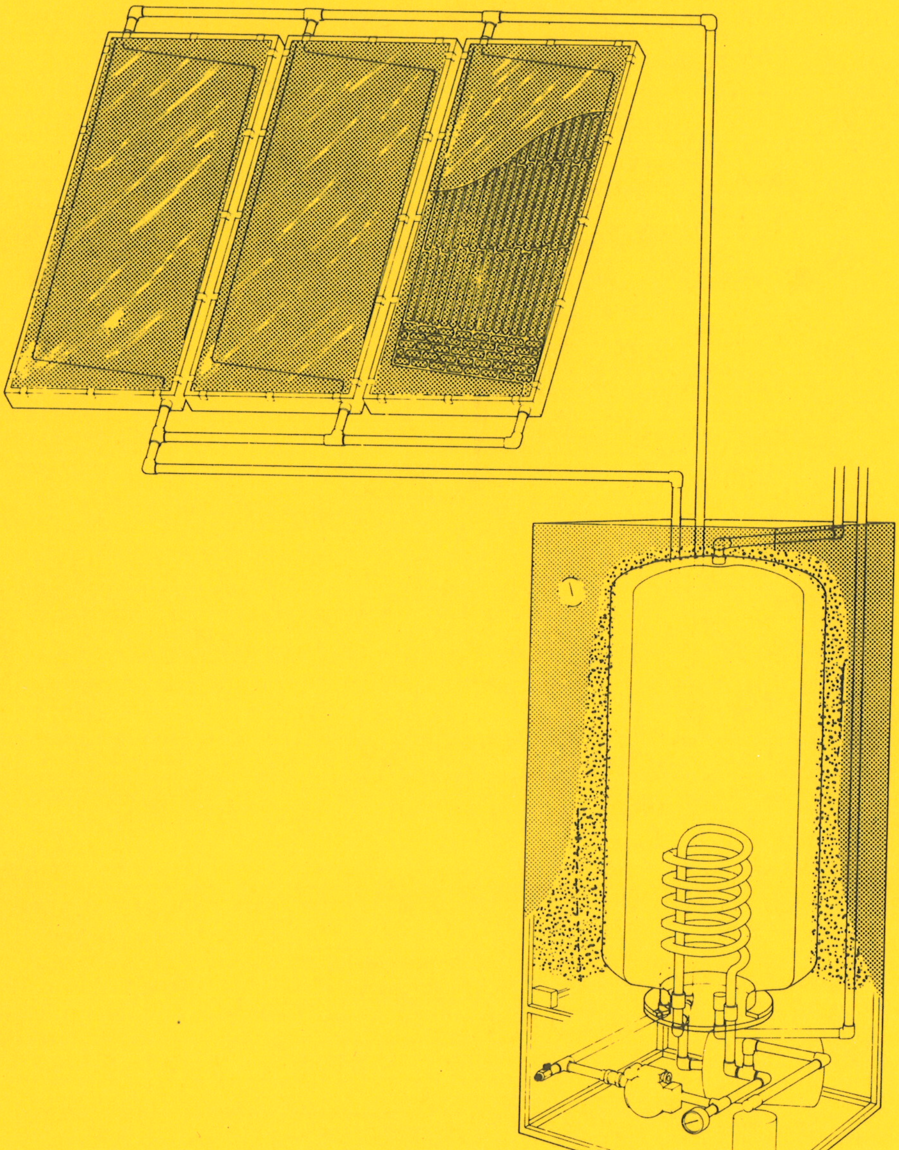
SOLAR SYSTEMS FOR DOMESTIC HOT WATER

The development of an efficient solar system for domestic hot water



Thermal Insulation Laboratory
Technical University of Denmark

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November 1982

THERMAL INSULATION LABORATORY
TECHNICAL UNIVERSITY OF DENMARK

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KLAUS ELLEHAUGE

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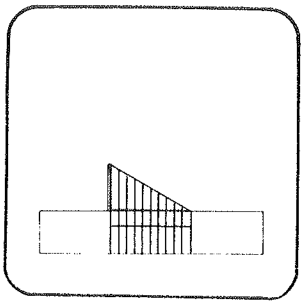
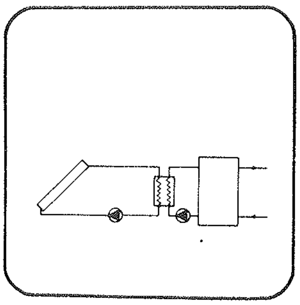
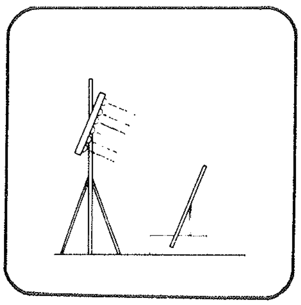
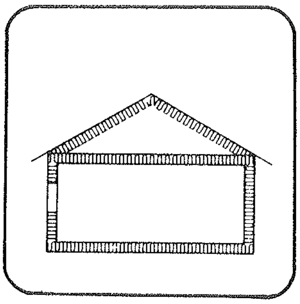
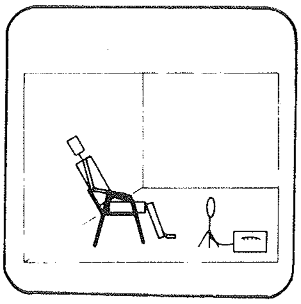
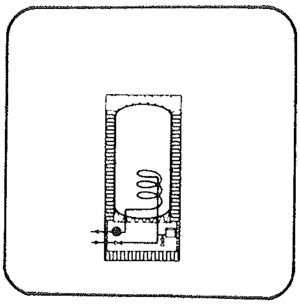
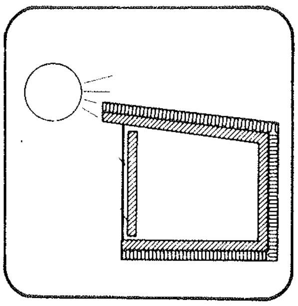
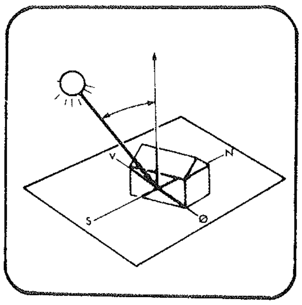

ABSTRACT

Systematic work has been carried out to analyse the function of domestic hot water solar systems for single-family dwellings. In collaboration with manufacturers of solar components a solar system has been developped. This system has been mounted at the laboratory and measurements have been performed for a year.

The system has had a yearly performance of 380 kWh/year m^2 collector and this gives a system efficiency of 38% over a year.

The fraction of solar used for domestic hot water has been 66% over the year while the fraction of solar for six summer months has been about 90%.

These figures show a distinct improvement compared to measurements which have earlier been reported in Denmark and throughout Europe.

The measurements have been used to validate a computer model and with this model a lot of parametric variations have been performed to analyse the system.

The experiment has been followed by three other experiments.

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PREFACE

In this report there is a description of a solar system for domestic hot water which has been developed at the Thermal Insulation Laboratory in collaboration with manufacturers of solar components. The system has been monitored and measurements have shown that the efficiency has been as good as expected. This means that the system shows a distinct improvement compared with previous systems.

Furthermore, the report describes the methodical work which has been carried out at the Laboratory as part of the project. The interaction between theoretical work and practical experiments leads to quick development of improved system design.

This project is part of the Danish Solar Energy R & D programme totally funded by the Ministry of Energy. The results have been described in the Danish report "Solvarmeanlæg til varmt brugsvand", September 1981. The project has been carried out by research engineers Leif Sønderskov Jørgensen, Svend Erik Mikkelsen, Carsten Nielsen and Klaus Ellehauge, while Poul Erik Kristensen has assisted in writing this report.

This project has been followed by new systems, one with an improved collector and one with a smaller storage tank. Furthermore the system has been built in a private house to test the performance under normal conditions.

1. THE BACKGROUND

The project is part of the research and development programme for solar systems which is funded by the Danish Ministry of Energy.

A similar solar system has been built at the Technological Institute and the measurements made there have shown the same results as the results obtained at our laboratory.

The background for this project has been the results obtained under the above mentioned programme in the period 1977 to 1980. During this period some solar system demonstration projects have been carefully monitored. The thermal performance of these systems has not proved as good as expected. Due to the detailed monitoring programme and a subsequent thorough analysis of the monitoring data it was, however, possible to draw detailed conclusions as to why the systems did not perform as expected.

On the basis of this it was decided to build some new improved systems to demonstrate that it is possible to design solar heating systems which perform significantly better (250 - 350 kWh/m^2 per year compared to 80 - 150 kWh/m^2 per year). The first attempt to fulfil this objective is the construction of a solar system for domestic hot water, the BV 300 system.

As part of the BV 300 project a detailed computer simulation of the system has been validated with the measured weather data and it has been possible to predict the monthly and yearly performance of the system very accurately.

Using the validated model, it has been possible to make parameter variations to find the optimal design of the system.

The experiments have previously been made available to a wider audience through the work within the Performance Monitoring Group, funded by the Commission of the European Communities. The project has been described using the standard reporting format developed by this group, as shown in Appendix 2.

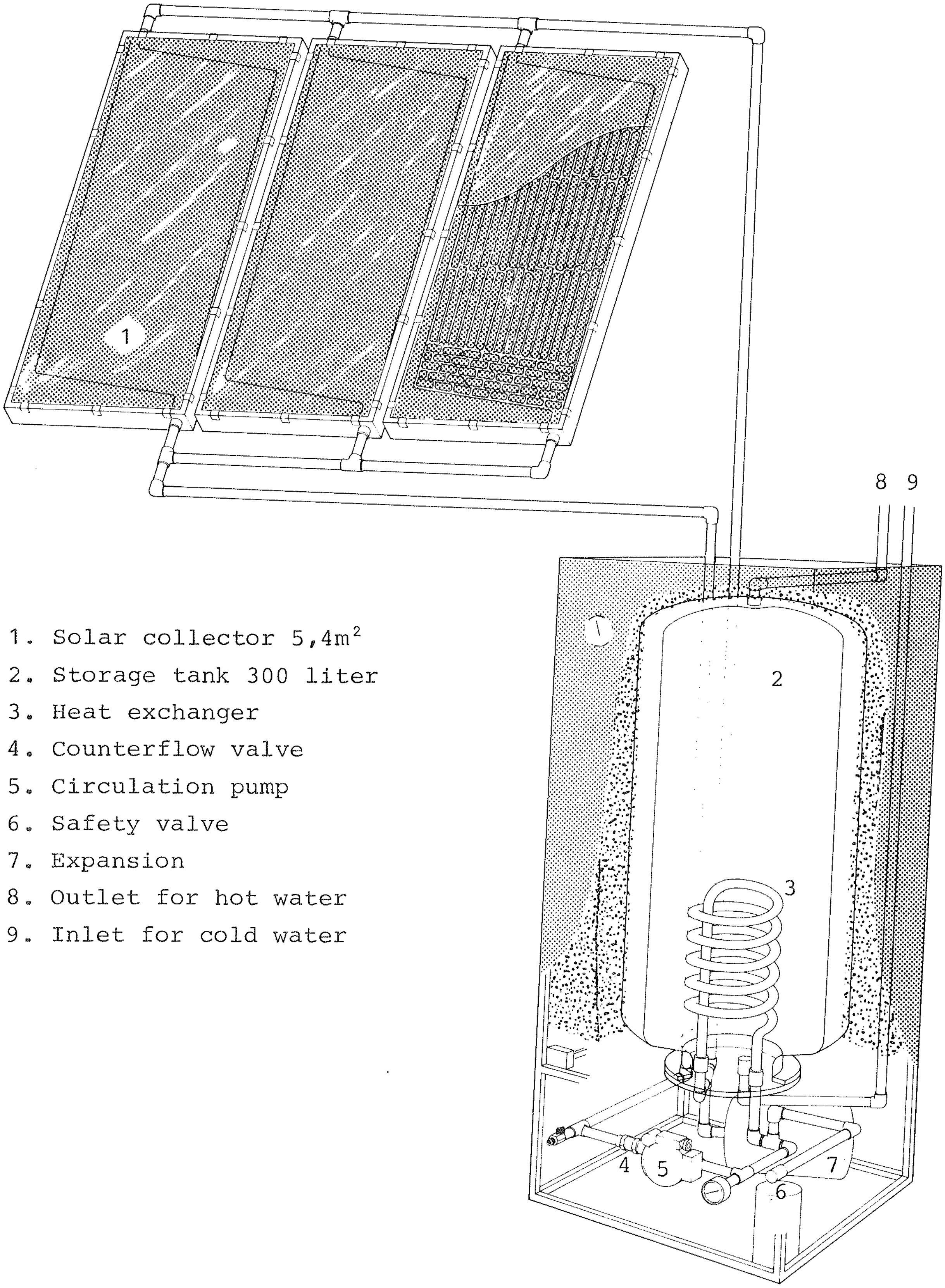
1.1 The results

The solar system is designed for heating of domestic hot water, DHW, in a single-family dwelling. It consists of a 5,4 m^2 flat plate solar collector with a selective absorber and a 300 liter water storage tank with a heat exchanger (see figure 1). The system has been loaded with what corresponds to 200 liter water heated from 8°C to 45°C. This is supposed to match the normal consumption of a family consisting of 4 persons. The results of the measurements made are:

Solar energy for hot water	380 kWh/m^2 year
Solar fraction of hot water	66%

If the solar system is combined with an oil fired boiler it will be possible to turn off the oil burner during the summer. In this way it will be possible to save 62 liter oil/m^2 per year if the oil burner is new (no-load loss 350 W), or 86 liter oil/m^2 per year if the oil burner is old (no-load loss 600 W).

The components and solutions used for this DHW system will not be expensive compared with solutions used in traditional systems and the durability is expected to be equal to that of other systems. Furthermore, the components are or have been available on the market.



1. Solar collector 5,4m^2
2. Storage tank 300 liter
3. Heat exchanger
4. Counterflow valve
5. Circulation pump
6. Safety valve
7. Expansion
8. Outlet for hot water
9. Inlet for cold water

Figure 1.

The system has a high performance because of the following facts.

- the system has been dimensioned for the actual hot water consumption.

- the solar collector has a high efficiency

- there are only small heat losses from storage tank and the piping

- good temperature stratification in the storage tank

- an efficient control system

2. THE SOLAR SYSTEM AND THE MEASUREMENTS

This chapter will give an overview of the information given in the reporting format in appendix 2.

2.1 The solar system and its components.

A diagram of the system is given in figure 2.

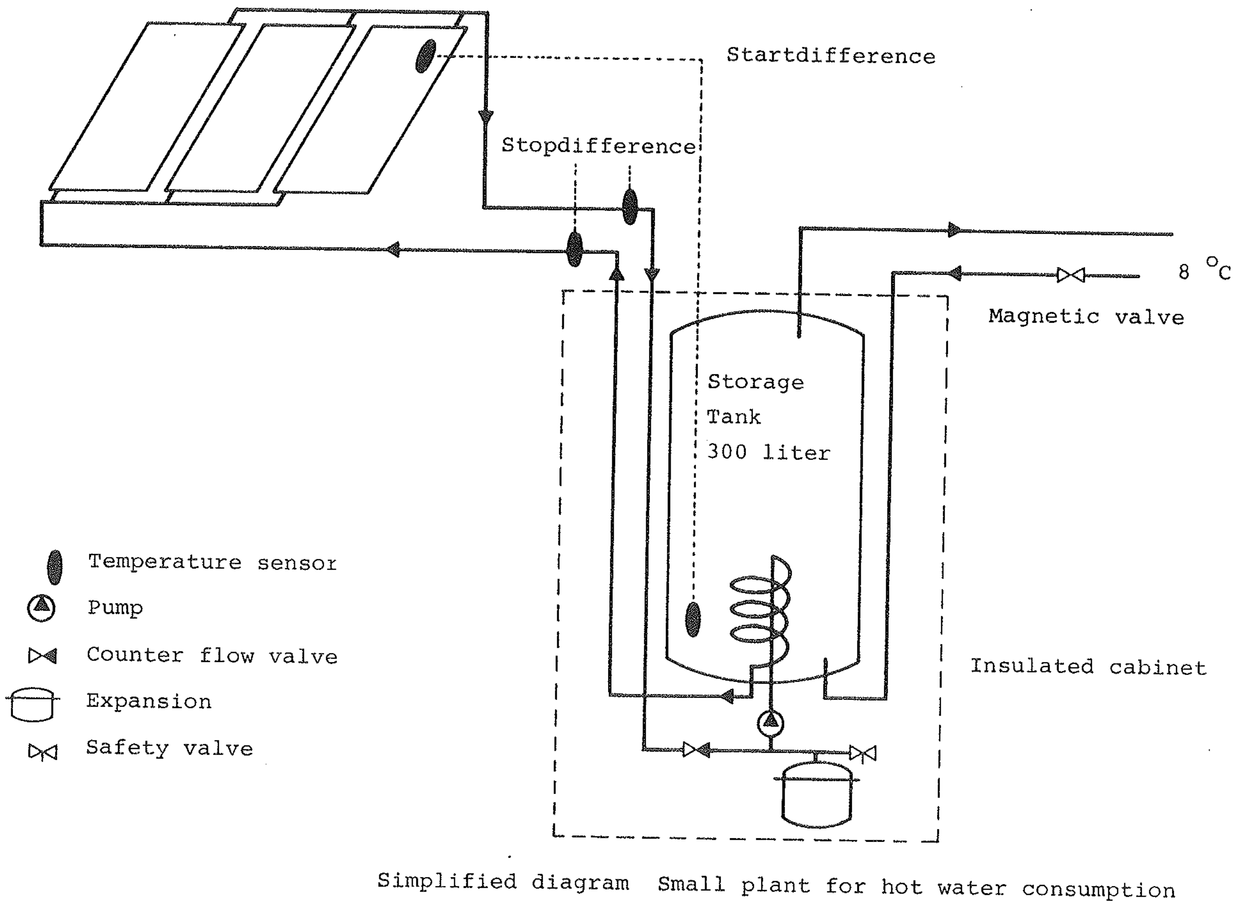


Fig. 2.

It is important that the size of the system fits the consumption. A normal consumption for a single-family dwelling with four occupants could be 200 liter/day heated from 8°C to 45°C. This load is presupposed in the experiment.

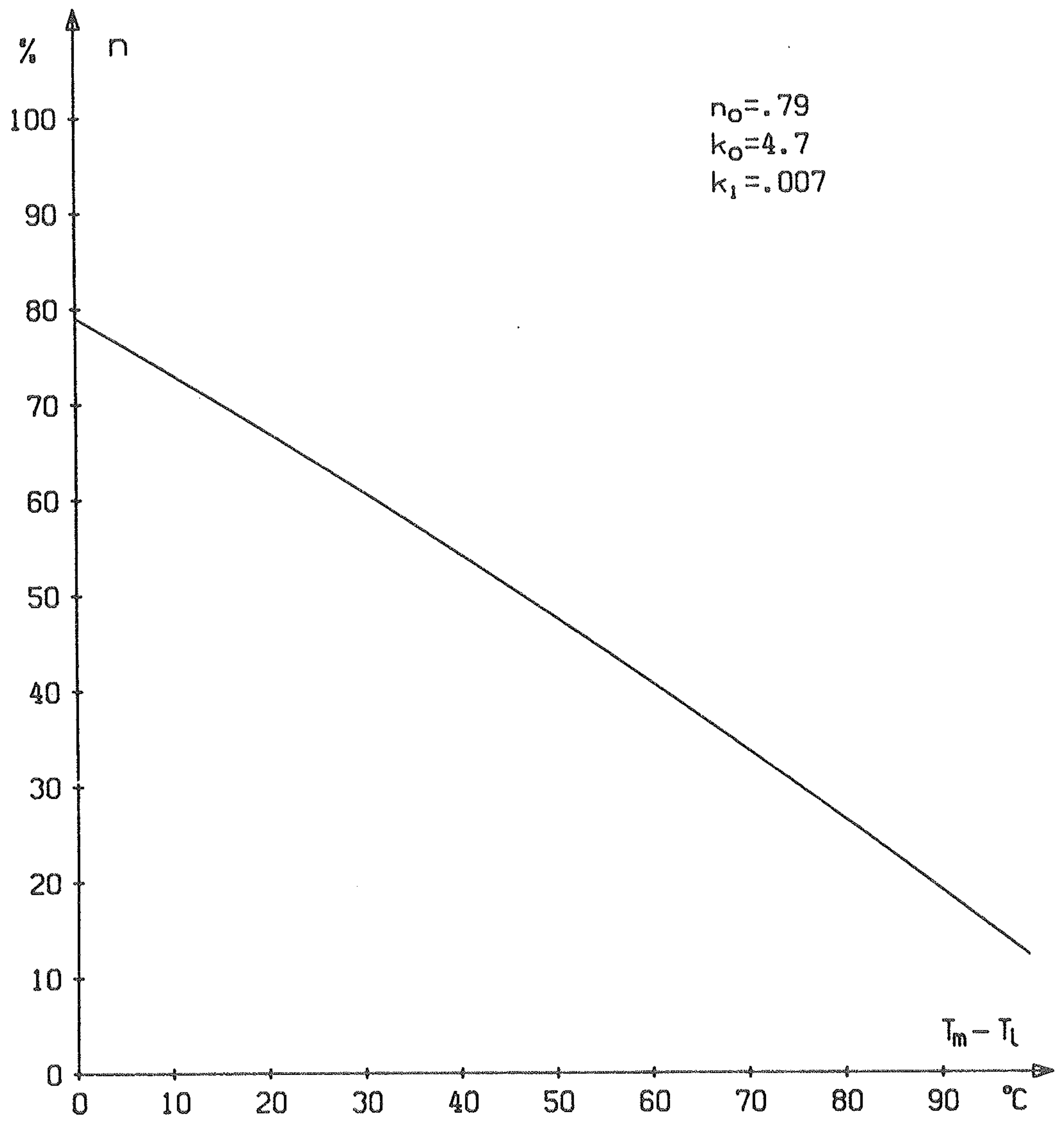
By computer simulations it was found that a collector area of 5,4 m^2 (three panels) would give a high percentage of solar energy used (66% solar fraction) combined with a high production per m^2 solar collector (380 kWh/m^2 per year).

This area is small compared with what has been used earlier for single-family DHW systems.

2.2 The solar collector.

The collector is a Danish produced flat plate collector with single glazing and a roll-bond aluminium absorber. The absorber has a selective surface of "maxorb solar foil". The collector was selected between more than 30 collectors tested at the laboratory.

The thermal performance of the collector is good as shown in figure 3.



Efficiency of collector
Irradiation 800 W/m^2, Slope 45^o
Angle of incidence less than 30^o
Velocity of air at least 5 m/s
Propylene glycol (PKL 30). Flow 0.35 kg/s, area 1.81 m^2
T_m = mean temperature of liquid in collector
T_l = temperature of surrounding air
(Thermal Insulation Laboratory, S. Svendsen, report no. 107)

Fig. 3. Efficiency of solar collector

2.3 The storage tank

The storage tank is a 300 l pressurized tank containing domestic water. It has a small heat loss because of its construction. The storage tank is also produced in Denmark.

At the laboratory there has been a testing of different manufactured storage tanks for solar systems. When the tests were made it was found that only one storage tank which is developed in collaboration with the laboratory, using the experience from earlier testings, could fulfil the demand for a reasonably low heat loss.

For the other storage tanks it was found that the heat losses were equivalent to the heat losses from storage tanks with ideal insulations (i.e. insulations without cold bridges) of only 1 - 2 cm though the actual thicknesses of the insulations were bigger.

This means that you will have to be very much aware of the effect of cold bridges, especially cold bridges at the top of the storage tank.

Ideal thicknesses under 5 cm is critical for the production of the solar system.

For the actual storage tank the thickness of the ideal insulation was found to be 4.5 cm.

A figure of the storage tank is shown in figure 4. Nearly all the tubings and supportings are located in the bottom of the tank. The thermal bridges will then be eliminated most of the time as the bottom is cold.

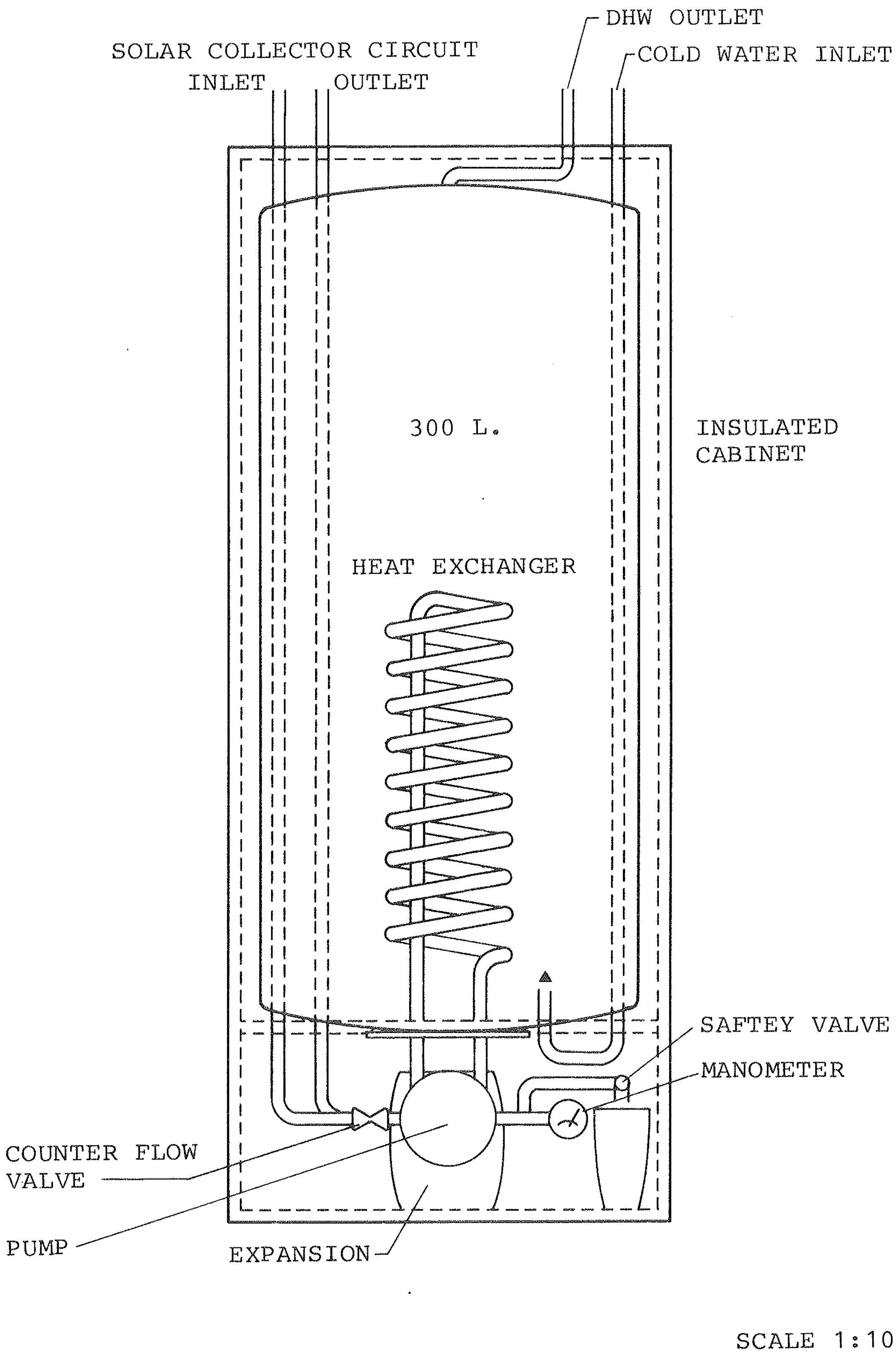


Fig. 4. Storage tank

The inlet of cold water is found at the bottom of the tank and the outlet of hot water at the top, which ensures a good stratification.

The heat exchanger is placed in the lower half of the tank and this always permits the solar collector to work on the colder part of storage.

The pump, valves etc. are placed under the tank and have been insulated within the same insulation as the tank. This means that heat losses from these components are decreased.

3. MEASUREMENTS

Measurements have been performed by a computer-based datalogger system. The system is shown in figure 5.

The same datalogger simulates the tappping of hot water by operating a magnetic valve.

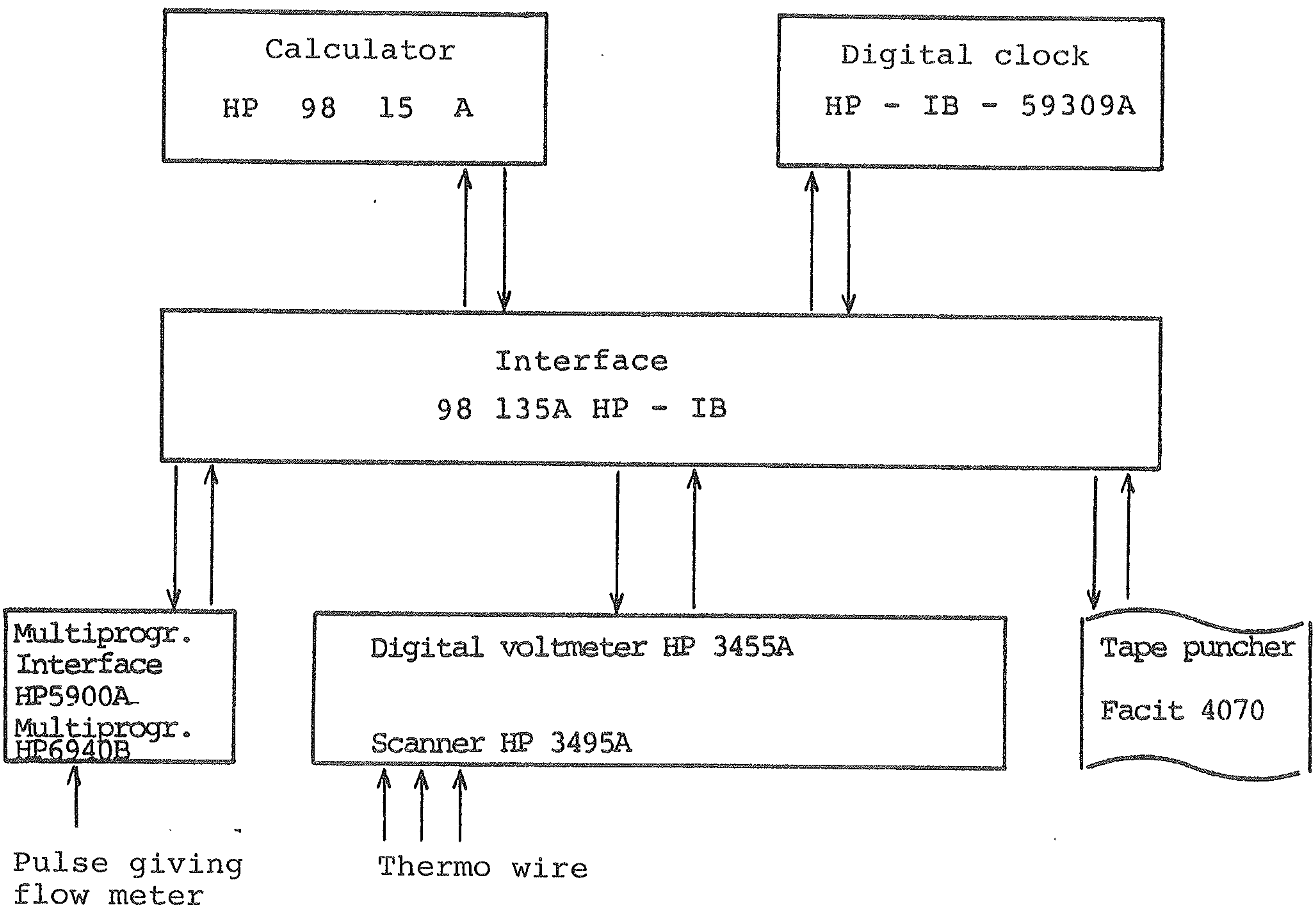


Fig. 5 Measuring equipment at the Thermal Insulation Laboratory

The tapping is done 4 times a day. Each tapping is equivalent to 50 liters water of 45°C, i.e. if the storage temperature is below 45°C 50 liters are tapped, if the temperature is more than 45°C an amount of water is tapped which contains energy equivalent to 50 liters of water at 45°C. The inlet temperature to the storage is kept at 8°C.

At every tapping the following parameters have been measured

- the tapped energy
- mean temperature of the cold inlet water
- mean temperature of the hot water tapped
- the amount of water which is tapped

The results are punched on papertape and together with weather data which are measured at the Laboratory these results are handled by the central computer at the University.

The parameters are measured with a very good accuracy. The temperatures are measured with thermo couples of copper constantan connected to a precision voltmeter.

This gives a accuracy of $\pm$0.5-1,0^{o}K on absolute temperatures and $\pm$0.1-0.15^{o}K on temperature differences. Temperature differences are measured using thermopiles of 10 elements.

The flow is measured with an Aqua-Metro ring piston meter with a precision of less than 2% in the range in which it is used.

Measurements have been performed from 1.July 1980 until 1.July 1981.

The system has been functioning without problems in this period but due to other problems there has, however, been losses of measurements in 5% of the time. In this period simulated values using actual weather data have been inserted as measured values. Because of the very few values which have been inserted in this way, this doesn't affect the conclusions.

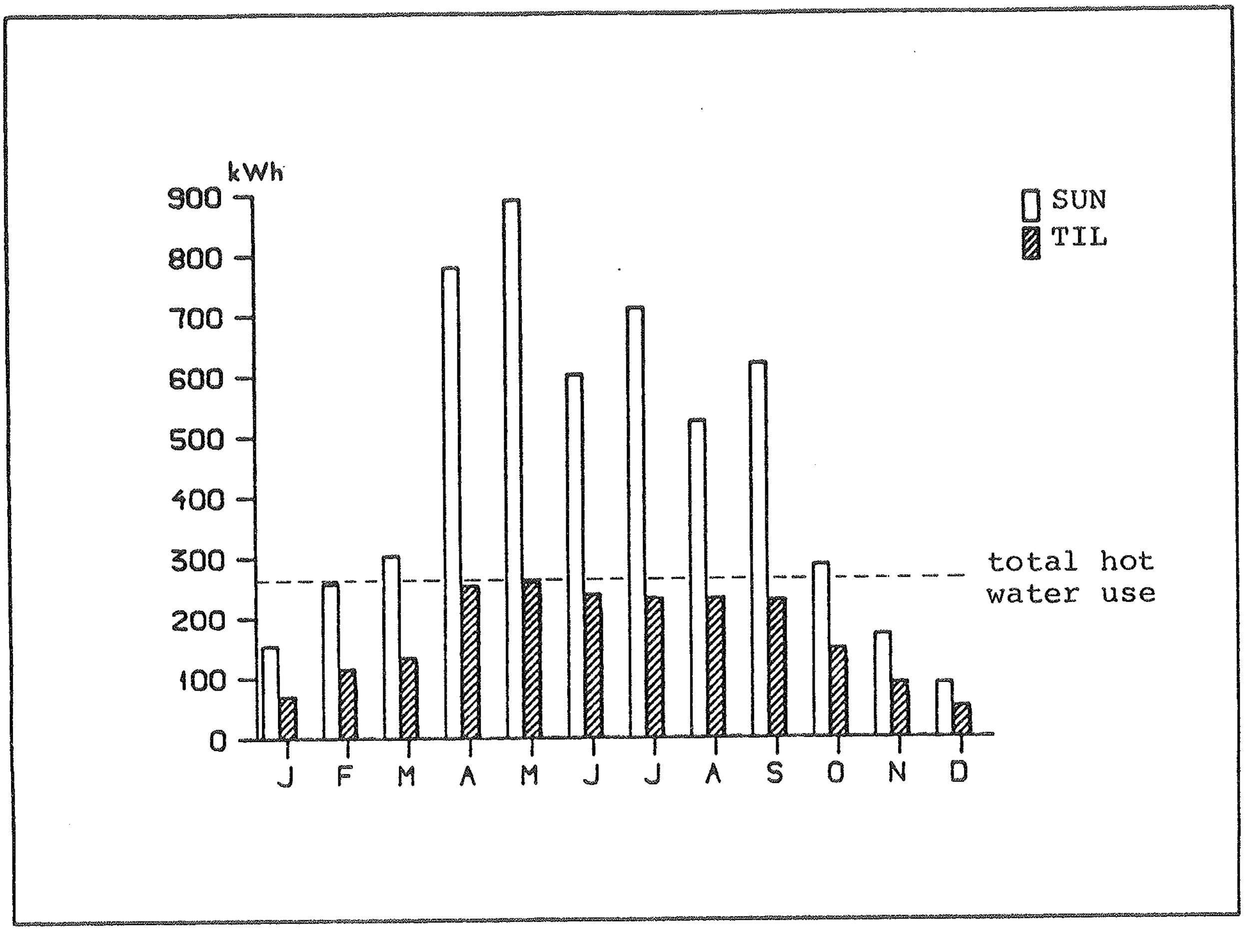
The measured values on monthly basis are shown in apppendix 2.

The system has delivered in one year:

2050 kWh solar heated water, or
380 kWh per m^2 solar collector

The fraction of solar has been 66%.

In the summer months, April to September, the fraction of solar has been appprox. 90%. (See figure 6).

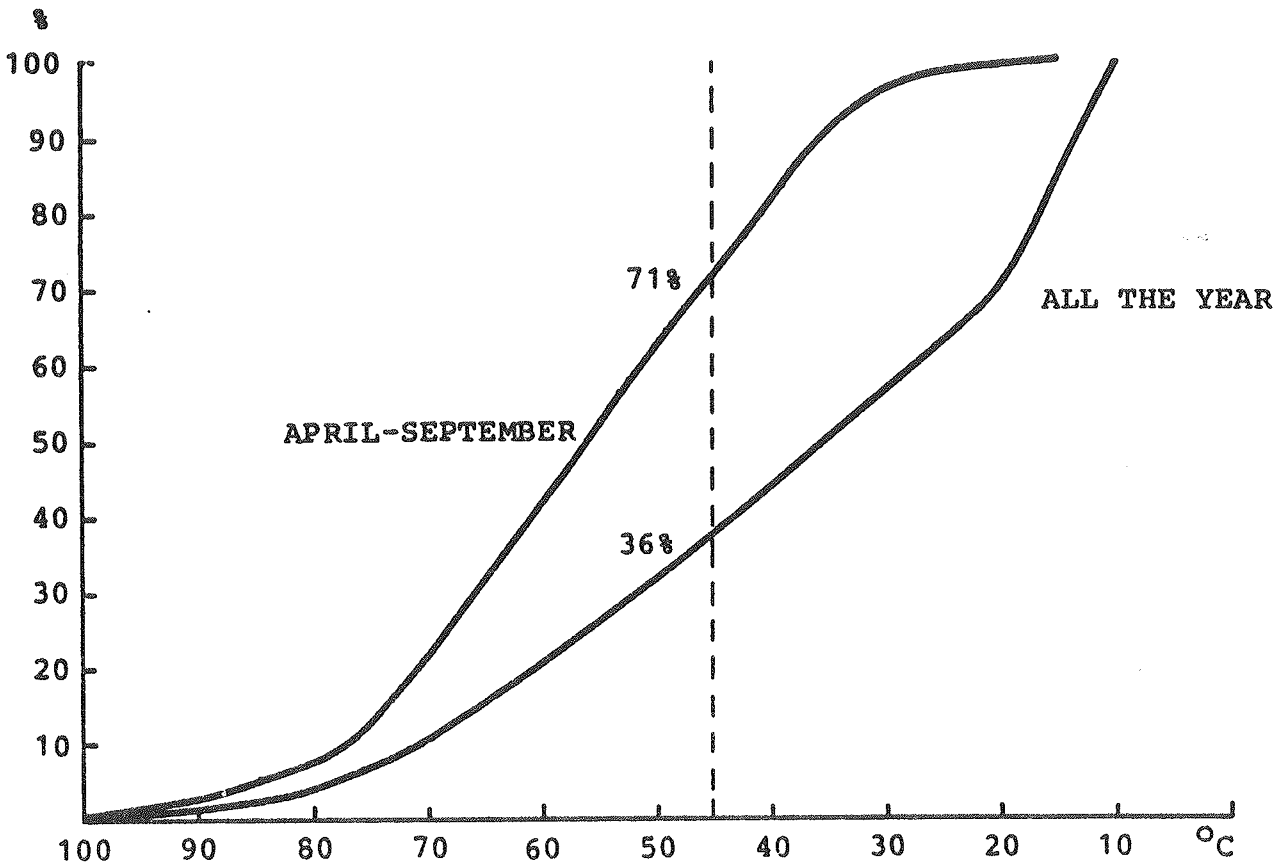


SUN: Insolation measured at the Thermal Insulation Laboratory

TIL: Solar energy used, measured at the Thermal Insulation Laboratory

Fig. 6 Measured insolation and performance

The tapping temperature has been as shown in figure 7.



Distribution of tapping temperatures

Example: In the summer the tapping temperature has been higher than 45°C for 71% of the time. For all the year the tapping temperature has been higher than 45°C for 36% of the time.

Fig. 5 Distribution of the tapping temperatures for the plant at the Thermal Insulation Laboratory.

4. COMPUTER SIMULATIONS

At the Laboratory a computer model for the system has been worked out. The model has been validated against the measurements and it is found that the model is able to simulate the solar system very accurately (see figure 8).

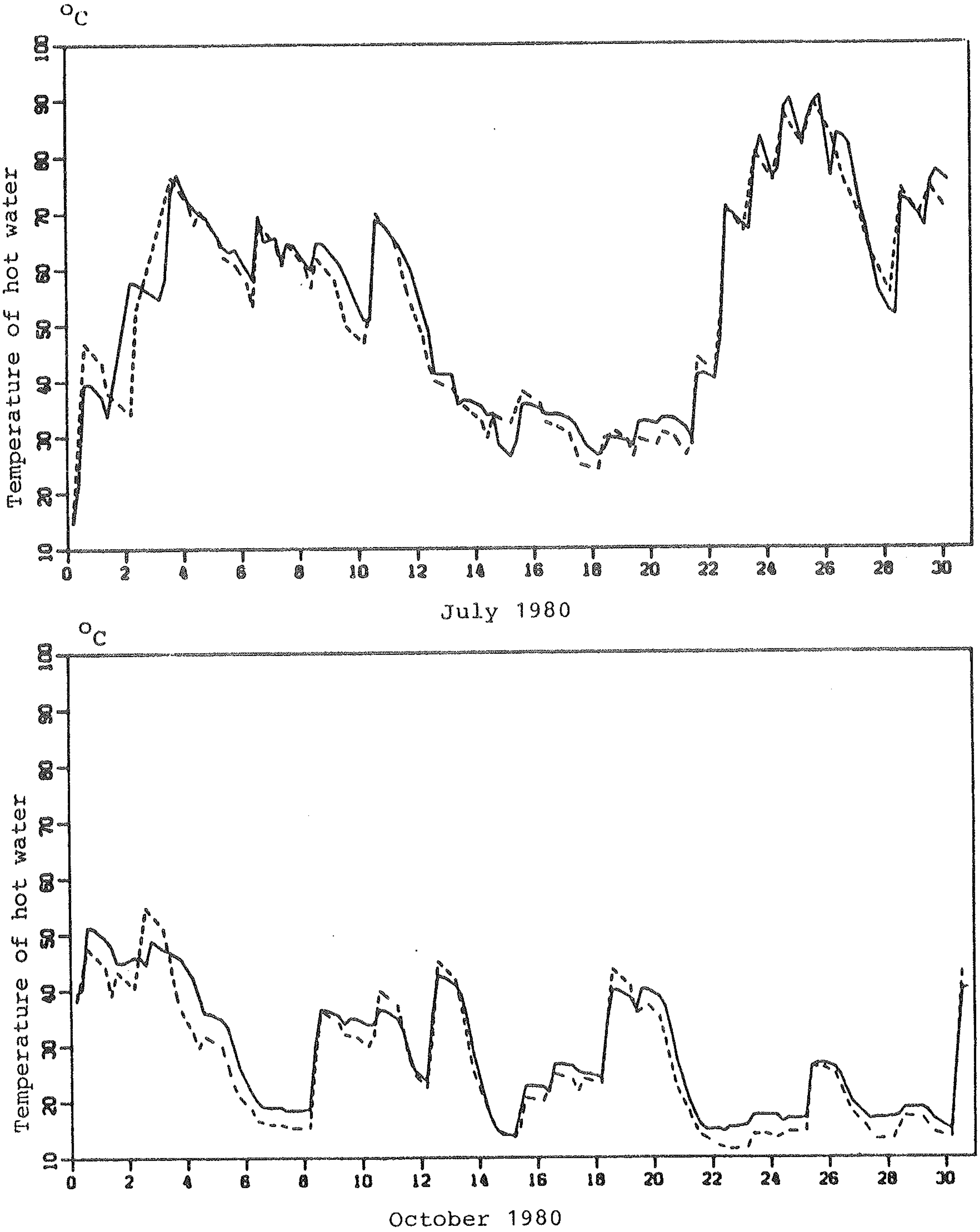


Fig. 8

_____ Measured temperature of hot water

----- Calculated temperature of hot water

For a year the result has been

	solar used	fraction of solar
Measured	2052 kWh	66%
Calculated using measured weather data	2011 kWh	64%

The monthly values are shown in figure 9. In the figure values calculated with weather data from a "normal" year, the socalled Danish Test Reference Year (new version) are also shown.

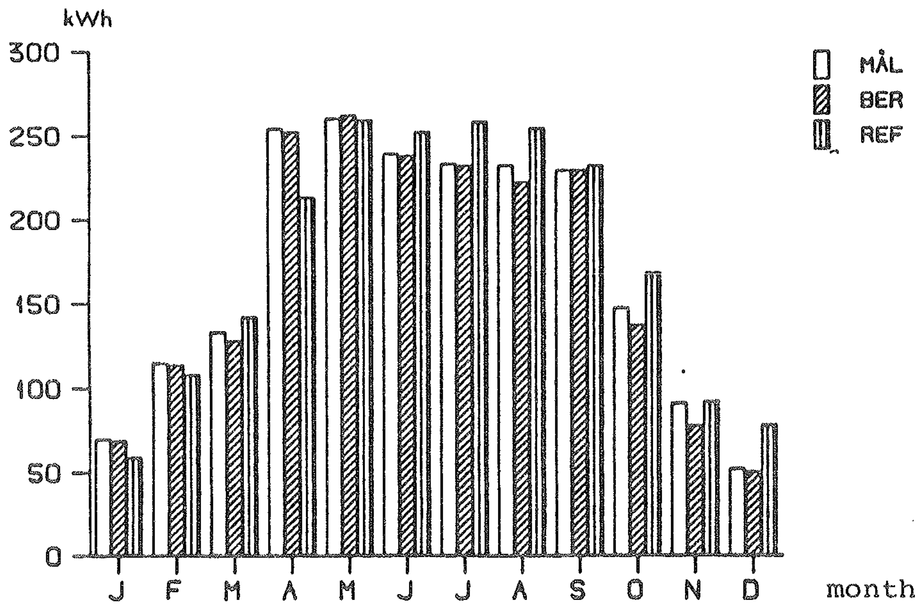


Fig. 9

Mål: Measured solar heat used, (total = 2052 kWh/year)

Ber: Solar heat used, calculated with actually measured weather data, (total = 2011 kWh/year)

Ref: Solar heat used, calculated with weather data from the"Danish reference year"

The model has then been used to investigate the effect of variations in the solar system design and in the weather data. It has also been used to investigate the effect of variations from the programmed tapping of hot water from the system.

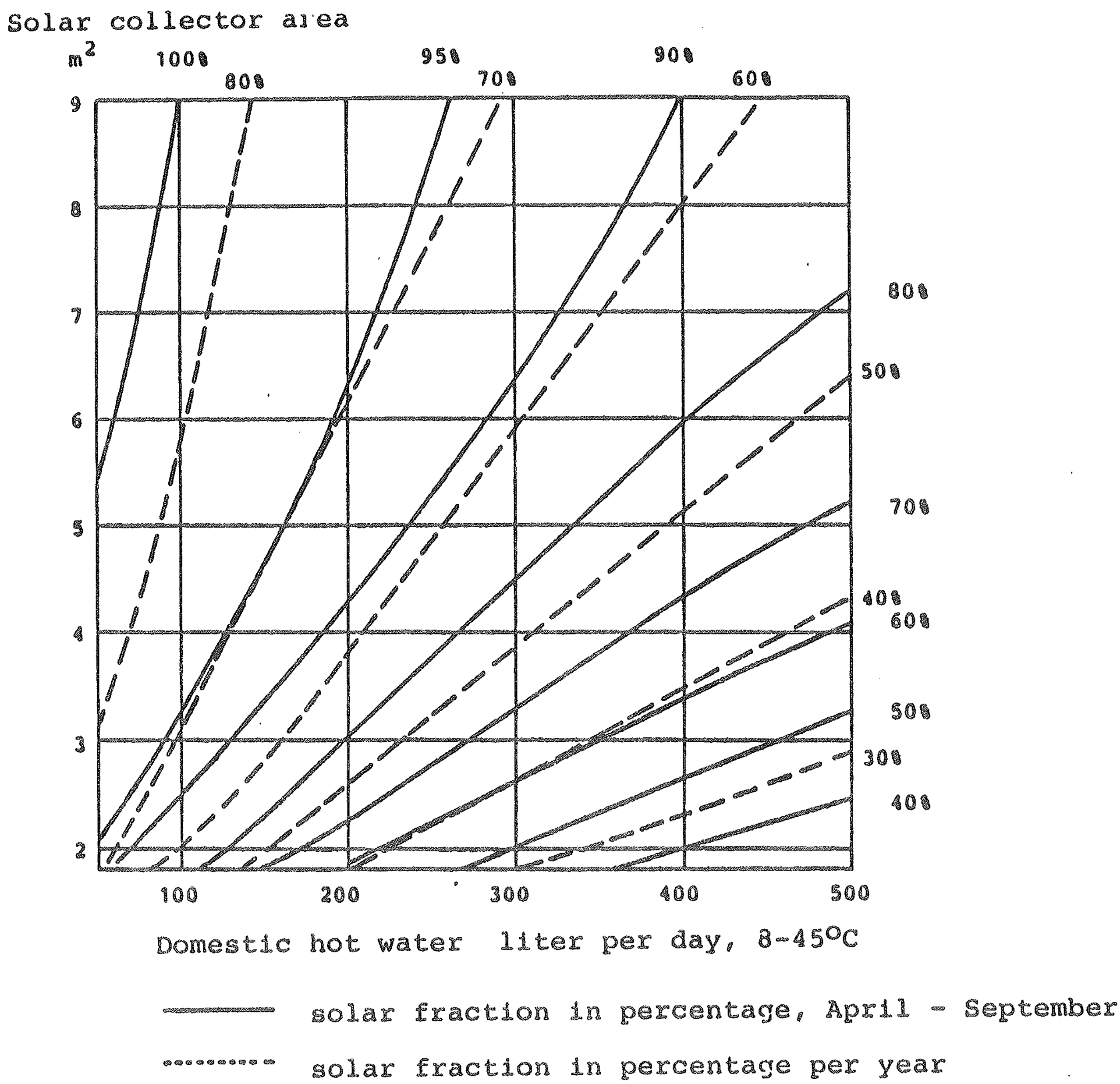
With the reference year the calculated yearly solar energy used is 2110 kWh so the measured 2050 kWh could be taken as quite normal for Danish conditions.

The reference year is used as basis for the following calculations.

In the calculations different parameters are varied to investigate the influence on the efficiency of the system.

4.1 Solar collector area and hot water consumption

By the calculations it is found that the solar collector area and the average hot water consumption are the two most important factors influencing the performance of the systems. If the other components of the system are chosen within reasonable limits, it is possible to find the necessary collector area knowing the hot water consumption and the requested percentage of solar supply. This is shown in figure 10.



Assumptions:

Collector: Efficient, selective coating facing south 45° inclination

Storage: 0.3 m³, stratified, small heat loss, sufficient heat exchange

Weather data: "The Danish reference year"

Fig. 10 Solar collector area - solar fraction in percentage - domestic hot water consumption.

4.2 Volume of storage tank

According to the model the volume of the storage tank could be half the actual storage tank volume with a performance which is only 3% smaller. This item is now being especially investigated as a system like this is now being monitored at the laboratory.

The volume has on the other hand an important influence on how often the storage temperature will exceed a high level. With a volume of 0.3 m^3 the temperature will be exceeding 95°C only 4 days a year. With a volume of 0.15 m^3 the figure is 25 days.

4.3 Influence of the programmed tapping of hot water

The programmed tapping is made 4 times a day.

With the model it is shown that this daily tapping programme gives the same production of the system as a more realistic tapping programme.

The model calculations also show that the production is not influenced if there is no consumption during the week-end assuming that the missing week-end consumption is distributed over the other days in the week. This means that the distribution of the consumption over the day and over the days in the week within certain limits is not important, but it is the average consumption that determines the production of the system.

If the variation in the daily tapping, however, is very large this might cause problems. This item and other related problems are being investigated in a current project.

It is also shown that two weeks with no tapping in a period with a high solar input (i.e. at summer-time) reduces the yearly production with only 6 - 7%, which is nearly the same as the reduction in the consumption.

4.4 Solar collector without selective coating

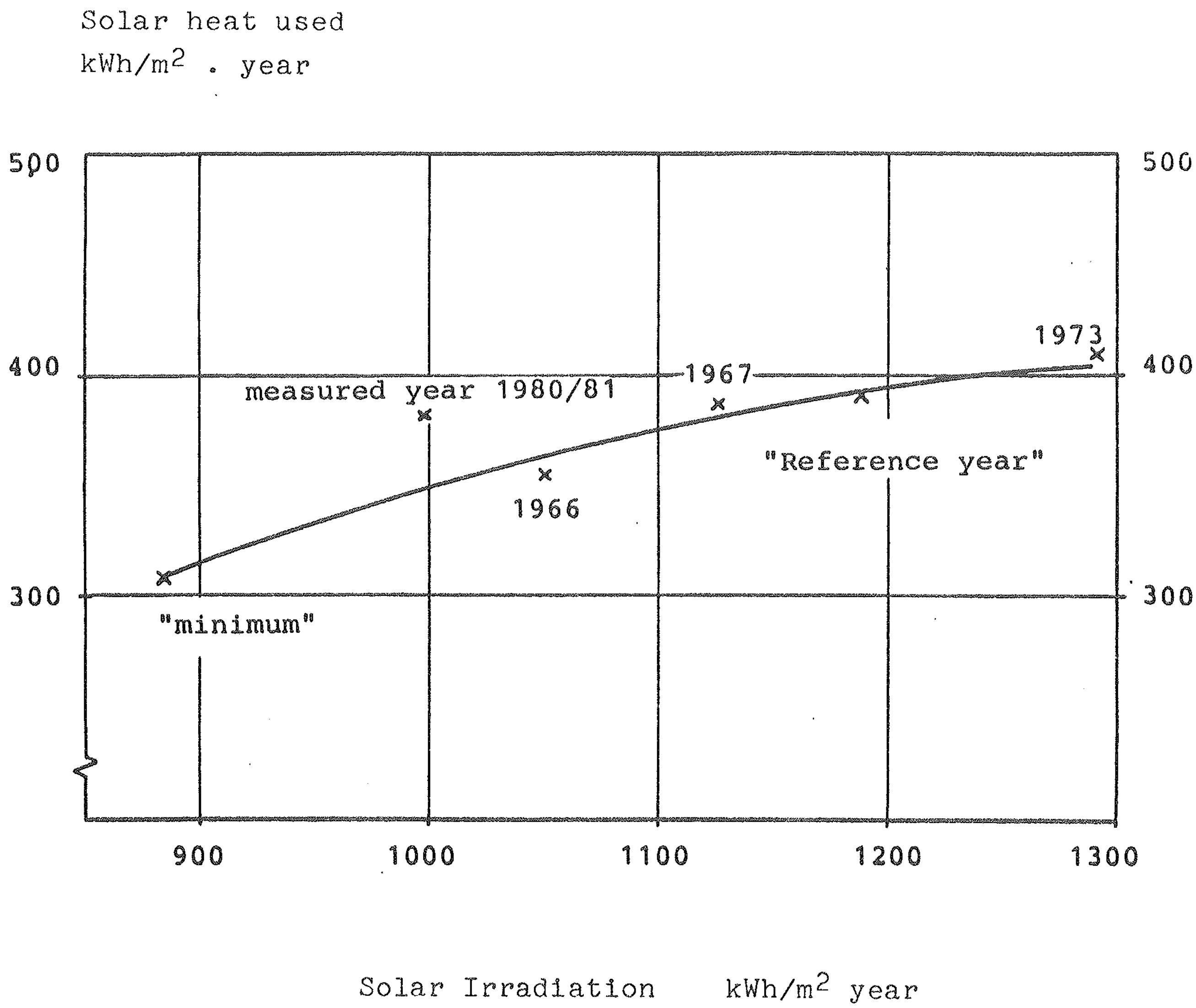
It is found that the production would be 10% smaller if a collector without selective coating is being used. If you wish to have the same production using a collector without selective coating, the collector area should be chosen to 8.4 m^2 instead of 5.4 m^2.

4.5 Stratification in the storage tank

If there had been no temperature stratification in the storage tank the production would have been 7% smaller than with a stratified storage tank.

4.6 Calculations with other weather data

If we use the model with measured weather data from other years compared to the reference year, it is found that the measured performance is very representative for Danish conditions. (This is shown in figure 11). The validated model has also been run with weather data from other countries as shown in table 1.



1973, 1967 and 1966 are the highest, the medium and the lowest year respectively of weather data measured in 15 years, minimum is a year made from the worst months of the 15 years.

Fig. 11. Solar energy used, calculated for different weather data.

In the measured year the production has been high compared to the low solar irradiation. The reason for this is that the solar irradiation has been especially low in the summer months but not equally low during autumn and spring.

Table 1: Thermal Performance of the BV300 system using weather data for different locations

Location	North Latitude	Annual Solar Radiations 45° facing south kWh/m^2 . year
1. Carpentras, The South of France	44.03	1758
2. Trappes, The North of France	48.48	1209
3. Ireland	51.57	1198
4. Copenhagen	55.41	1189
5. Hamburg	53.30	1101

Solar collector Area, m^2	Location 1 Y	f	2 Y	f	3 Y	f	4 Y	f	5 Y	f
1.8	1062	62	726	42	708	41	692	40	651	38
3.6	735	85	543	63	545	63	512	59	481	55
5.4	531	92	416	72	427	74	391	68	368	64
7.2	411	95	333	77	345	80	313	72	297	68
9.0	334	96	275	79	288	83	261	75	248	71

Y = Solar heat gain, kWh/m^2 . year f = Solar fraction in percentage

5. ENERGY SAVINGS

The energy savings have been calculated in 3 cases:

1. The system installed in an electrically heated house.

2. The system installed in a house heated by a new oil-fired boiler (no-load loss from the boiler 350 W)

3. The system installed in a house heated by an old oil-fired boiler (no-load loss from the boiler 600 W)

In the last two cases it is supposed that the oil burner is turned off for 4 1/2 months in the summer when there is no need for space heating. The hot water will then be delivered by the solar system with back-up in the form of an immersed electric heater in the storage tank.

The system has for a year delivered 2050 kWh from the storage and it has used 120 kWh electric energy for the pump in the solar circuit.

The hot water consumption has been 3120 kWh.

1. Electrically heated house

A. Energy use in house without solar system

hot water	3120 kWh
heat loss from water tank	200 kWh
	3320 kWh

B. Energy use in house with solar system

hot water 3120-2050 kWh =	1070 kWh
(heat loss from storage was covered by solar)	
pump	120 kWh
	1190

energy saving 3320-1270 = 2130 kWh

2. House heated by a new oil-fired boiler
(no-load loss from the boiler 350 W)

A. Energy use in house without solar system:

hot water use	3120 kWh
no load loss for 12 months	3066 kWh
	6186 kWh

caloriferic value (net) og oil 9.85 kWh/l
Efficiency 0.85

This equals $\frac{6186}{9.85 \times 0.85}$ = 739 liter oil

Electrical energy for oil burner (12 months)
12 x 3.3 kWh = 40 kWh electric energy

B. House with solar system

The oil burner is turned off for 4 1/2 months in the summer

hot water use for 7 1/2 months	1950 kWh
solar energy used for 7 1/2 months in the winter	-980 kWh
no load loss for 7 1/2 months	1916
	2886 kWh

This equals $\frac{2886}{9.85 \times 0.85}$ = 345 liter oil

Use of electricity

electric energy for oil burner 7 1/2 months	25 kWh
electric energy for pump in solar system	120 kWh
electric energy for immersed heater for 4 1/2 months	150 kWh
	295 kWh

Energy savings.

oil: 739 - 345 = 394 liter oil

electricity: 40 - 295 = -255 kWh

3. House heated by an old oil-fired boiler
(no-load loss from the boiler 600 W)

A. Energy use in house without solar system

hot water use	3120 kWh
no-load loss, 12 months	5256 kWh
	8376 kWh

Caloriferic values (net) of oil 9.85
Efficiency 0.80

This equals $\frac{8376}{9.85 \times 0.80}$ = 1065 liter oil

B. House with solar system

The oil burner is turned off for 4 1/2 months in the summer

hot water use for 7 1/2 months	1950 kWh
Solar energy used for 7 1/2 months in the winter	-980 kWh
no-load loss 7 1/2 months	3285 kWh
	4255 kWh

This equals $\frac{4255}{9.85 \times 0.80}$ = 540 liter oil

Energy savings

oil: 1063 liter oil - 540 liter oil = 523 liter oil

electricity: the increase of electricity used will be as in case 2: 295 kWh electricity

6. OTHER EXPERIMENTS

The experiment has been followed by 3 experiments which are related to the BV300 experiment.

6.1 Gl. Holte

A system similar to the BV300 has been installed in a single-family house in a suburb of Copenhagen called Gl. Holte 8 km north of the Technical University. The house is occupied by 2 adults and 2 children.

Measurements have been performed since 1 January 1982 and will continue for one year. It is the purpose of the project to demonstrate the BV300 system in practice.

The installation has been without problems and the functioning of the system has been good during the winter.

6.2 BV400

In the original BV300 system the solar collector has been replaced by one one with an even better thermal performance and the system has been operated with an electrical heater at the top of the storage tank to secure a minimum tapping temperature of 45°C. Measurements have been made from July 1981 to May 1982 and the measurements will be evaluated.

6.3 VV150

At the same location as the BV300 system the laboratory has installed a system like the BV300 system but with a storage tank of only 150 liter (BV300 had a storage of 300 liter). Computer calculations have shown that the solar energy gain should not be influenced very much by the smaller storage tank, but it was desirable to investigate this in practice. Measurements have been performed since March 1982.

APPENDIX 1. COMPONENTS OF THE SOLAR PLANT

Solar Collector

Make: HS-Kedler, Box 30, 6880 Tarm

Cover: 1 layer of glass

Absorber: Roll-bond aluminium plate with channels and selective cover of "Maxorb solar foil"
Absorption coefficient greater than 0.95
Emission coefficient smaller than 0.12

Area: 5,4 m^2 (3 panels)

Storage tank

Make: Solarmatic, Nordre Beddingsvej 35, 3390 Hundested.

Volume: 300 liters

Dimensions: 80 x 80 x 175 cm (inclusive insulation)

Design: Rilsan prepared steel tank with lid at the bottom in which heat exchanger and tube inlets are placed. The tank is placed in a steel frame so that the cold bridges are to be found at the bottom of the tank.
The tank and the insulation are placed in a cabinet. Pump, tube connections, expansion tank, valves etc. are confined in the insulated cabinet..

Insulation: On an average 50 mm mineral wool between tank and cabinet. There has been added an after insulation of 50 mm polystyrene plates around the cabinet.

Heat loss coefficient: By a single measurement the heat loss has been found to be 1.3 W/^{o}C.

Solar collector circuit

Tube dimensions:	5.2 m of 15 mm copper tubes and 2.0 m of 18 mm copper tubes
Heat exchanger:	9 m copper rib tubes bent in spiral. It should be noticed that in this experiment there have been no problems concerning depositing of calcium as it is the same water which is recirculated for the tapping.
Fluid:	Pkl 300 (propylene glycol)
Amount of fluid:	Solar collector 3.5 liters Tubes 2.2 liters Heat exchanger 1.8 liters in all 7.5 liters
Expansion tank:	8 liters, 6 bars
Pump:	SMC Commodore 130-45 W
Non-return valve:	Ball valve (CN)
Insulation:	60 mm Armaflex and 22 mm Armaflex. Heat loss coefficient piping: 2.1 W/^{o} (calculated)

Control

A control with 4 sensors are used	1 sensor is glued at the back of the absorber. 1 sensor is to be found inside the tank in a brass block thermally insulated from the tank and at a height straight in front of the heat exchanger

	1 sensor is placed in an immersion pocket at the inlet to the heat exchanger. 1 sensor is placed in an immersion pocket at the outlet from the heat exchanger.
Starting difference:	1°C
Stop difference:	0.3°C

As sensors are used thermoelement wire controlled by micro computer.
Ni 100 resistance sensors are further used for a later utilization of a difference thermostat.

The control with 4 sensors is used to ensure optimum operation conditions, but a control with 2 sensors would be sufficient.

PMG

PERFORMANCE MONITORING GROUP

Reporting Format for Solar Heating Systems

Domestic Water Heating Systems

Project Name: Test rig for domestic hot water (BV300)

Location: Thermal Insulation Laboratory, Lyngby

Country: Denmark

Completed by: Klaus Ellehauge date: September 1981

Commission of the European Communities

PROJECT DESCRIPTION

ref: DHW LYNGBY
project: t.i.l. DHW test rig

1

Photograph

actual solar collectors to the left on building

Participating Organisations

Monitoring: Thermal Insulation Laboratory, Technical University of Denmark, Building 118, DK-2800 Lyngby, Denmark.

Funding: Ministry of Energy, Strandgade 29, DK-1401 Copenhagen, Denmark.

Design: Thermal Insulation Laboratory, Technical University of Denmark, Building 118, Dk-2800 Lyngby, Denmark.

Contact for further information: Klaus Ellehauge (M.Sc.engineer)
Thermal Insulation Laboratory, telephone 02 88 35 11
Building 118, DK-2800 Lyngby, Denmark.

Description of Project

A domestic hot water system has been mounted on a cabin placed at the laboratory's 'test-area'. The solar system has been carefully dimensioned so as to produce about 90% of the hot water supply during the six summer months for a family consisting of two children and two adults. If there is no need for room-heating during the summer it will be possible to turn off the oil-burner of the house for six months if the last 10% of the hot water supply is delivered by electric heating. Even if the system has had a high productivity it has been smaller and not more expensive compared with similar systems.

Main Objectives

The main objective is to demonstrate that a carefully designed domestic hot water system using efficient components can have a higher production without being more expensive than similar domestic hot water systems.

It has been the objective to measure on the system for one year.

SUMMARY

ref: **DHW** LYNGBY
project: t.i.l. DHW test rig

2

Building

Building Type: A cabin used for experiments with solar systems

No. Occupants (Actual): -

Site Latitude: 55°47'N Longitude 12°31'E

Floor Area: .... m²

Water Heating Design Load: 11250 MJ (3125 kWh)

Design Consumption: 200 l/day

Design Temperature: 45 °C

Cold Water Feed: 8 °C

Climate

(Long term averages)

Source of data: Danish Reference Year (new version)

Source Latitude: 55°40'N Longitude 12°18'E

Average Ambient Temperature:

Oct–Apr 3,3 °C Annual 8,1 °C

Global Irradiation on Horizontal Plane:

Oct–Apr 1074 MJm⁻² (298 kWh m⁻²)

Annual 3666 MJm⁻² (1018 kWh m⁻²)

Sunshine Hours:

Oct–Apr 481 hrs Annual 1518 hrs

System

Collector: Aperture Area: 5.4 m²

Absorber: Material Aluminium

Absorber: Coolant Propylene glucol

Surface Nickel foil (Marxorb)

Glazing Single glass

Orientation 180 ° (South = 180°)

Tilt 45 ° (Horizontal = 0°)

Heat Storage:

Medium Water

Volume 0.3 m³

Preheat Configuration: The domestic hot water is heated directly from the primary circuit in the storage tank by a heat exchanger. If necessary the hot water can be heated afterwards outside the tank.

Auxiliary: Type ....

Nominal Heating Power .... kW

Generic System Type

Hot Water:	Active	X
	Thermosyphon	
	Direct	
	Indirect	
Heat Storage Tank:	Single	
	Multiple	
	Short Term	X
	Long Term	
Solar Space Heating:	Active	
	Passive	
Heat Pump:		
Heat Recovery:		
Other:		

Measured Data

Data shown for Period from 1 July 1980 to 1 July 1981

Total Hot Water Used (col 6): 73 (simulated) m³

Total Solar Energy Used (col 11): 7397 MJ (2052 kWh) 1370 MJm⁻²

Total Auxiliary Energy Used to DHW (col 12): 3853 (simulated) MJ (1072 kWh)

Total Hot Water Load (col 15): 11250 (simulated) MJ (3124 kWh)

Solar Fraction (of Total Load) (col 17): 65 %

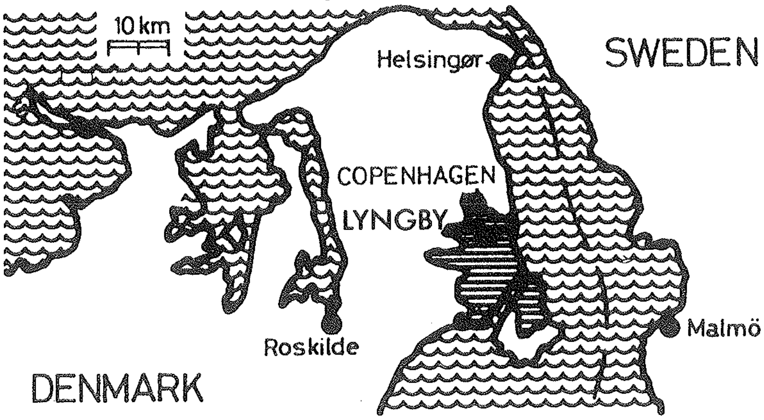
System Efficiency (col 18): 38 %

Total Solar Energy Used to DHW (col 11)=Output from Preheat Tank. Numbers refer to columns in Performance Data Sheet.

CLIMATE

ref: DHW LYNGBY
project: t.i.l. DHW test rig
3

Site Location Map



Site

Latitude: 33°47'N Longitude 12°31'E

Altitude: 37 m

Nearest Main City: Copenhagen

Distance from Main City: 15 Km(from centre)

Direction from Main City: North

Obstructions: none, cabins in nearest surroundings are under level of solar collector

Site Micro-Climate

The solar collectors are placed on top of a cabin at the laboratory's test-area north of the Technical University in suburban surroundings. There are cabins in the nearest surroundings of the collectors but none of them are at heigher levels than that of the collectors.

Monthly Long Term Averages

Month	Solar Irradiation on Horizontal Plane		Sunshine Hours	Average Ambient Temperature
	Global	Diffuse		
	MJm⁻²		hrs	°C
January	45	31	25	-0.6
February	120	59	62	-1.1
March	211	127	78	2.6
April	428	199	159	6.6
May	560	267	186	10.6
June	668	282	264	15.7
July	579	286	226	16.4
August	485	221	217	16.7
September	299	160	144	13.7
October	158	87	87	9.2
November	69	42	30	5.0
December	43	23	40	1.6

Annual Averages

Prevailing Wind Direction: West

Average wind speed: 4.9 $m\ s^{-1}$

Total Precipitation: 600 mm

Relative Humidity: 83 %

Global Irradiation on Horizontal Plane: 3666 MJm^{-2}

Diffuse Proportion: 49 %

Sunshine 1518 hrs

Ambient temperature: 8.1 °C

Source of data: Danish Reference Year (New version) Latitude 55°40'N Longitude 12°18'E

Distance from site: 15 km

Period of Measurement: from .... to ....

SYSTEM

ref: **DWH** LYNGBY
project: t.i.l. DWH test rig

4

Collector

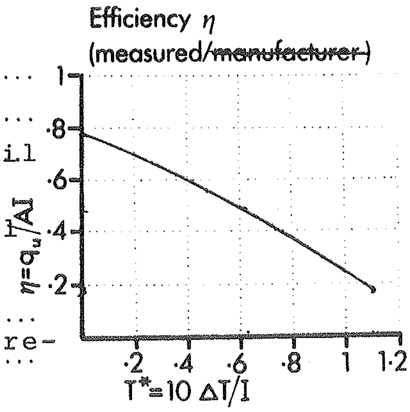
Absorber Material: aluminium

Absorber Surface: nickel foil (Maxorb)

Coolant: propylene glucol

Glazing: single glass 4 mm

Insulation: 50-60 mm polyurethan foam (back)



Collector

Aperture Area: 5.4 m^2

(Absorber Area: (a bit smaller) m^2)

Orientation: 180° Tilt: 45°

Collector: Fluid Content 0.00064 lm^2

Flow Rate 0,02 $lm^{-2}s^{-1}$

Collector Efficiency Equation:

$$\eta = 0,79 - 4,4\frac{\Delta T}{I} - 0,007\frac{\Delta T^2}{I}$$

Primary Circuit (collector excluded):

Fluid Content 0.0075 l

Heat Loss .... WK^{-1}

Heat Storage

Medium: water

Description/Location: cylindrical steel tank placed in cabin

Insulation/Cold Bridges: 50 mm min.wool + 50 mm polystyrene.

Heat Exchanger Type: ribbed pipes inside tank

Storage

Volume: Preheater 0.3 m^3

Overall Heat Loss Coefficient:
(measured/~~calculated~~)

Preheater tank 1.3 WK^{-1}

Postheater tank – WK^{-1}

Thermal Capacity:

Preheater tank 1.24 MJK^{-1}

Postheater tank – MJK^{-1}

Heat Exchanger:

Exchange Coefficient 250 WK^{-1}

Area .... m^2

Domestic Hot Water

Auxiliary Energy: The afterheating by auxiliary power and the function of the mixing

Mixing Valve: valve is simulated by the calcu-

Pipework Insulation: lator which controls the drain off of hot water from the tank.

Controls: ....

Domestic Hot Water

Design Temperature: 45 °C

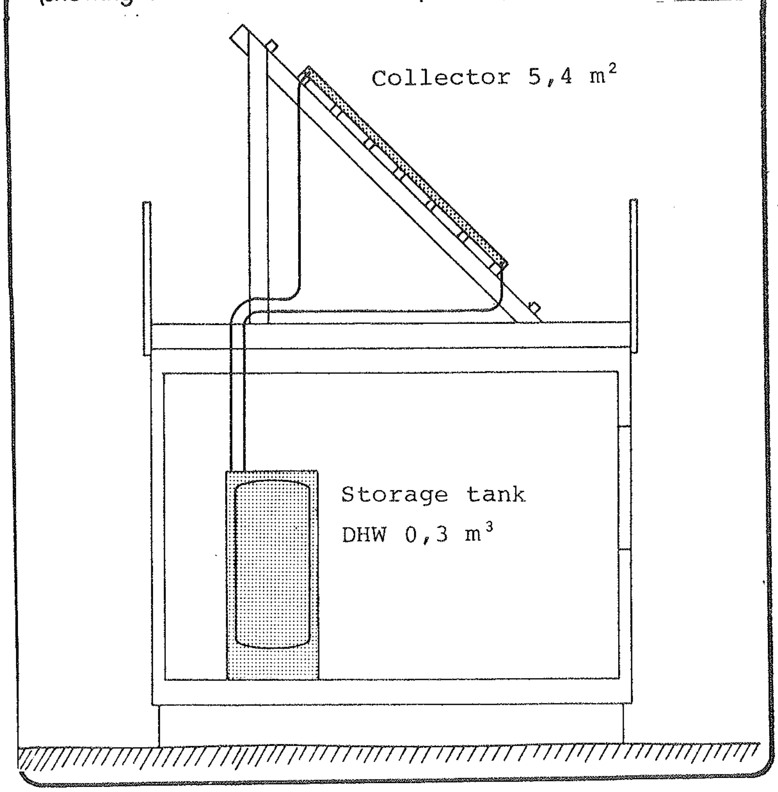
Cold Water Feed Temp: 8 °C

Design Consumption: 200 l/day

Immersion Heater: (none) kW

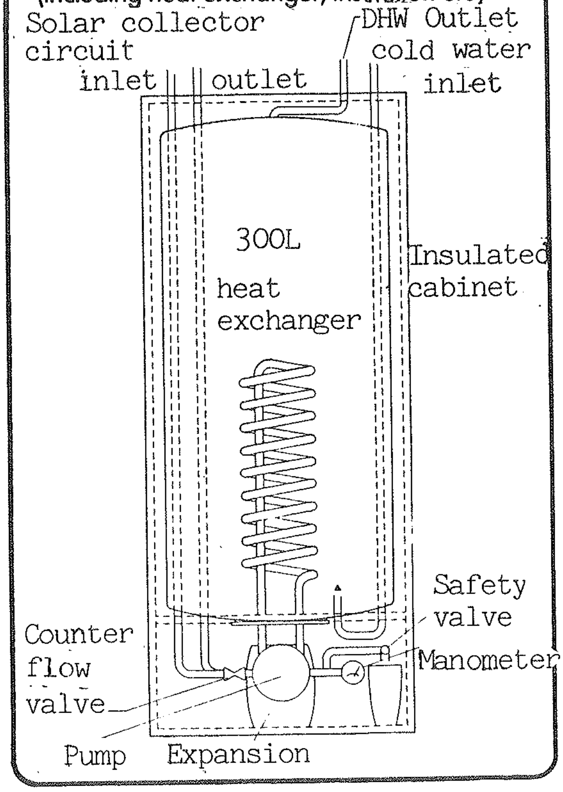
Section Through House

(showing location of main solar components)



Section Through Store

(including heat exchanger, insulation etc)



SYSTEM DIAGRAM

ref: **DHW** LYNGBY
project: t.i.l. DHW test rig

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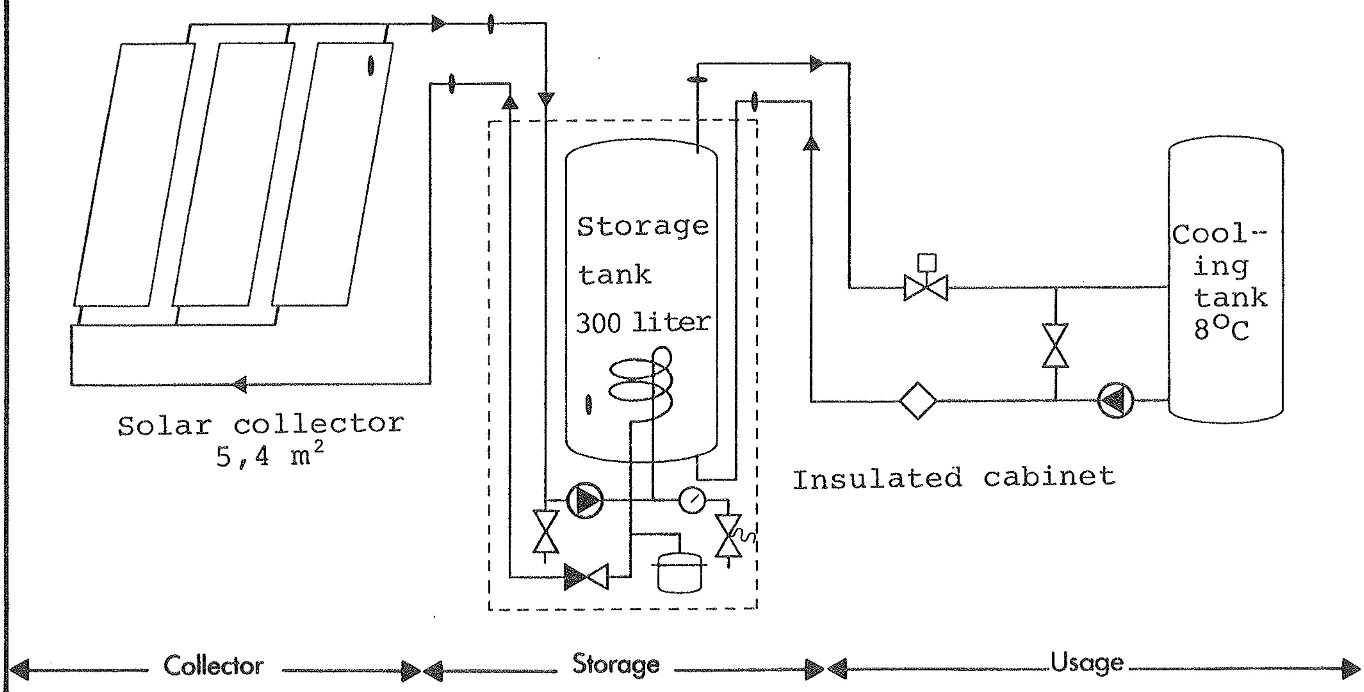
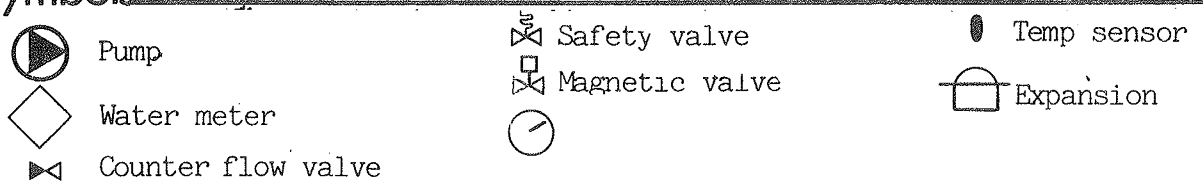
Diagram
(showing sensor locations)



Symbols



Controls

Frost Protection: Propylene glycol

Overheating Protection: Tapping of hot water from the tank controlled by calculator.

Corrosion Protection: Corrosion inhibitors in glycol

Type of Controller: Controlled by calculator (Hewlett-Packard 9815)

Setting and Estimated Accuracy:

Operating Modes:

Primary circuit: The pump is controlled by the calculator using 4 temperature sensors.

a) If the temperature of the collector is more than 1°C higher than the temperature of the storage the pump is started.

b) If the inlet temperature from the heat exchanger is less than 0.1°C higher than the outlet temperature from the heat exchanger the pump is stopped.

Tapping of hot water: The tapping is controlled by the calculator operating a magnetic valve. The tapping is equivalent to 4 daily tappings of 50 liters of water of 45°C.

TECHNICAL APPRAISAL

ref: **DHW** LYNGBY
project: t.i.l. DHW test rig

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Description of problem, solution modifications & recommendations

System components

The insulation of the collector (polyurethan foam) has partly been disintegrated due to the high temperatures in the collector. This has caused chemical decomposition of the nickel in the selective foil in small spots.

It has not been proved that the efficiency has been decreased by the damage.

Controls

To investigate the function of the control, the system has been operated with too high a flow in the primary circuit and too many pump hours due to the small temperature difference settings of the control. Calculations have shown that the energy used for the pump could be decreased without loss of efficiency.

Problem Summary

Keyword: explanation to be given in left hand column

Building: [ ]

1 ....
2 ....
3 ....

System Design: [ ]

1 ....
2 ....
3 ....

System Installation: [ ]

1 ....
2 ....
3 ....

System Components: [X]

1 Durability of collector
2 ....
3 ....

Controls: [X]

1 Too much electric energy to pump
2 ....
3 ....

Sensors: [ ]

1 ....
2 ....
3 ....

....

....

Data Recording and / or Transfer: [ ]

1 ....
2 ....
3 ....

....

MONTHLY PERFORMANCE

ref: **DHW** LYNGBY
project: t.i.l. DHW test rig

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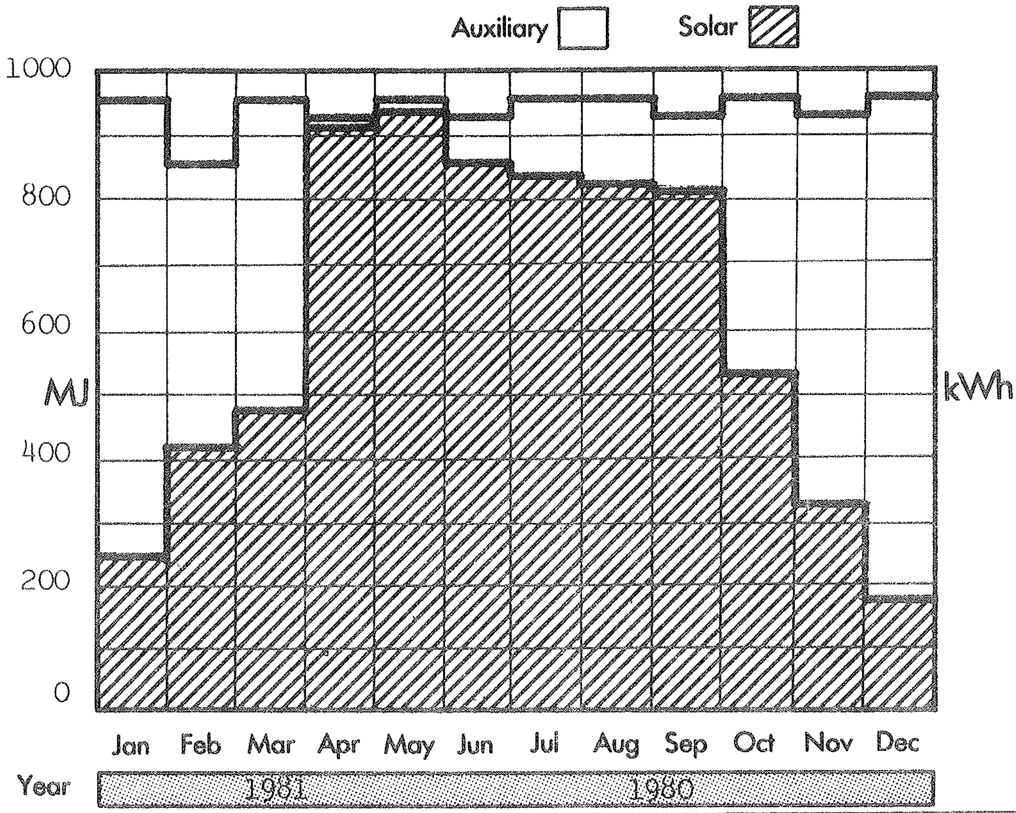
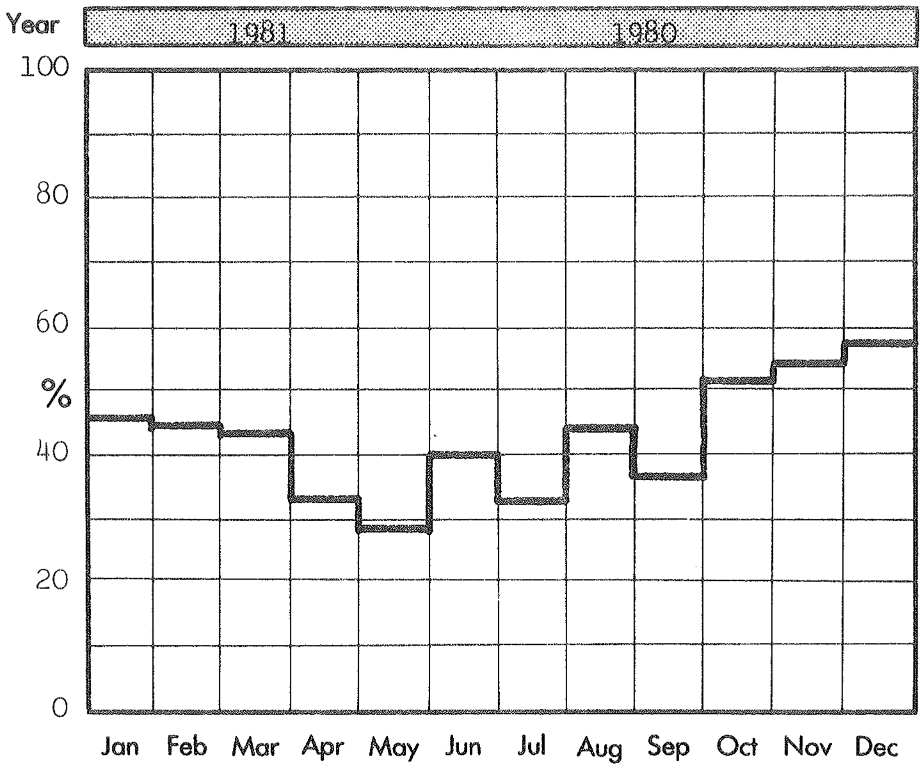
Monthly Hot Water Load



Monthly Efficiency: Collection ( ) System (x)



Note: Collection = 100 × (9) ÷ (8)
System = (18)
Numbers refer to column numbers in Performance Data Sheet

ANNUAL PERFORMANCE
(and User Profile)

ref: **DHW** LYNGBY
project: t.i.l. DHW test rig

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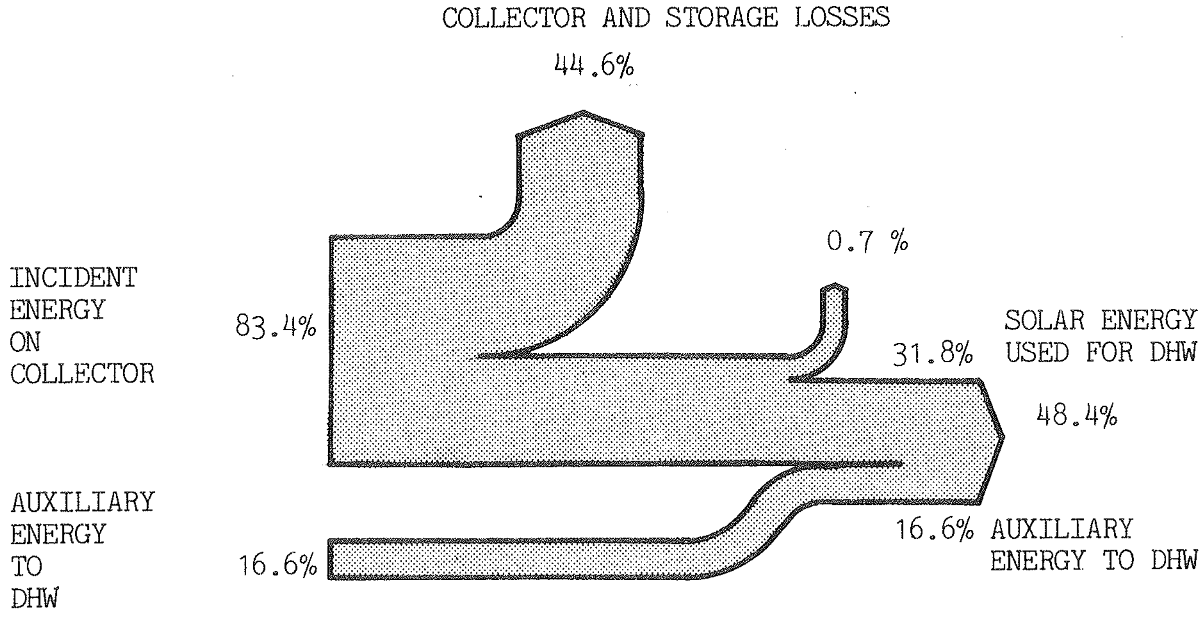
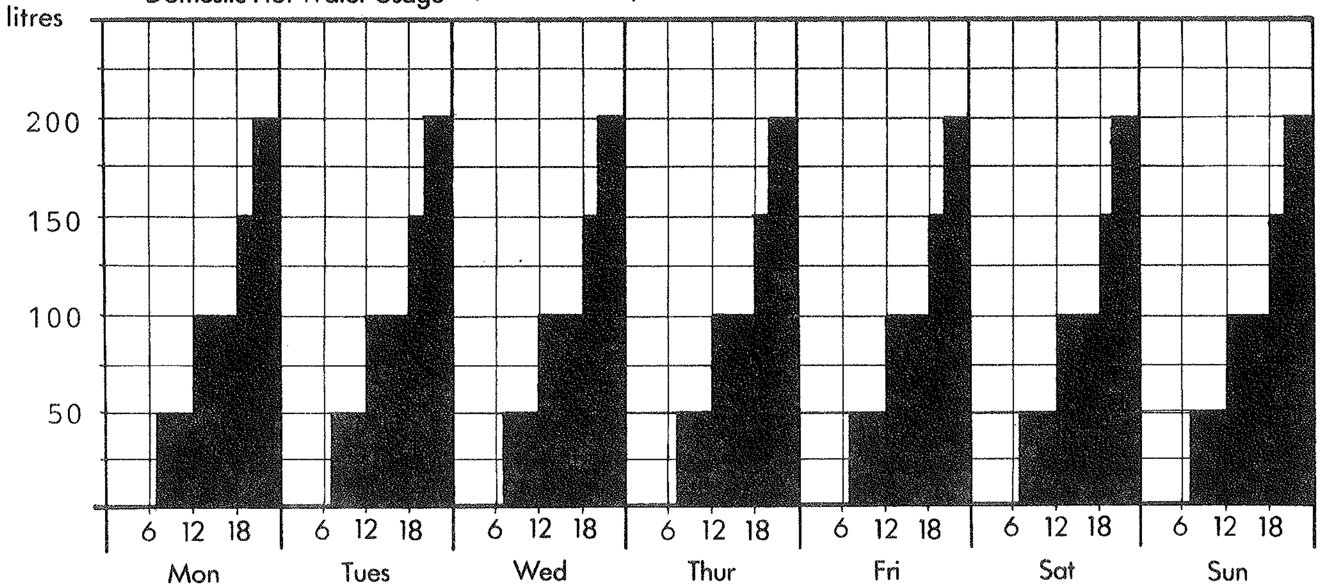
Sankey Diagram
(Annual Energy Flows)



100% = 23264 MJ

Average Draw Off Profile

Domestic Hot Water Usage (simulated)



PERFORMANCE DATA SHEET

Data shown for period from: to:

ref **DHW** LYNGBY
project t.i.l. DHW test rig

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Group	Column	Item	Units	J	F	M	A	M	J	J	A	S	O	N	D	Total MJ (kWh)	Average
Summary	18	System Efficiency	%	46	45	44	33	29	40	33	44	37	51	54	58	—	38
Summary	17	Solar Fraction	%	26	48	50	99	98	93	88	87	89	55	35	20	—	65
Summary	16	Total Solar Energy Used per unit Collector Area (aperture)	MJm^{-2}	47	76	89	169	173	159	155	155	153	98	61	35	1370	
Summary	15	Total Load	MEGA JOULES	955	865	955	925	955	925	955	955	925	955	925	955	11250	
	14	Heat Recovered from Waste Water to DHW Preheat	MEGA JOULES														
Auxiliary Energy	13	Auxiliary Energy Used by pumps/fans in Solar System 3)	MEGA JOULES	18	36	53	77	79	81	85	83	77	67	41	28	725	
Auxiliary Energy	12	Auxiliary Energy to DHW 2)	MEGA JOULES	703	451	476	11	19	65	116	120	101	426	597	768	3853	
Solar Energy	11	Solar Energy Used for DHW Output from Preheat	MEGA JOULES	252	414	479	914	936	860	839	835	824	529	328	187	7397	
Solar Energy	10	Solar Energy Used for DHW Input to Preheat	MEGA JOULES														
Solar Energy	9	Solar Energy Collected	MEGA JOULES														
Solar Energy	8	Incident Energy on Collector	MJ	551	929	1091	2808	3211	2167	2563	1890	2232	1033	612	324	19411	
Solar Energy	7	Horizontal Solar Radiation	$MJ\ m^{-2}$														
	6	DHW Consumption	m^3	6.2	5.6	6.2	6.0	6.2	6.0	6.2	6.2	6.0	6.2	6.0	6.2	73	
Average Temperature	5	Postheat Storage Temperature	°C													—	
Average Temperature	4	Preheat Storage Temperature 1)	°C	18	23	28	60	69	50	55	53	53	29	21	15	—	
Average Temperature	3	Cold Water Feed Temperature	°C	8°	8°	8°	8°	8°	8°	8°	8°	8°	8°	8°	8°	—	
Average Temperature	2	Average External Temperature	°C													—	
Average Temperature	1	Average Internal Temperature	°C					20 -	24°C							—	22
		No Days Data															
		Month		J	F	M	A	M	J	J	A	S	O	N	D		
		Year															

SYSTEM COEFFICIENT OF PERFORMANCE (COP) = (COL 11/13) 10

Definitions:

(15) = (11) + (12) + (14)
(16) = (11) ÷ Collector Aperture
(17) = 100 × (11) ÷ (15)
(18) = 100 × (11) ÷ (8)

NOTES:

DHW.: Domestic Hot Water

1) Average temperature at top of storage
2) Simulated values
3) Approximate values

COST INFORMATION *)

ref: DHW LYNGBY
project: t.i.l. DHW test rig
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Solar Components

(including installation costs; excluding monitoring, research and development)

Collector: (including glazing, fixings, insulation etc) 10.150 danish kr.	1285	EUA	1
Solar Heat Distribution System: (excluding DHW post heat tank) 14.890 d kr.	1885	EUA	2
Controls: 1.223 d kr.	155	EUA	3
Builders work in association with the system:		EUA	4
Total cost of solar components: (1 + 2 + 3 + 4)	3325	EUA	TOTAL A

Building Elements

Extra built space to accommodate system:	0	EUA	5
Savings in roof, walls etc:	0	EUA	6
Total extra cost of building elements: (5 – 6)	0	EUA	TOTAL B

Auxiliary Heating System

Actual cost of Post Heat Tank: 30 liter electrical post heat tank	312	EUA	7
Typical cost of Conventional DHW Tank:		EUA	8
Total extra cost of Auxiliary Heating System: (7 – 8)	312	EUA	TOTAL C

Net Cost of Solar System (A+B+C)

3637 EUA

Date costed: July 1981 (1 EUA = 7.90 danish kr.)

Cost of Conventional Energy Sources

Electricity:	Normal Tariff 0,71 d.kr. 0.090	EUA/kWh	date: August 1981
	OFF peak Tariff	EUA/kWh	date:
Gas:		EUA/kWh	date:
Oil:	0,43 d.kr/kWh 0,054 (burner efficiency 75%)	EUA/kWh	date: August 1981
Solid Fuel:		EUA/kWh	date:

*) It is not possible to give the price on the actual system. Instead has been given the price on a similar system installed in a existing single-family in August 1981.

CONCLUSIONS

ref: DHW LYNGBY
project: t.i.l. DHW test rig

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Comparisons with Predictions
(including description of model used)

The system has been simulated on a computer with measured weather data and load.

Predicted	Measured
Thermal Loads:	
DHW 11250 MJ	(col 15): 11250 MJ
Total Solar Energy Used:	
DHW 7240 MJ	(col 11): 7397 MJ
Auxiliary Energy Used:	
DHW 4010 MJ	(col 12): 3853 MJ
Solar Fraction:	
DHW 64 %	(col 17): 66 %
System Efficiency	
DHW 37 %	(col 18): 38 %

Occupancy/Comfort

Conclusions

The system has been operated without problems and has had a high production. The experiment has shown that with a careful design and using components available on the market it is possible to raise the productivity of domestic hot water systems to a reasonable level without extra cost.

Future Work

The experiment will continue in three parts

a) a immersion heater has been installed in July 1981 at the top of of the storage tank to secure minimum 45 °C at the tapping place. A new solar collector is installed.

b) A similar system using only 0.15 m^3 storage will be installed in September 1981.

c) The system has been installed in a occupied single-family house in August 1981.