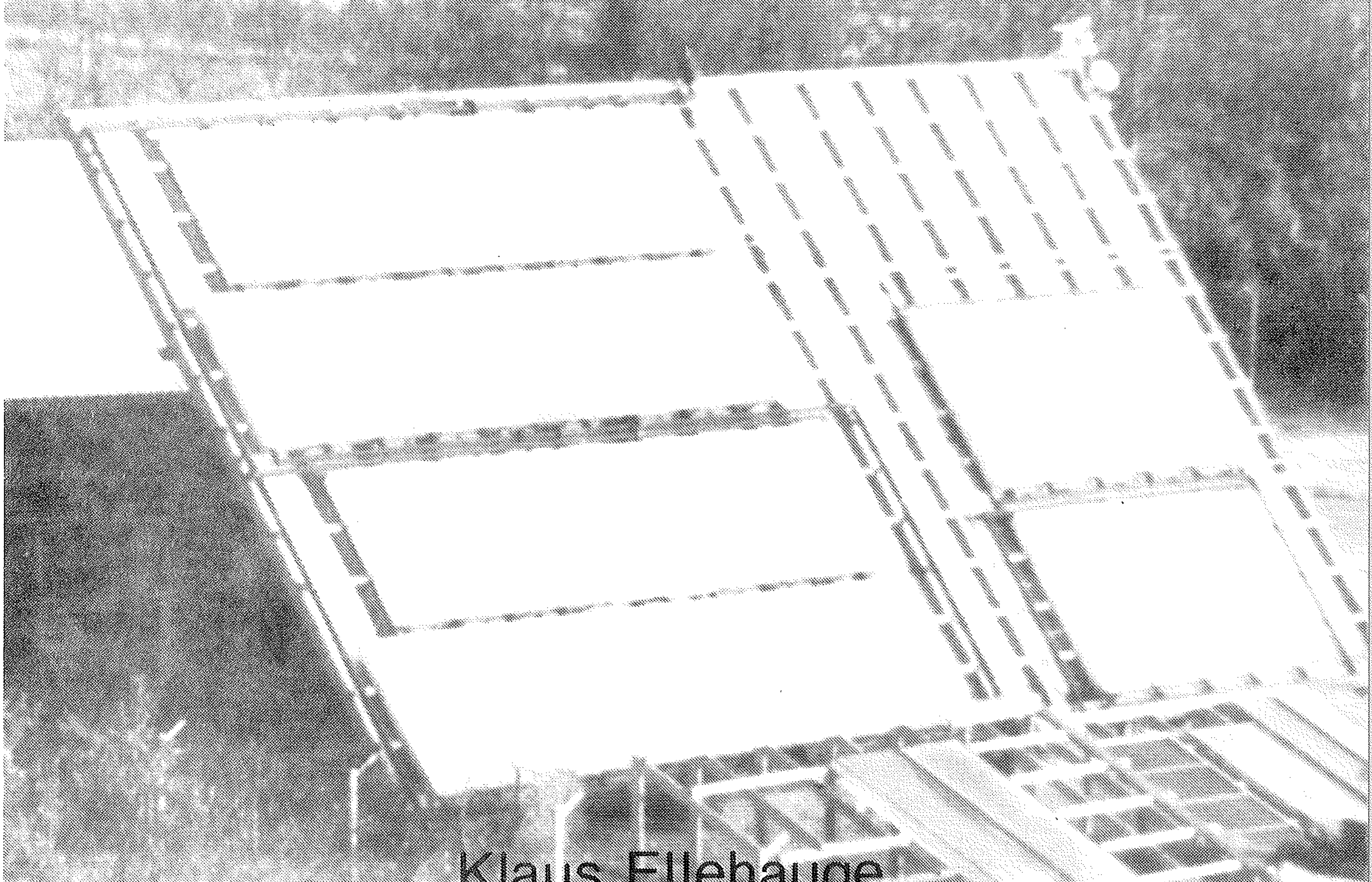
SOLAR PILOT TEST FACILITY

FINAL REPORT - DENMARK



Klaus Ellehauge

Ole Balslev Olesen

Nick Bjørn Andersen

Thermal Insulation Laboratory
Technical University of Denmark

Contract-ESA-T-003-DK

OKTOBER 1983

SOLAR PILOT TEST FACILITY

FINAL REPORT - DENMARK

BY

KLAUS ELLEHAUGE

OLE BALSLEV OLESEN

NICK BJØRN ANDERSEN

THERMAL INSULATION LABORATORY

TECHNICAL UNIVERSITY OF DENMARK

OKTOBER 1983

MEDDELELSE NR. 136

Table of contents page

Abstract 1

Preface 2

Introduction 4

1. SPTF-operation 7

1.1 Data production.. 7
1.2 Central control system 8
1.3 Data storage 8
1.4 Operational check procedures 10

1.4.1 Checking the SS1-data 11
1.4.2 Checking the SS2-data 11

1.5 Control accuracy SS1/SS2 13
1.6 Calibration of various instruments 13
1.7 System parameter measurements SS1 14
1.8 System parameter measurements SS2 18

1.8.1 Storage heat loss 18
1.8.2 Storage capacity 20
1.8.3 Other parameters 20

2. System behaviour studies SS1 23

2.1 The stratification of storage temperatures 23
2.2 System performance SS1 25
2.3 Links between the studies of the participants from the different countries 26

3. System behaviour studies SS2 29

3.1 System SS2.2 - Combined system 29

3.1.1 Description of the system 29
3.1.2 Measured data and calculations 31

3.2 System SS2.3 - Thermal valve 33

3.2.1 Description 33
3.2.2 Measurements 34
3.2.3 Results 34

Page

3.3 System SS2.4 - Combined system 34

3.3.1 Background 34

3.3.2 Description of the system 35

3.3.3 Measurements 37

3.3.4 Expected performance 37

3.3.5 Economy 37

4. EMG + PTF - results 38

4.1 Introduction 38

4.2 Physical system 38

4.3 Simulation model 39

5. Conclusions and recommendations for further work ... 45

Appendices:

Appendix 1: List of participants

Appendix 2: Data descriptors, Logsheets

Appendix 3: Design Drawings

Appendix 4: Installation descriptors

Appendix 5: Contents of the cassettes

Abstract

This report describes the work on the Danish Solar Pilot Test Facility in the period from October 1981 to June 1983. This work has been part of a "concerted action" within the project A of the solar energy programme under the Commission of the European Communities (CEC). The Solar Pilot Test Facility Group consists of participants from the following 8 member-countries: Belgium, Denmark, France, Federal Republic of Germany, Ireland, Italy, the Netherlands and the United Kingdom.

In the contractual period described in this report the work on the Danish SPTF has consisted in routined collection of measurements on different system configurations. In the SPTF's there are two measuring and control installations, the SS1 and the SS2. On the SS1 installation the system has been changed to a domestic hot water system and the effect of stratification and the effect of different heat exchangers has been investigated.

On the SS2 installation there has been investigations on solar systems for combined space heating and domestic hot water. Two combined systems have been mounted and the latter is to be considered as a 2. generation "ready to install" system. The investigations have been closely linked to the work in the European Modelling Group and calculations made of the Danish member of this group have formed the basis by the optimization of the system.

Preface

The Solar Pilot Test Facilities are one of several "concerted actions" within the project A of the solar energy programme under the Commission of the European Communities (CEC).

Under this project the topics studied are in general

- the development of European test procedures for solar components (collectors, heat storage systems, etc.)
- the development of uniform approaches for total system design, monitoring and evaluation of total system performance and validation of computer simulation models for different solar systems, both for active and passive solar designs, etc.

The activities as listed above are in general directed towards design, development and improvements of solar systems (passive and active) in order to stimulate the implementation of these systems within Europe.

The Solar Pilot Test Facilities are a valuable tool in this work. The Solar Pilot Test Facility Group consists of participants from the following 8 member-countries: Belgium, Denmark, France, Federal Republic of Germany, Ireland, Italy, the Netherlands and the United Kingdom. The work of each participant is funded partly by the CEC, who is also fully funding the co-ordination of the group.

The Solar Pilot Test Facility is a test rig where you can mount two solar systems at a time. Furthermore it consists of a physical simulator which controls the load imposed on the system. This simulater is interactive with the prevailing weather conditions and can be programmed to represent any type of house construction, type of heat distribution system and occupancy.

In this way you can define the test conditions in a way which is not possible if the solar system is mounted in a real occupied house.

One of the solar systems (solar system one) is as far as possible identical in the eight locations, the other (solar system two) is designed by the individual participant to reflect both national interests and the climate of the location.

The most important aspect of the work on the Solar Pilot Test Facilities is the production of measuring data to be used ofthe European Modelling Group for the validation of computer based simulation models of solar system performance. The development of these models is a necessity for real optimization of solar system design. For the purpose of this validation work the measuring data have to be detailed and accurate and furthermore it is a big advantage to have the possibility of making changes in the solar system to get measuring data for variations of the system design.

The Solar Pilot Test Facilities fit very well for these purposes.

Another important aspect of the work is the system development studies. With the solar system two a widespread number of different solar systems are being tested. With the exchanges of information and measuring data within the group and to the European Modelling Group, every country can draw advantages of the results of testing in all the countries.

Project participants:

Civil engineer	Klaus Ellehauge
Civil engineer	Ole Balslev-Olesen
Civil engineer	Nick Bjørn Andersen
Technican	Ole Ravn
Technican	Bertil Morelli
Technican	Flemming Karn
Secretary	Hanne Godtfredsen
Drawings	Kenneth Sørensen

Introduction

The Solar Pilot Test Facilities Group (SPTF-group) together with the European Modelling Group (EMG) were created 1977 by the Commission of the European Communities (CEC). The objective of the SPTF-group was to supply the EMG with reliable experimental data and also to undertake system development studies.

The objective of the EMG group was to improve and develop mathematical models simulating the thermal behaviour of solar systems. In this work the data produced by the SPTF-group are used to validate the models.

The construction of the eight SPTF's (Belgium, Denmark, France, Federal Republic of Germany, Ireland, Italy, the Netherlands and the United Kingdom) started in 1978.

The basic design of the test facility and of the solar system one was delivered by COSTIC (France) which also took care of the coordination of the group.

The solar system two was designed by the national organisations. The construction of the SPTF's was completed in the middle of 1979. After this different trials took place to verify that the SPTF's were operating well and that the measurements were of a certain accuracy.

These trials took place until July 1980 when the first year of operation started.

During this year of operation some problems about the data production were addressed.

The period until July 1981 belongs to earlier contracts and for the Danish participant this period has been reported in ref (1).

After this two years of operation and measuring took place. The systems in the SPTF's have been changed or modified in order to obtain more information from the measurements. These two years of operation belong to the contractional period which is taken up in this report.

The work on the Danish SPTF has followed the same scedule as mentioned above. After having established the SPTF the first measurements of sufficient quality are from April 1980.

In the precedent contractual period the work on the solar system one consisted of making different heat demand load's and in changing the control system.

On the solar system two we have tested two solar systems for combined space heating and domestic hot water.

For the present contractual period the work has consisted in:

For the SS1 there has been four new system configurations. The main topic has been the temperature stratification of the storage. It has been interesting to operate the system as a domestic hot water system and the system configuration has been changing in accordance with this. Experiments have been carried out by changing the inlet to the storage and furthermore we have changed the heat exchanger between the primary and secondary loop.

During the different configurations of the SS1,data for model validating has been produced but the changes have also been evaluated without the use of computer models.

Concerning the SS2, the work has been concentrated on systems for combined space heating and domestic hot water as in the preceding contractual period.

In October 1981 we were still operating a system which was the second SS2 system on the SPTF. This system was remarkable because it had a storage which was an ordinary manufactured container with a mantle around it. The domestic hot water was contained in the mantle while the rest of the container was used for the space heating.

Having the relatively cold domestic water in the mantle the heat losses were reduced.

After having measured on this system in detail we decided to design a new system to be considered as a "2. generation" system and to be based on the experience of the first two systems. This system should be designed and built to a "ready to install" state to be quite sure of the performance of the system under completely realistic conditions.

While designing the new system we had room on the SPTF for carrying out an experiment with a "thermal valve".

This valve should secure that when operating a solar system for space heating then the outlet temperature to the heating system would be the return temperature from the radiators if this was higher than the temperature in the storage. Otherwise if the temperature in the storage was higher than the return temperature from the radiators then the temperature in the storage should be used.

The valve was functioning with thermal stratification and without any mechanical or electronic devise.

The new designed SS2 for space heating and domestic hot water was constructed in the autumn of 1982 and the measurements started at the end of 1982. We used some time to find the system characteristics and had some trouble with the data acqusition system. Regular data for model validation are available from May 1983. The yearly performance of the system has been calculated with the EMGP2 programme to be 311 kWh/m^2 solar collector with a solar fraction for domestic hot water on 66%, a solar fraction for space heating on 19% and a solar fraction for the total demand on 28%.

In the contractual period the Danish participant in the EMG Ole Balslev Olesen has also been a member of the Danish SPTF group. This has been a great advantage since all the computationel work has been done very closely linked to the SPTF work. The design of the third SS2 has for example been based on contemporary calculations.

1. SPTF-operation

Most of the time the measuring equipment has been functioning very well but in the spring 1983 the system was interrupted several times due to power supply drop outs and computer break down. Now the system has been operating since May 83 without breakdowns.

1.1 Data production

At the SPTF all measuring points are scanned every twenty seconds and the mean values over a period of half an hour are stored on magnetic tape cassettes. For the moment a magnetic file contains 400 files and every file contains data for four half hour periods (36 lines).

The temperatures are measured by means of copper-constanten thermo elements of the highest calibration class. The reference element is placed in a box with a temperature of 40°C. Temperature differences are measured by thermopiles with 10 elements in each pile.

The solar radiation is measured by pyranometers from Kipp & Zonen.

The flow measurements are measured by means of ring piston meters from Aqua-Metro.

The heat flows are calculated on the basis of flow, temperature difference, specific heat and density of the single circuits. The heat flow is calculated every twenty seconds, and a mean value is found.

The energy flow is calculated by:

$$E = \frac{1}{3.6} \cdot \frac{1}{N} \sum^{N} \Delta T \cdot \rho \cdot C_p \cdot F \qquad \text{kWh}$$

where

N = number of 20 sec. intervals in which the flow rate in the considered pipe is not zero

ΔT = temperature difference measured every 20 sec. with an uncertainty interval at 0.1°C

F = Flow rate measured every 20 sec.

ρ = fluid density, calculated $\rho = \rho(T)$ every 20 sec.

C_p = specific heat, calculated $C_p = C_p(T)$ every 20 sec.

1.2 Central control system

Measuring and control equipment

The measuring system has been based on a 80-channel data-logger system from Hewlett-Pachard, 3025A. This system consists of the following components:

1.	Scanner	HP 3495 A
2.	Voltmeter	HP 3455 A
3.	Disk-calculator (controller)	HP 9825 A
4.	Multi-programmer	HP 6940 B
5.	Magnetic-band station, Penny and Giles 2100 D.	

Most of the time the equipment has been well functioning, though there has been some troubles especially in the spring 1983, where in a few periods it has been impossible to read the tapes produced by the Penny and Giles recorder. The memory of the HP-9825A computer has broke down once in this period and moreover there has been some power supply drop outs.

1.3 Data storage

The half hour values are converted to SAS-datasets (Statistical Analysis System, SAS Institute Inc., Cary, N.C., USA) on the regional data machine according to this SAS-program which at the same time is a list of the variables used in the latest version of the system one and system two (ID1.ID2).

```
DATA A ;
INFILE PTA MISSOVER;
INPUT Æ1 TOWN A DAY MONTH YEAR HOUR NDAY NHOUR NMIN
      Æ2 AT   STT1 WV   CGR  HGR  HDR  ILT  STT2 STT3
      Æ3 CTDA CTDB OCT1 STT4 IPT1 PTD1 ITD1 OIT1 EIT2
      Æ4 HTD1 STT5 ICT2 CTD2 CWI2 DWD2 OPT2 PTD2 IAT2
      Æ5 ITK2 OIT2 ITD2 CTR2 TRU2 ITA2 ITB2 STY1 STY2
      Æ6 STY3 STY4 STI1 STI2 STI3 STI4 T_EL SOLT CTD1
      Æ7 FPF1 PCF1 SPF1 IIF1 F1   F2   F3   F4   W_EL
      Æ8 E151 E451 E253 E354 U458 U558 U155 U256 U357
      Æ9 HP2  RUM;
   YEAR=YEAR-1900;
   DAY=DAY+NDAY;
   IF DAY>31 THEN MONTH=MONTH+1;
   IF DAY>31 THEN DAY=DAY-31;
   DATE=MDY(MONTH,DAY,YEAR);
   TID=DHMS(DATE,NHOUR,NMIN,0);
   TID1=TID;
   FORMAT TID1 DATETIME13.;
```

The data on the SAS-datasets are being used for further computations and of course for control of the data reliability (see section 1.4). Also the data have been kept as datasets in the ordinary way and these are put on magnetic tape cassettes and send to the data bank.

The obtained measurements are seen on the following schemes.

Measurements obtained at the Danish SPTF:

1) 1980/81

Cassette no.	DD0	DD1	DD2	ID1	ID2	N
2001	1	1	1	1	1	184
2	1	1	2	1	1	231
3	1	1	2	1	1	378
4	1	1	2	1	1	259
5	1	1	2	1	1	209
6	1	1	2	1	1	399
7	1	1	2	1	1	386
8	1	1	3	1	1	399
9	1	1	3	1	1	237
10	1	1	3	1	1	330
11	1	1	3	1	2	331
12	1	1	3	1	3	221
13	2	2	4	2	4	140
14	2	2	4	2	4	353
15	2	2	4	2	4	338
16	2	2	4	2	*	382
17	2	2	4	2	*	383
26	3	3	5	3	5	111
27	3	3	5	3	5	331
28	3	3	5	3	5	336
31	3	3	5	3	5	361
32	3	3	5	4	5	354
33	3	3	5	4	5	363
34	3	3	5	4	5	379

N: Number of hour-values

DD: Data descriptor

ID: Installation descriptor

2) 1982/83

Cassette No.	DD0	DD1	DD2	ID1	ID2	N
2036	3	3	5	5	5	332
37	3	3	5	5	5	183
38	3	3	5	5	5	327
39	3	3	5	5	5	188
40	3	3	5	5	5	362
41	3	3	5	5	5	309
42	3	3	5	5	5	150
45	4	4		6		306
46	4	4		6		307
47	4	4		6		187
49	4	4		6		379
50	4	4		6		299
51	4	5		7		399
52	4	5		7		340
53	4	5		7		365
54	4	5		7		381
55	4	5		7		123

N: Number of hour-values

DD: Data describtor

ID: Installation descriptor

The format of the stored data is included in appendix 2.

1.4 Operational check procedures

While there has been a lot of troubles in the first months of 1983 a considerable amount of work has been done on checking the measured data on the spot using the printer in the HP 9825 with the central control and monitoring equipment.

When making this report the problems seem to be solved and the necessity of checking the data on the spot has been reduced.

1.4.1 Checking the SS1-data

Some variables are selected to be printed out in the following way:

STATISTICAL ANALYSIS SYSTEM

OBS	TIDI	NI	CGR	E151	E451	E253	E354	IIF1	TMIN	TMAX	TMEAN
1	29MAR83	26	36.7	-0.3	-0.5	1.0	54.3	1.4	30.26	40.52	37.04
2	30MAR83	48	59.6	-0.3	0.9	2.2	43.8	2.0	15.44	30.48	24.37
3	31MAR83	46	217.8	73.6	72.7	69.2	30.1	2.0	14.83	23.01	18.59
4	01APR83	46	458.5	184.9	171.8	158.9	63.3	2.0	21.50	41.46	31.49
5	02APR83	30	23.2	0.0	0.0	0.0	32.8	0.9	40.21	40.81	40.55

With this output the energy transport etc. is visualized and the energy quantities can then be compared.

1.4.2 Checking the SS2-data

Solar gain

The solar gain, the efficiency of the solar collectors etc. is printed and the printed data form the basis of checking the functioning of the primary circuit. The progress of temperatures (T1-T4) can be followed.

STATISTICAL ANALYSIS SYSTEM

OBS	TIDI	T1	T2	T3	T4	CGR	U458	U558	EFF	DTR	R	SPIEFF
29	01JUN83:10:00	50.6	50.1	35.8	35.4	10.4	6.1	5.7	0.587	24.5	14.4	0.630
30	01JUN83:10:30	54.8	54.3	38.6	38.1	11.5	6.9	6.6	0.601	27.6	13.6	0.638
31	01JUN83:11:00	58.3	57.8	41.1	40.7	12.5	7.5	7.1	0.603	29.6	13.3	0.651
32	01JUN83:11:30	61.7	61.1	43.6	43.2	13.2	7.9	7.5	0.600	32.0	13.7	0.659
33	01JUN83:12:00	64.6	63.9	46.1	45.6	13.7	8.1	7.7	0.595	34.5	13.6	0.668
34	01JUN83:12:30	66.7	66.1	48.6	48.0	13.9	8.1	7.7	0.585	37.0	12.7	0.673
35	01JUN83:13:00	68.0	67.4	50.4	49.8	13.9	8.3	7.8	0.595	38.4	13.4	0.686
36	01JUN83:13:30	68.4	67.8	52.0	51.6	13.3	7.7	7.3	0.581	39.1	12.5	0.665
37	01JUN83:14:00	69.1	68.3	53.7	53.4	12.9	7.1	6.6	0.549	40.1	11.9	0.679
38	01JUN83:14:30	68.5	67.8	55.1	54.8	12.0	6.3	5.9	0.527	40.8	11.2	0.667
39	01JUN83:15:00	67.3	66.8	56.0	55.6	10.8	5.4	4.9	0.497	40.4	10.2	0.664
40	01JUN83:15:30	65.7	65.1	56.4	56.1	9.6	4.4	4.0	0.456	39.8	9.8	0.656
41	01JUN83:16:00	62.8	62.5	56.3	56.1	7.8	3.1	2.8	0.395	38.8	7.3	0.640
42	01JUN83:16:30	59.0	59.4	55.8	55.6	3.5	0.4	0.4	0.121	37.7	-0.4	0.580
43	02JUN83:07:30	31.6	29.3	31.6	28.2	1.9	0.4	-0.2	0.199	11.2	54.7	2.568
44	02JUN83:08:30	35.3	34.6	33.1	32.5	2.8	1.0	0.5	0.354	14.8	29.5	0.370
45	02JUN83:09:00	35.8	35.8	34.3	34.1	1.9	0.6	0.5	0.316	15.5	3.0	0.398
46	02JUN83:11:30	45.6	44.2	37.7	36.4	7.1	3.4	2.5	0.480	22.4	43.6	0.592
47	02JUN83:12:00	41.4	41.3	38.7	38.5	3.5	1.2	1.0	0.340	21.3	7.3	0.532

Domestic hot water

The tapping of the warm water is checked by use of this printed output:

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

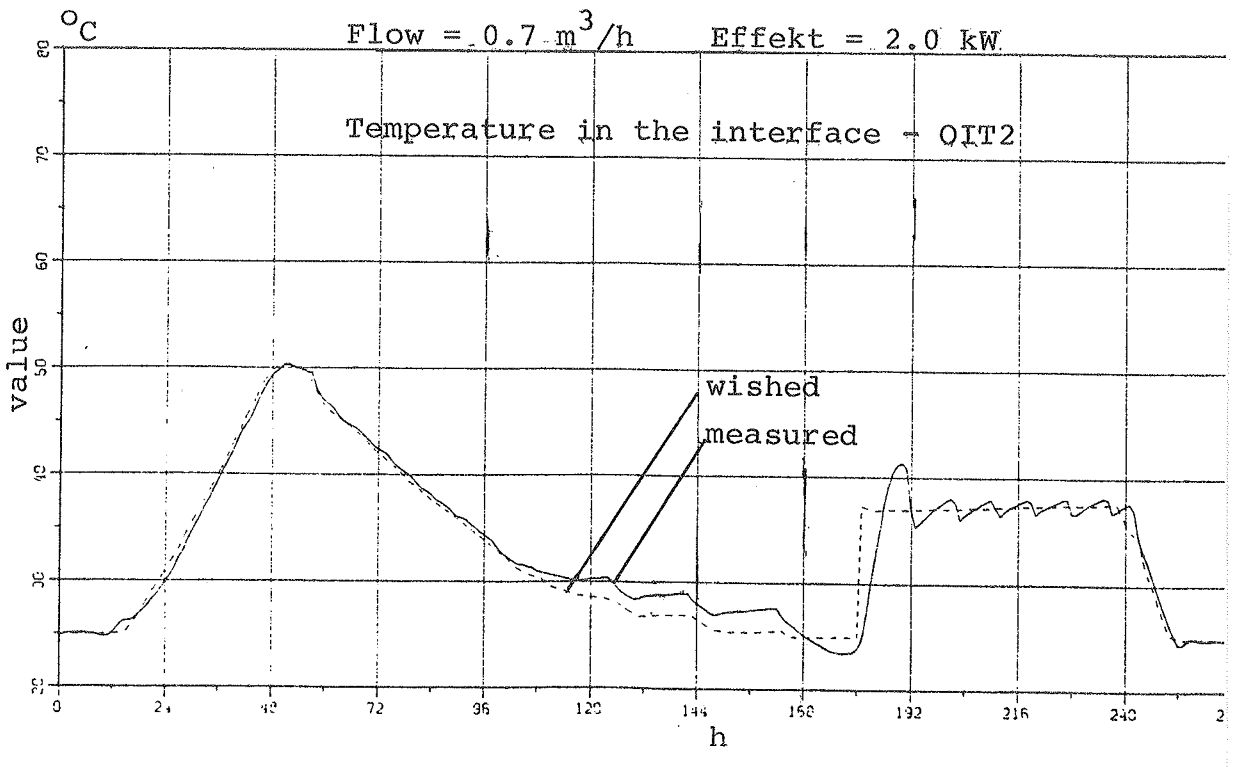
OBS	TID1	F1	F3	T1	T2	T3	T4	U357	U155
1	03MAY83:12:00	0.079	0.079	9.52	21.74	22.03	49.22	1.114	2.523
2	03MAY83:16:30	0.078	0.078	9.82	21.73	22.06	44.39	1.111	2.184
3	04MAY83:07:00	0.058	0.058	10.12	21.42	21.87	50.45	0.767	1.924
4	04MAY83:07:30	0.020	0.020	7.97	21.25	21.19	31.53	0.311	0.273
5	04MAY83:12:00	0.077	0.077	9.48	21.09	21.33	44.91	1.041	2.246
6	04MAY83:16:30	0.078	0.078	9.52	21.02	21.33	45.86	1.035	2.248
7	05MAY83:07:00	0.055	0.055	10.84	21.27	21.86	50.17	0.689	1.885
8	05MAY83:07:30	0.022	0.022	7.96	20.96	20.92	31.52	0.335	0.332

As seen on the table the tapped volume is about 80 l three times a day and the tapping temperature is about 45-50^{o}C when the tapping starts.

Heat removal

The heat removal in the interface system is controlled by the computer. The return temperature from the interface is calculated and set by the computer according to the actual heat demand and the measured return temperature can be compared with the computer return temperature.

This output is to check that the interface return temperature is set to the right value.



1.5 Control accuracy SS1/SS2

The pump control in the primary circuit is an ELECTROMATIC ST 185 with two ETR temperature transducers. The result of testing the accuracy was that the difference between the set difference temperature and the measured difference temperature would be as a maximum:

0,8°C for the start differens
0,5°C for the stop differens

1.6 Calibration of various instruments

Flowmeters: When the systems were installed the accuracy of the flowmeters was checked by counting the pulses according to a measured volume in a measured period. The flowmeters showed the right value with a maximum deviation of 1%.

After two years of operation they were checked again and the result was the same.

Solarimeter: When mounted it has been checked and calibrated and every year the calibration is checked again. Uncertainty 5%.

Temperatures:

The uncertainties are:

temp. diff.	0,10°C
Temp. abs.	0,35°C

1.7 System parameter measurements SS1

During the last working period the system has been changed from a space heating to a domestic hot water system with a draw off profile according to the consumption of 20 dwellings.

The system is shown on the next page (fig. 1.7).

The cold water inlet is in the bottom of the storage tank and the outlet from the top. The secondary collector loop is modified so the heated water from the heat exchanger is returned into the middle layer of the storage tank. The primary collector loop is unchanged.

The storage tank of the system will function as a preheating tank. The auxiliary is not included in this experiment, but it can be calculated by simulation program.

The system is characterized by a high degree of stratification in storage which will be of interest in the modelling work.

Parameters measured in the previous work period

Most of the parameters were already determined at the start of this contractual period, for more information see ref (1). The already determined parameters are:

Collector

Total heat loss: UA = 174 W/^{o}C ± 5%

Capacity of collector:

		HOUR		
		1-2	2-3	3-4
ΔOCT1	(^{o}C)	7.3	4.4	3.1
Δτ	(s)	3600	3600	3600
HOC1	(W)	-5290	-5400	-5570
TM	(^{o}C)	17.6	24.0	28.0
C	(kJ/^{o}C)	1194	1214	1176
δ(C)	(kJ/^{o}C)	160	310	520

$$TM = (OCT1 - 0.5 \cdot CTD1 - AT)_{mean}$$

Back and side losses

UA = 91 W/^{o}C ± 5%

Piping

Pipe loss: U =1,12 W/^{o}C ± 20%

Heat capacity of piping

	HOUR	
	0 - 1	1 - 2
ΔT (^{o}C)	57.6 - 49.8 = 7.8	49.8 - 45.4 = 4.4
$\Delta \tau$ (s)	3600	3600
Q_{in} (W)	210	210
Q_{out} (W)	1735	1326
TM (^{o}C)	31.15	23.8
C (kJ/^{o}C)	700	900
$\frac{\delta C}{C}$	0.2	0.2

Heat exchange

Effectiveness 0,37 ± 3%

Storage

Heat loss coefficient: UA = 15,6 W/K ± 5%

Capacity C = 13.400 kJ/K ± 7%

The heat loss coefficient in fact was obtained by means of two different methods which are reported in ref (1).

Other parameters

The following is a list of all the parameters including the measured ones:

System parameters

Collector:

Absorber area	46.47 (m^2)
Tilt	56.0° $\pm 1^{\circ}$
Azimuth	0.0° $\pm 1^{\circ}$ (south)
Cover refractive index	1.52
Absorber absorptance	0.93
Absorber emittance	0.30
Space between cover and absorber	0.035 (m)
Back and side losses incl. their connections	91.0 ±5% (W/K)
Heat capacity for all collectors and their connections incl. fluid	1200 ±13% (kJ/K)
Specific heat of fluid	3.91 ±2% (kJ/K kg)
Density of fluid	1060 ±2% (kg/m^3)
Optical factor of collector ($\alpha\tau$)	0.85

Piping (primary collector circuit):

Length of cold side piping	32.4 ±0.2 (m)
Outside length (cold side)	23.2 ±0.2 (m)
Heat capacity incl. content	16.0 ±20% (kJ/K m)
Heat loss	1.12 ±20% (W/K m
Electrical power of the pumps	420 ±5% (W)
Power delivered to the fluid	210 ±20%
Length of hot side piping	16.9 ±0.2 (m)
Outside length (hot side)	11.6 ±0.2 (m)

Control:

Start differential ΔT_{on}	8 ± 1	(K)
Stop differential ΔT_{off}	0 ± 1	(K)

Heat exchanger:

Heat exchanger effectiveness	$0{,}553+1{,}116\cdot10^{-3}\cdot$IHT1 ± 2%

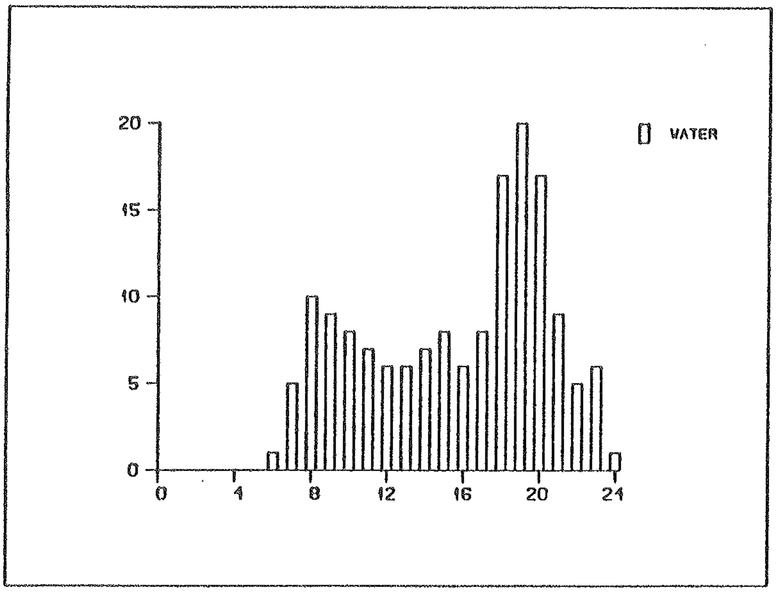
Storage tank:

Volume of tank	3	$(m)^3$
Length of secondary circuit	7 ± 0.2	(m)
Specific heat of the fluid	4.2 ±2%	(kJ/kg K)
Density of the fluid	1000 ±2%	(kg/m^3)
Heat capacity of tank incl. secondary collector circuit	13400±7%	(kJ/kg K)
Heat loss coefficient of tank	15.4 ±3%	(W/K)
Heat loss coefficient of piping	3.5 ±20%	(W/K)
Electrical power of the pump	230 ± 5%	(W)
Power delivered to the fluid	115 ±20%	(W)

Draw off profile.

Consumption for 20 dwellings: 3500 l/day

Distribution!



Distribution of the domestic hot water
for a block of flats.

1.8 System parameter measurements SS2

Only the parameters measured in the present contractual period are to be found in the following. Concerning system SS2.2 - the combined system (DHW+SH) the parameter measurements have been reported in ref (1) and concerning system SS2.3 there was no need for parameter measurements.

Some experiments have been carried out to determine the main parameters of system SS2.4. The measuring points of interest are shown on fig. 1.8.

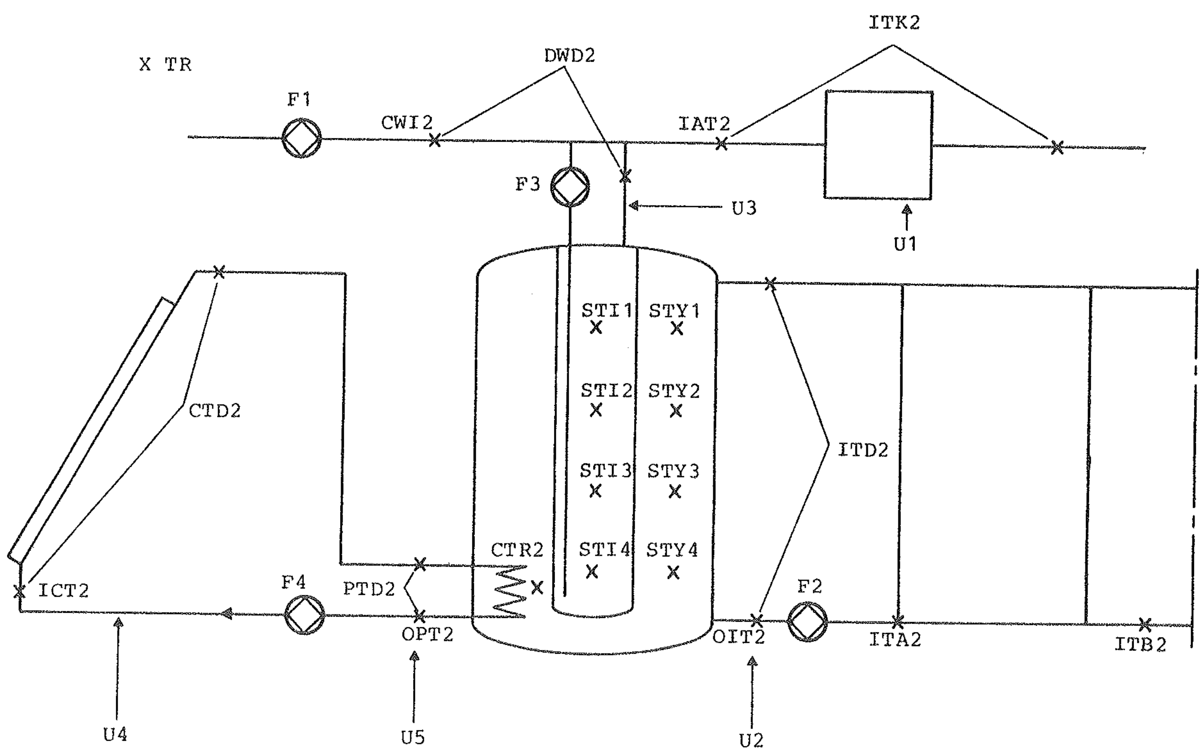


Fig. 1.8. System configuration SS2.4

1.8.1 Storage heat loss

The storage heat loss has been obtained under steady state conditions. With use of the electric heater in the interface system the mean storage temperature is kept at a certain constant value and the heat loss coefficient is evaluated by the formula:

$$UA = U2 \;/(TL - ILT)$$

where

$$U2 = F2 \cdot RO \cdot CP \cdot ITD2$$

RO : fluid density
CP : fluid thermal capacity

and the storage mean temperature TL:

$$TL = (STI1 + STI2 + STI3 + STI4 + STY1 + STY2 + STY3 + STY4) \;/8$$

ILT : room temperature

OBS	TL [°C]	UA [W/°C]	STD ERROR OF MEAN [W/°C]
46	58,56	5,95	0,010
220	79,11	6,72	0,008
47	84,06	6,96	0,019

where the standard error of mean is given by $STD(\bar{X}) = \frac{STD(X)}{\sqrt{N}}$

These results incorporated in the SAS-general linear models procedure give the following dependence:

$$UA = 3{,}662 + 0{,}038983 \cdot TL \quad [W/^{o}C]$$
$$TL > ILT$$

This linear dependence is shown on fig.1.8.1:

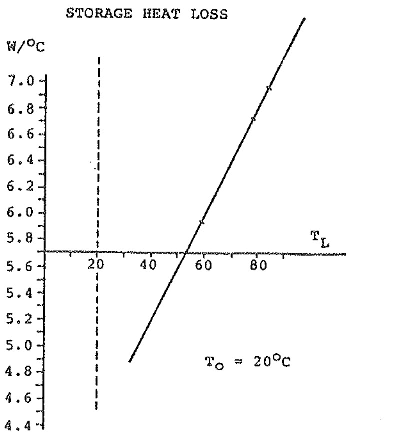


Fig. 1.8.1 Storage heat loss coefficient versus storage temperature.

One of the reasons why the heat loss coefficient is strongly dependant on the storage temperature is the temperature dependance of the thermal conductivity of the insulation. Furthermore you can imagine changes in the pattern of convection, but a full explanation can not be given for the moment.

The expected value of the heat loss coefficient obtained by computation is approx. 2,9 W/^{o}C at 50^{o}C.

This coefficient only takes into account the heat transmission through 10 cm Rockwool, but neither the losses due to the pipes going through the insulation nor the temperature dependance of the thermal conductivity.

1.8.2 Storage capacity

The storage capacity is evaluated under an unsteady warm-up period by this procedure:

$$CP = EAUCC\ /(TSTOP - TSTART)$$

where the accumulated energy EACCU is given by:

$$EACCU = \sum_{N} (U2 - (TL - ILT) \cdot UA)\Delta t$$

for a warm-up period of N times Δt (1800 sec)

U2 : delivered energy to storage

(TL - ILT) · UA : storage heat loss

The result of computing CP from four different warm-up periods was:

period	
1	5263,5
2	5318,3
3	5560,6
4	5452,3

and the mean value

$$CP = 5399\ KJ/^{o}C \quad (\pm\ 3\%)$$

Simple computations of the capacity of the water and steel give the value of:

$$CP = 5150\ kJ/^{o}C$$

1.8.3 Other parameters

The other parameters which also are listed in installation description ID2.206 are estimated to be (the measured parameters are marked with an M):

Collector:

	Absorber area	15.7	±1%	(m^2)
	Tilt	56.0	±1	(^{o})
	Azimuth	0.0	±1	(^{o})
	Cover refractive index	1.52		
	Absorber emittance	0.1	±10%	
	Space between cover and absorber	0.018	± 0.001	(m)
	Back and side loss (for all collectors)	28.3	±1%	(W/K)
	Heat capacity for all collectors and their connections incl. fluid	160	±15%	(kJ/K)
	Fluid content (for all connectors + connections)	0.044	±5%	(m^3)
	Specific heat of fluid	3.515	±1%	(kJ/kgK)
M	Density of fluid	1037	±1%	(kg/m^3)
M	Optical factor of collector	0.85	±2%	(W/m^2K)
M	Constant therm of the top heat loss coefficient	4.5	±2%	(W/m^2K)
M	Temperature coefficient of the top heat loss coefficient	0.015	±2%	(W/m^2K^2)

Piping, cold side:

Total lenght of cold side piping	25.0	±0.3	(m)
Outside length	21.5	±0.25	(m)
Heat capacity (inside piping)	6.8	±10%	(kJ/K)
Heat capacity (outside piping)	41.7	±10%	(kJ/K)
Heat loss coefficient (inside piping)	0.88	±5%	(W/K)
Heat loss coefficient (outside piping)	5.38	±5%	(W/K)
Electrical power of the pump	77	±5%	(W)
Power delivered to the fluid	38	±20%	(W)

Piping, hot side:

	Total length of hot side piping	32,5	±0.5	(m)
	Outside length	29,0	±0.4	(m)
	Heat capacity (inside piping)	6,8	±10%	(kJ/K)
	Heat capacity (outside piping)	56.3	±10%	(kJ/K)
	Heat loss coefficient (inside piping)	0.88	±5%	(W/K)
	Heat loss coefficient (outside piping)	7.25	±5%	(W/K)

Control:

	Δ t on	3	±1	(K)
	Δ t off	0	±1	(K)

Heat exchanger:

	Heat exchanger efficiency	0.7	±7%	

Storage:

	Volume of tank	1.1916	±1%	(m^3)
	Specific heat of the fluid	4.182	±0.01	(kJ/kgK
	Density of the fluid	998.2	±3	(kg/m^3
M	Heat capacity of tank	5399	±3%	(kJ/K)
M	Heat loss coefficient of tank	3,662 + 0,038983 · T_L	±½%	(W/K)
	Volume of tank for domestic hot water	0,206	±1%	(m^3)
	Heat transfer coefficient between tanks	200	±30%	($W/^oC$)

2. System behaviour studies SS1

During the last four years of operation on the SS1 device eight different system configurations have been connected to the measuring and control equipment.

Combined system

ID1.201*):Common configuration

ID1.202*):ID1.201 + lower heat demand and lower requested distribution temperature

ID1.203*):ID1.201 + ID1.202 + renewed collector control System and stratified storage tank

ID1.205 : ID1.204 + new control strategy

ID1.206 : ID1.205 + new heat exchanger

Domestic hot water system

ID1.204*):ID1.201 + ID1.203 + domestic hot water production

ID1.207 : ID1.206 + another inlet position

ID1.208 : ID1.207 + new heat exchanger

*) See ref (1)

The work and the results for the first four of them have been reported in ref (1). In this contractual period the main topic has been the temperature stratification of the storage.

2.1 The stratification of storage temperatures

The reason why the focus has been put on this subject is that the system performance is very much dependant of the available higher temperatures of the system. The early system configurations simply had the inlets to the storage tank in the bottom and the outlets in the top as shown on the diagram 2.1 (installations descriptor ID1.201-202).

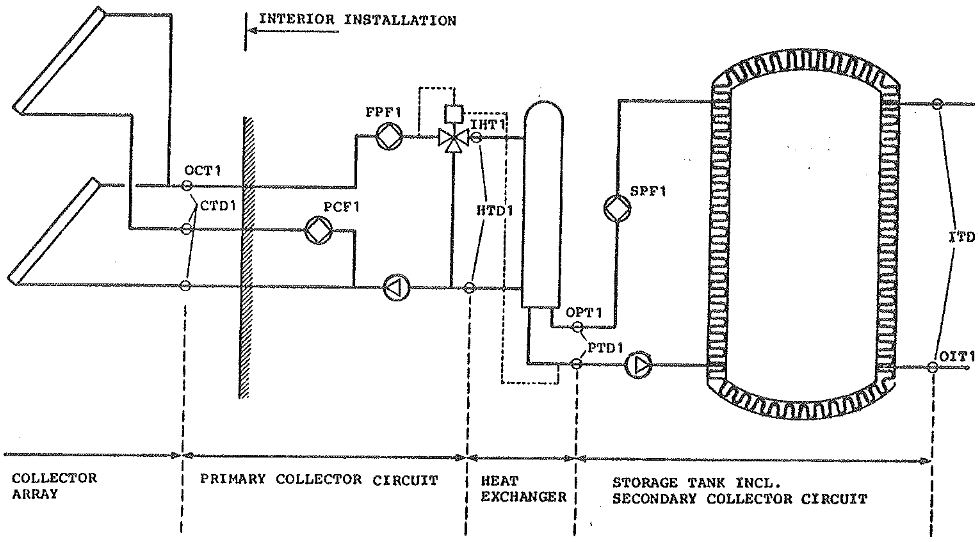


Fig. 2.1 Schematic diagram of the solar system one, SS1.

This strategy has shown to be unappropriate. Consequently the flow direction was changed (installation descriptor ID1.203) as the heated water from the heat exchanger is led into the top of the storage. In order to measure the temperature gradient, the stratification, a rod with five thermocouples is placed vertically in the center of the storage.

With a persistent flow in the secondary collector loop as a consequence of solar insolation the hot water from the top of the storage will be mixed with the colder water from the bottom and hereby the temperature stratification will be destroyed.

Therefore another configuration has been set up (installation descriptor ID1.207).

Here the inlet from the heat exchanger is lowered to permit the hot layer in the top not to be mixed with the cold water in the bottom unless the inlet temperature is higher that the temperature in the top layer. The system is now for the purpose of producing domestic hot water only.

2.2 System performance SS1

Comparisons have been made between the temperature curves for the unstratified and the stratified storage. As seen on the fig.2.2.b the temperature rise due to solar gain had not disturbed the high temperature in the top of the storage (point 1). One and a half hour later at point 2 the temperature is falling, but it is now due to the tapping of hot water.

The unstratified storage is behaving otherwise. When the pump starts the top temperature is falling down immediately and the high top temperature can not be obtained. (Fig. 2.2.a).

Fig. 2.2.a

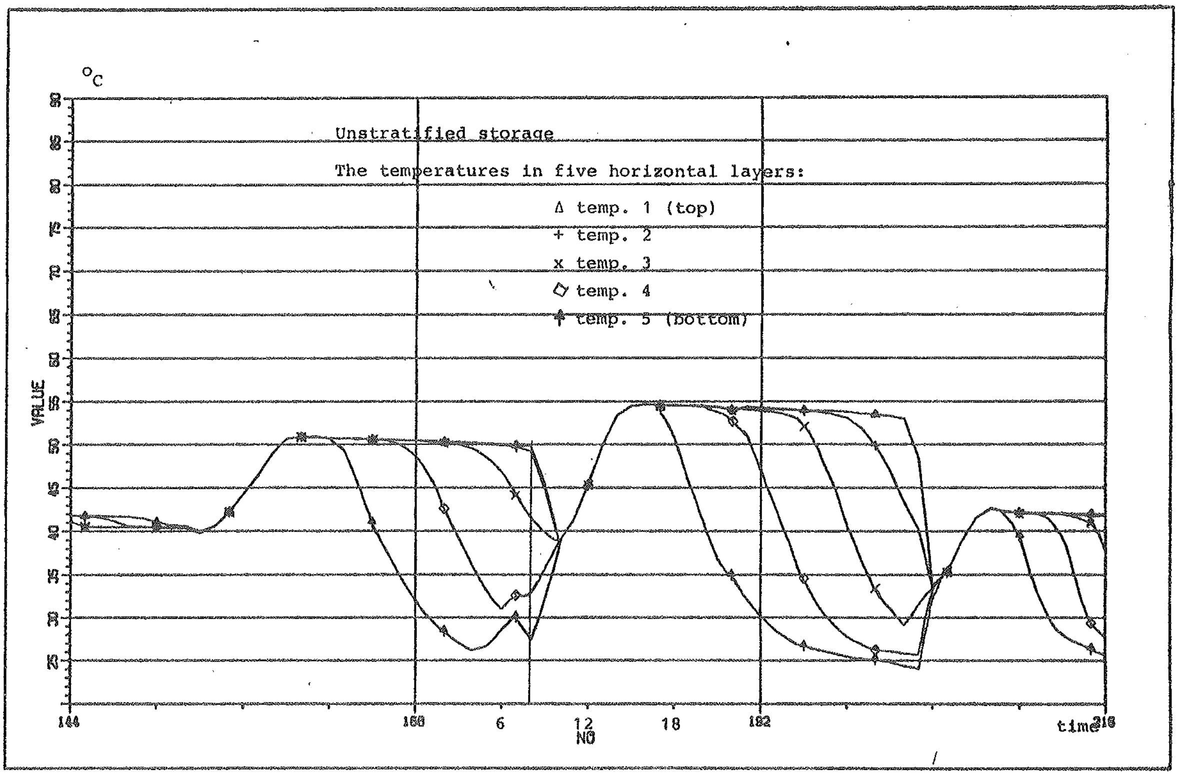
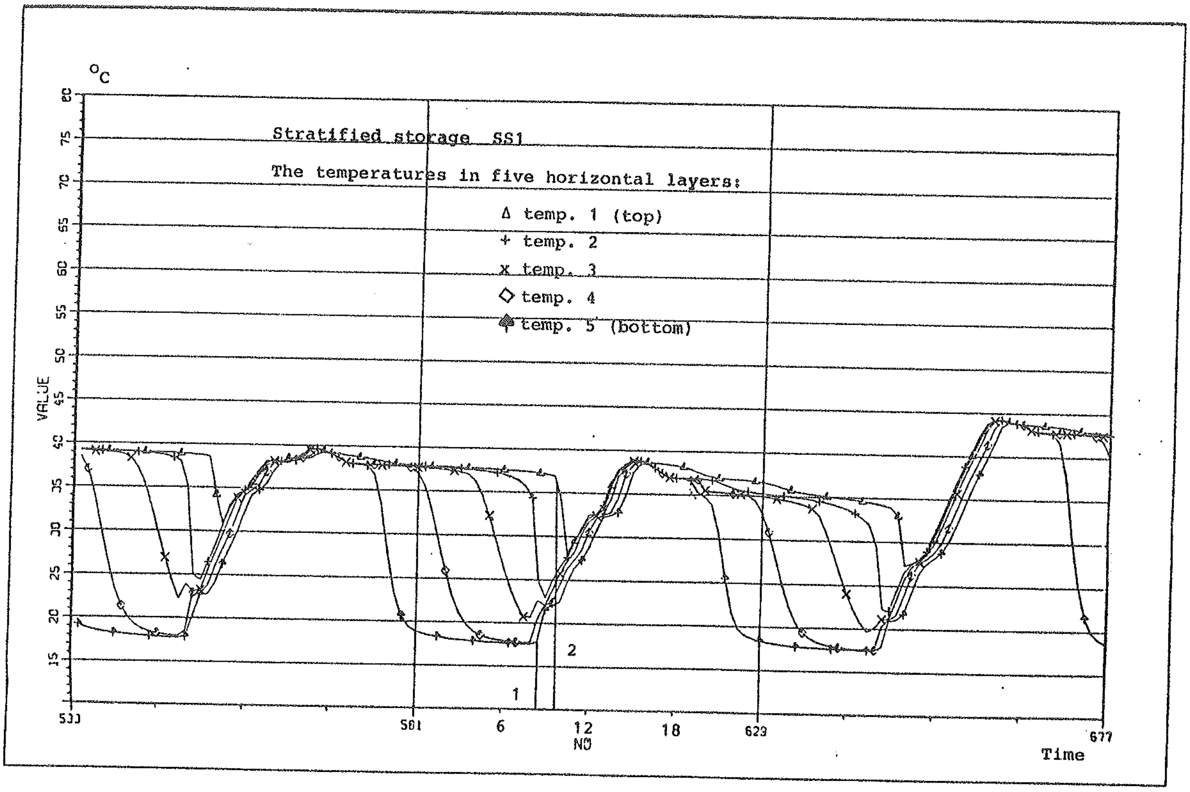


Fig. 2.2.b



2.3 Links between the studies of the participants from the different countries

During most of the second contractual period the focus has been put on the following topics.

Primary circuit

I - on-off controll
  - static
  - dynamic

  threshold studies

II - flow rates
  - correlation between flow rates and on-off control (dynamic)
  - heat exchanger effectiveness

III - pump control
  - reduction of pump consumption
  - action 3 with actions 1 & 2

Solar storage

IV - storage volume/collector area ration
  - same ratio obtained in different ways
  - action 4 + stratification

V - stratification
  - action obtained by actions 2 & 3
  - actions carried out simultaneously with actions 6,7 & 9

Secondary circuit

VI - requested distribution temperature

0 permanent }
0 seasonal } reduction

VII - heating demand reduction

VIII - control system strategies

control of return temperature
optimization of day/night behaviour

IX - combination of function

space heating + domestic hot water

Others

X - components and arrangements.

Fig. 2.3.a
SSI 1981-1982

DATES OF ACTIONS CARRIED OUT

type of action / country	I	II	III	IV	V	VI	VII	VIII	IX	X	N
BELGIUM											
DENMARK	4/9/81 13/12/81 3/2/82 27/4/82				4/7/81 20/7/81 3/2/82 27/4/82	4/9/81 13/12/81 3/2/82 27/4/82	4/9/81 13/12/81 3/2/82 27/4/82		4/7/81 20/7/81	3/2/82 27/4/82	
FRANCE			27/7/81 8/9/81	17/3/82 1/5/82						17/3/82 1/5/82	
GERMANY	26/10/81 14/12/81 15/12/81 15/1/82	5/4/82 7/5/82	10/9/81 19/9/81 15/12/81 15/1/82	5/4/82 7/5/82				30/1/82 18/3/82 5/4/82 7/5/82			
IRELAND	15/10/81 22/11/81			19/3/82 5/4/82	1/3/82 11/3/82	23/11/81 7/1/82	23/4/82 13/5/82	13/5/82 28/5/82			10/2/82 28/2/82
ITALY		11/2/82 15/3/82				6/4/82 29/4/82					10/11/81 30/12/81
THE NETHERLANDS		15/2/82 19/3/82	9/12/81 26/4/81			15/1/82 15/2/82	8/4/82 26/4/82	9/12/81 15/1/82			
UNITED KINGDOM					28/3/82 19/4/82 23/4/82 4/5/82				23/4/82 4/5/82		

— 2nd year of operation of SSI

Fig. 2.3.b

periode / country	1.09 1st	20.10 2nd	15.12 3rd	1.02 4th	20.3 5th	15.05 6th
BELGIUM			I+II+III	I+II+III	IV+V	IV+V
DENMARK	IX	IX	IX	VIII	VIII	VIII
FRANCE	IV	IV	IV	VII	I	I
GERMANY	I	II	II	VII	VII	I
IRELAND	VIII	VIII	III	III	VII	VII
ITALY	IV	IV	I	I	V	V
THE NE-THERLANDS	V	V	VIII	VIII	VII	VII
UNITED KINGDOM	V	V	IV	IV	IX	IX

: PROGRAMME OF ACTIONS - 1982-1983

Efforts have been done to deal with the mentioned topics as well as possible. Therefore the researches concerning a specific topic have been done in more than a single country. The information about the work done by the different participants has been exchanged on the meetings of the SPTF-group. A comparison between the work of all participants is shown on fig. 2.3.a and fig. 2.3.b.

3. System behaviour studies SS2

The SS2 Pilot Test Facility has been of great use for the development of combined systems for SH and DHW, the main scope of the work on the SS2 installation of the Danish SPTF. In the four years contractual period measurements have been done on three different combined systems. The results from the first of them (system SS2.1) have already been reported in ref (1). The work and the results from the two others (the system SS2.2 and SS2.4) will be presented in this chapter which also includes a presentation of a special thermal valve (system SS2.3).

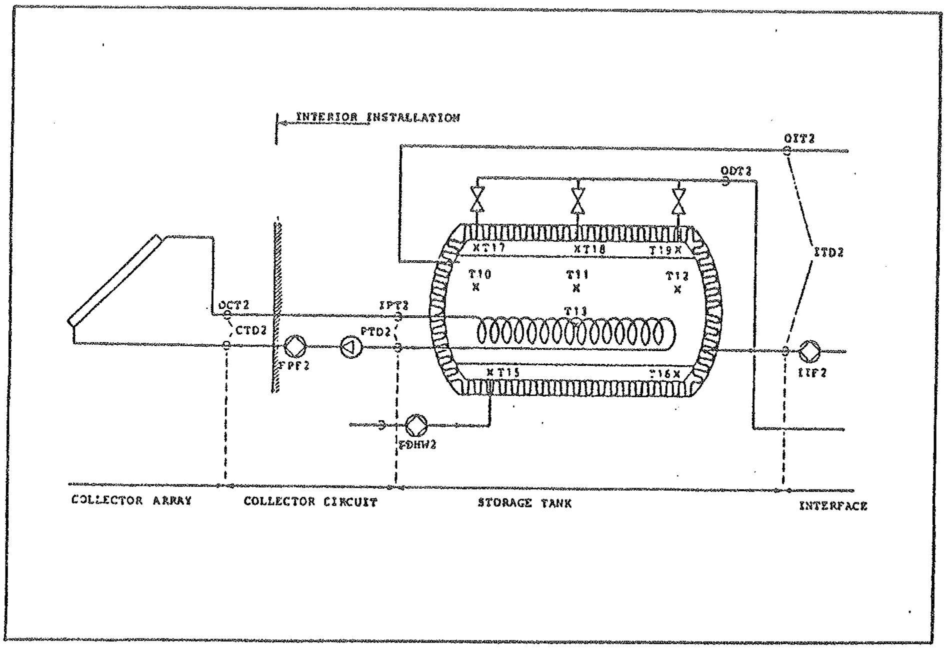
3.1 System SS2.2 - Combined system

The system is a combined space-heating and domestic hot water supply system. The size of the system is determined in order to reach a suitable delivery of energy of about 20-25% of the demand of a standard dwelling for one family.

3.1.1 Description of the system

The system consists of a storage (1,4 m^3) with a mantle around it, the mantle containing the hot water (0,13 m^3). The solar collectors (18,84 m^2) are liquid based and with one layer of glass and selective absorber coating. A diagram of the system is shown on fig. 3.1.1.

Fig. 3.1.1



This system is equipped with an advanced primary circuit control system including four sensors.

One sensor is placed at the back on one of the absorbers, another at the bottom of the storage tank and two sensors in the collector circuit very close to the storage tank. The sensors in the collector circuit stop the pump when the energy flow to the tank is negative.

Data for the system

Solar collectors:	18.84 m^2 sunline absorbers (1,57 m^2 each) 1 layer of glass
Control:	differential thermostat
Storage:	hot water tank 130 l storage (excl. hot water) 1400 l
Heat exchange:	effiveness: 0.61 (40°C) heat transfer coefficient: 1538 W/°C (40°

3.1.2 Measured data and calculations

The measured results for five measuring periods in 1981 are shown in table 3.1.2.a. In this table is also shown the thermal performance as calculated from the actual weather data with the SVS computer program.*) It is seen that there is a fairly good agreement between predicted and measured results.

Fig. 3.1.2.a

. Measured and calculated performances of plant SS2-i

	period measured 1981		lays	Space heating predicted	Space heating measured	Domestic hot water predicted	Domestic hot water measured
1	10/6 -	20/7	41	664	643	192	171
2	5/9	18/9	14	0	0	128	120
3	24/9	1/10	8	151	142	56	42
4	6/10	19/10	14	254	265	45	42
5	21/10	1/11	12	96	96	27	24

The yearly thermal performance has been calculated with the weather data from the Test Reference Year and the results are shown in table 3.1.2.b. It is seen that the total contribution of solar energy is 33% of the total heat requirement and that the system delivers 301 kWh/m^2 collector per year. In particular the solar contribution to the space heating is high certainly because of the choice of simulating a floor heating distribution system. This is dimensioned for a supply temperature of 33°C.

In the third solar system (SS2.4) this distribution system is changed to a more common one for a dwelling.

*) SVS computer program: Program developed at the Danish Thermal Insulation Laboratory.

Table 3.1.2.b: **Yearly performances of plant SS2-2**

Solar radiation on collector (18,8 [m^2])	20138 [kWh]
heat requirement for space heating	14076 [kWh]
solar heat for space heating	4118 [kWh]
covering %	29
heat requirement for domestic hot water	3143 [kWh]
solar heat for DHW	1555 [kWh]
covering %	49
total heat requirement	17219 [kWh]
total solar contribution	5673 [kWh]
covering %	33

5673 [kWh] ∿ 301 [kWh/m^2 of collector]

3.2 System SS2.3 - Thermal valve

The system is a "thermal valve" connected to the SS2 interface. Measurements have been obtained during the period from June to August 1982. The thermal value is a simple construction made to control f.ex. the heat delivery from a solar storage tank without the use of electro-mechanical control devices. The advantages are obvious - a cheaper system which requests no maintenance.

3.2.1 Description

The thermal value is a mixing box which is connected with pipes to the storage tank and to the external device. The purpose of the value is to give the highest possible temperature at the outlet terminal T_{out}. This temperature can be either T_{in}, the inlet temperature, or T_{st}, the storage temperature. The function of the value can be described in the following formulas:

$$T_{out} = T_{in} \quad \text{if} \quad T_{in} > T_{st}$$
$$T_{out} = T_{st} \quad \text{if} \quad T_{in} < T_{st}$$

The driving forces are the differences in density at the different temperatures.

The pipes in the self-circulating circuit are of a bigger dimension to lower the pressure drop - the configuration is shown on fig. 3.2.1.

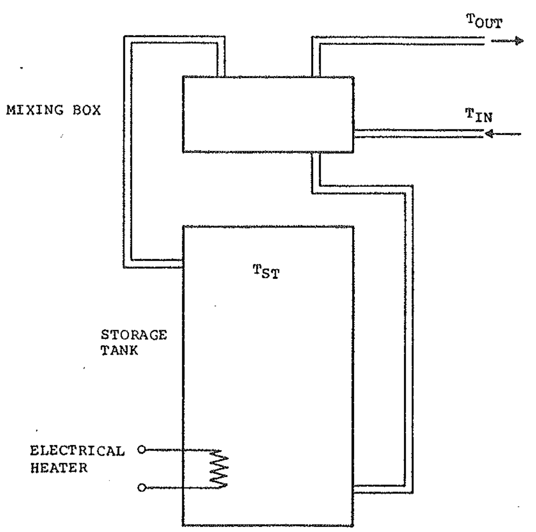


Fig. 3.2.1: Thermal valve

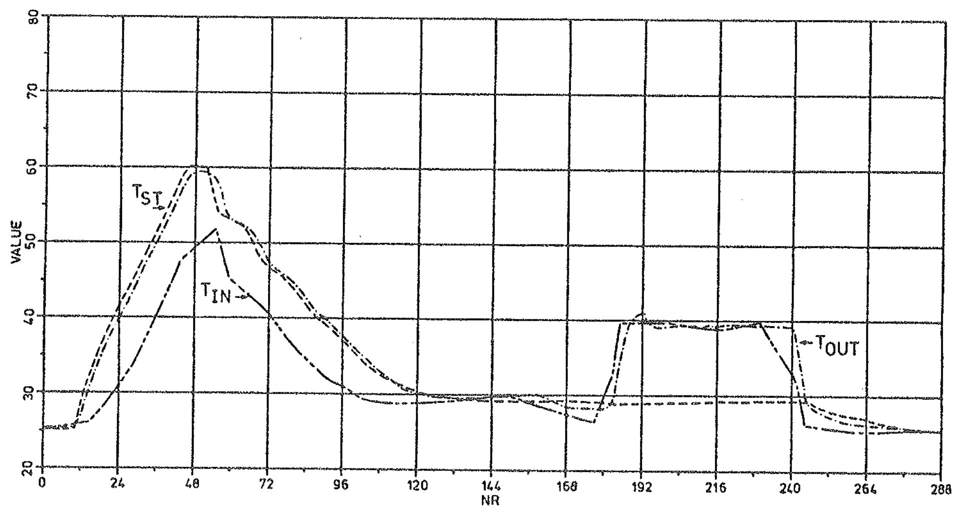
3.2.2 Measurements

The valve has been tested under variation of the inlet temperature, the inlet flowrate and the storage temperature.

The storage is heated with an electric spiral-heater and the inlet temperature is set by use of the SS2 interface equipment. All the mentioned temperatures are measured by the computer through the voltmeter and the scanner in the PTF data sampling system. Some of the results are presented in the next section.

3.2.3 Results

As seen on the diagram the thermal valve is functioning very well. The output temperature is the highest possible.



3.3 System SS2.4 - Combined system

This system, which for the moment is connected to the SS2 installation, has been build up during the period from Sept. to Dec. 1982 and the measurements have started at the end of Dec. The system is a combined space-heating and domestic hot water supply system and it is designed for an ordinary dwelling of 130 m^2 in size.

3.3.1 Background

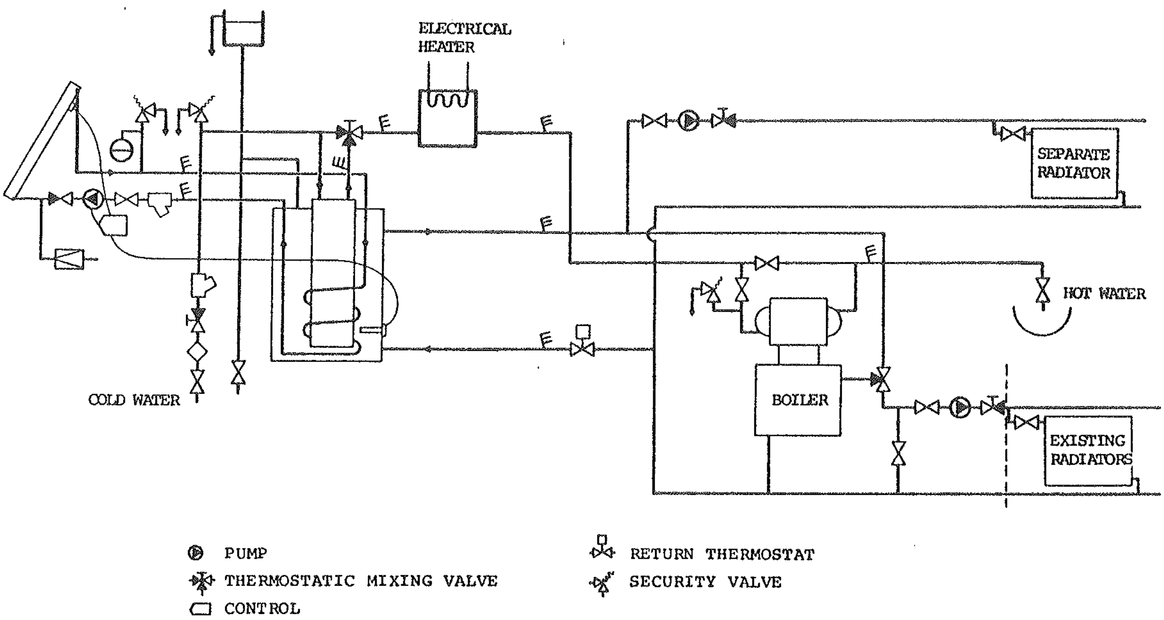
Several years of investigations under the SPTF-program and under the Danish National Solar Energy Program have made it possible to recommend a valid construction of a SH + DHW system. The experiences drawn from these investigations have been the basis of the design work.

The energy consumption of the house, which the system is designed for, is about 13.600 kWh for the space heating and 3.200 kWh for the domestic hot water supply.

3.3.2 Description of the system

The DHW storage tank (0.2 m^3) is placed inside the SH storage tank (1.0 m^3) and it has nearly the same height as the SH tank. The solar collector system is liquid based and it is connected to the storage with a pipe heat exchanger placed in the bottom part of the SH-storage. The inlet of the cold water is placed at the bottom at the DHW-tank and the outlet is placed at the top. This storage configuration provides higher efficiences of the primary circuit because the cold inlet will cool down the bottom of the storage and give higher temperature differences between the fluid in the primary circuit and the water in the storage tank.

Fig. 3.3.2: Solar system SS2.4



Back up (simulated)

As seen on the diagram of the system configuration the system is backed up with a boiler. In summer the no-load loss of the boiler would have been of considerable magnitude in comparison with the demand for DHW. Therefore the boiler is cut off when there is no heat demand and the DHW supply is backed up with an electric heater, which has only little no-load loss.

Seperate readiator: (simulated)

The space heating system is equipped with a separate radiator for the solar space heating. This seperate heater is placed in the largest room of the dwelling, which has f.ex. 25% of the total demand for space heating, and it will make better conditions for using low storage temperatures.

Data for the SS2 system

Solar collectors:	10 elements with selective surface (product sunline) 1 layer of glas transparent area: 15,7 m^2 liquid: propylene glycol flow: 0.111 kg/s (0.4 $l/min/m^2$)
Control:	differential thermostat with separate setting of the start- and stop difference
Storage:	hot water tank: 200 l storage (excl. hot water) 1000 l
Heat exchanger:	20 meter of 16 mm/18 mm copper tupe
Electric water heater:	30 l and 1.2 kW

3.3.3 Measurements

The measurements have started at the end of December and the period from the start to about the 1st March has been used to the storage. From the beginning of March and to June the system is put into the solar-gain mode of operation and the measurements here will be used for validation of an EMGP2-model of the system (see also chapter 4.). In collaboration with the Danish EMG-member the expected performance for a whole year has been computed

3.3.4 Expected performance

The expected performance for a year is computed by the EMGP2-program and the results were presented in table 4.5 in chapter 4. The main result is that the solar system will deliver 66% of the DHW-demand, 19% of the SH-demand and 28% of the total demand.

3.3.5 Economy

Installation costs (estimated)

Components	ECU
Storage tank with hot water tank	710.-
Pipes, fittings, etc.	610.-
Solar collectors 10 á 307.-	3070.-
Control	125.-
Space heating component	
pump	50.-
control	125.-
radiator	360.-
	5050.-
Wages	
Plumber, piping, fittings	970.-
Electrician	75.-
Insulation work	160.-
	1205.-
Total excl. sales tax	6255.-
Sales tax	1376.-
	7631.-

4. EMG + PTF - results

4.1 Introduction

In view of economic aspects the cost of a solar heating system must be low and the annual useful output must be high. Therefore, a simple system with a small to medium sized collector array and a small storage is selected for the Danish SPTF installation, SS2.

Together with planning a combined system for space heating and domestic hot water production the system performance is simulated with EMGP2. The purpose is to optimize the system performance and secure good operation. Different system parameters are optimized

The collector flow rate
SH-demand
Flow rate in the distribution system
Heat transfer coefficient

4.2 Physical system

A schematic diagram of the system is given on fig. 4.2.

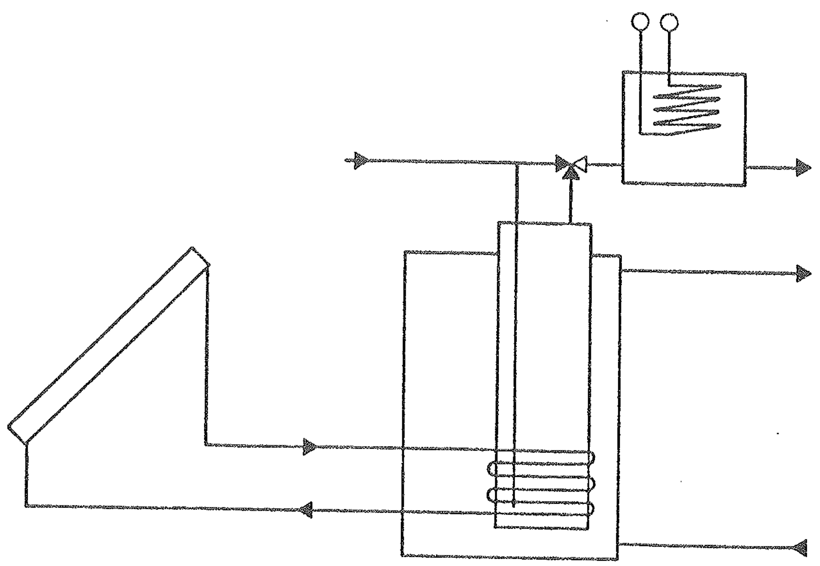


Fig. 4.2 Schematic diagram of solar heating system SS2.

The system is a combined space heating and domestic hot water system. The collector loop contains a collector array with 10 collectors (15.7 m^2) and a submerged heat exchanger in the bottom of the main storage. The preheating tank for domestic hot water is submerged in the main storage extending from bottom to the top layer. The distribution system for space heating is not included in the SPTF-installation but is controlled as a separate system with parallel auxiliary. The installation contains an auxiliary storage for heating domestic hot water.

4.3 Simulation model

A schematic diagram of the simulation model is given on fig. 4.3. The element serial members are indicated and the elements type members are given between brachets. The main storage is modelled as a stratified liquid storage tank with 4 thermal layers. The domestic hot water tank is modelled as a submerged stratified liquid storage with 4 layers extending over the four layers in the main storage. The heat exchanger is submerged into the bottom layer of the main storage. The collector array is modelled as two series connected elements since the dependence of the collector flow rate is investigated.

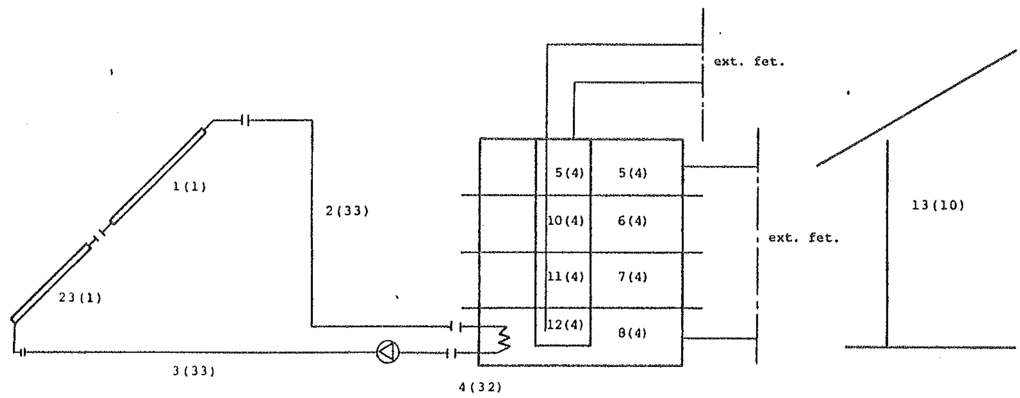


Fig. 4.3 Schematic diagram of the simulation model SS2.

System parameters

Collector:

Collector surface area 15.7 m^2

Single glass collector with selectiv absorber.

Collector efficiency curve:

$$\eta_o = \eta_o - k_o\ (T_m - T_a)/I - k_1 \cdot (T_m - T_a)^2/I$$

with

η_o = 0.85 T_m = mean collector fluid temp.

k_o = 4.5 T_a = ambient temp.

k_1 = 0,015 I = solar irradiance

Thermal capacity per unit surface area incl.pipings 20 kJ/m^2K

Storage

storage	layer MO	P(1) T_{int} ^oC	P(2) m^2	P(3) L m	P(4) K W/K	P(5) C_p kJ/m^3K
main	5	20	0,5695	0,425	2	4530
main	6	20	0,5695	0,425	1,3	4530
main	7	20	0,5695	0,425	1,3	4530
main	8	20	0,5695	0,425	1,3	4530
sub.	9	20	0,121	0,425	0,32	4530
sub.	10	20	0,121	0,425	0	4530
sub.	11	20	0,121	0,425	0	4530
sub.	12	20	0,121	0,425	0	4530

P(1) initial temperature

P(2) cross-sectional area

P(3) height of one layer

P(4) total heat loss coefficient

P(5) effective thermal capacity

Ambient temperature 20^{o}C

Piping of the collector loop

Pump power	77 W
50% of the pump power is dissipated in the fluid and the circulation pump is located in the cold pipe	
Heat loss coefficient	0,25 W/K m
Length of cold pipe	20 m
Length of hot pipe	20 m
Piping ambient temp.: outside temp.	

Submerged heat exchanger	0,6
DHW-draw off	
Flow rate	4,5 l/min
Cold water inlet	8 ^{o}C
Consumption temp.	45 ^{o}C
Daily consumption	202.5 l
with the following profile	
15 min starting 7	67,5 l
15 min starting 12	67,5 l
15 min starting 19	67,5 l

A dynamic heat balance of the dwelling is used together with heat extraction algorithm for space heating and has the following characteristics:

No usefull heat loss of other elements initial temperature	20 ^{o}C
Total heat loss coefficient	200 W/^{o}C
Thermal heat capacity	20000 kJ/K

The space heating demand is zero during same period of the year, which is specified as follows:

129 < number of the day < 266

Table 4.1

DHW demand	11450 MJ/year
SH demand	48835 MJ/year
Heat transfer coefficient between main storage and preheating tank for one layer	75 W/K

Collector flow rate	Solar heat		Solar fraction		
	SH	DHW	SH	DHW	SH+DHW
l/h m^2	MJ	MJ	%	%	%
21.6 *	7330	8082	64	17	26
47.8 *	7638	9393	67	19	28
47.8	7661	9521	67	19	29
31.8	7544	9038	66	19	28

* Only one element for the collector array

Table 4.2

DHW demand	11450 MJ/year
SH demand	48835 MJ/year
Collector flow rate	31.8 l/h m^2
Flow rate in distribution system:	0.14 kW/^{o}C

UA	solar heat	
	SH	DHW
W/K	MJ	MJ
50	9025	7514
75	9038	7544
100	9042	7562

Table 4.3

DHW demand	11450 MJ/year
Collector flow rate	31.8 l/h m^2
Heat transfer coefficient between main storage and preheating tank for one layer	75 W/K

SH demand MJ		Solar fraction DHW %	SH %	SH+DHW	System performance kWh/m^2 year
1	22325	69	31	44	261
2	48835	66	19	28	293
3	81650	64	12	18	303

1: 130 m^2 house with a today level of insulation

2: 130 m^2 house according to the Danish building regulation of 1977

3: 130 m^2 house with an insulation according to the level before 1960

Table 4.4

SH demand	48835 MJ/year
DHW demand	11450 MJ/year
Heat transfer coefficient between main storage and preheating tank for one layer	75 W/K
Collector flow rate	21.6 l/h m^2

Flow rate in distribution kW/^{o}C	Solar heat DHW MJ	SH MJ	SH+DHW MJ
0.14	7330	8082	15412
0.07	7829	6283	14112

Monthly values of the solar output from the combined space heating and domestic hot water system, installed on SPTF, SS2, are given in fig. 4.5.

Measurement from the system will be used to validate the EMGP2 with a similar model configuration.

Additional system data

System efficiency

$$\frac{\text{System output}}{\text{Collector global radiator}} = \frac{16583 \text{ MJ}}{62265 \text{ MJ}} = 27\%$$

Collector efficiency

$$\frac{\text{Collector heat withdrawal}}{\text{Collector global radiation}} = \frac{22519 \text{ MJ}}{62265 \text{ MJ}} = 36\%$$

Pipe efficiency

$$\frac{\text{Solar storage input}}{\text{Collector heat withdrawal}} = \frac{20631 \text{ MJ}}{22519 \text{ MJ}} = 92\%$$

Storage efficiency

$$\frac{\text{System output}}{\text{Solar storage input}} = \frac{16583 \text{ MJ}}{20631 \text{ MJ}} = 80\%$$

Table 4.5

	Solar Output		Heat demand		Solar fraction		
	DHW	SH	DHW	SH	DHW	SH	SH+DHW
	MJ	MJ	MJ	MJ	%		
Jan	320	242	972	8734	33	3	6
Feb	393	700	878	7738	45	9	13
Mar	471	906	972	6756	48	13	18
Apr	656	1799	941	4295	70	42	47
May	787	2034	972	2544	81	80	80
Jun	941	0	941	0	100	-	100
Jul	972	0	972	0	100	-	100
Aug	972	52	972	41	100	100	100
Sep	752	1445	941	1484	80	97	91
Oct	527	1055	972	3823	54	28	33
Nov	380	451	941	5811	40	8	12
Dec	373	353	972	7606	38	5	8
Tot	7545	9038	11450	48833	66	19	28

5. Conclusions and recommendations for further work

During the last two years of operation the SPTF groups have established a routine in acquisition and exchange of measuring data. Collaboration has also been established with the European Modelling Group with the purpose of validation models. This collaboration has for the Danish participant proved valuable not only for the validation but also for the immediate evaluation of the measured solar system and for new designs.

For the Danish SPTF the data acquisition has worked very well except for some power supply drop outs and computer break downs in the spring of 1983. In the period 17 data cassettes have been produced so the total number of produced data cassettes is now 41. The measurements have been obtained with good accuracy and there have been none or only unimportant problems with the measuring equipment. The data have been checked visually before being sent to the data bank.

At the SS1 system four new system configurations have been tested. The SS1 system has in this period been changed to a system producing only domestic hot water and the efforts have mainly been put on the investigation of stratification in the storage. The Danish work on the SS1 has been coordinated with the work of the rest of the SPTF group so that many aspects of the SS1 system have been investigated.

For the SS2 system the work has consisted in development and improvement of systems for combined space heating and domestick hot water. The first system in this period was a system using a storage with a mantle for the domestic hot water. It had a collector area of 18,8 m^2 and was operated to feed a floor heating system. From a model validated with the measurements an annual performance was calculated to be 301 KwH/m^2 with a solar fraction of 33%. From a thermal point of view the idea of the system was good but the system was abandoned because of construction problems with the domestic hot water in the mantle.

After this a "thermal valve" was investigated. This was constructed to control the heat delivery from a solar storage tank without the use of electro - mechanical control devices. The valve worked very well.

The last SS2 system was constructed during 1982 and lots of effort was put on optimizing the system using the experiences gained from the first systems and using the validated situation model. Furthermore, the system was developed to be "ready to install".

From model calculations it was found that the system would have an anual performance of 300 kWh/m^2 with a solar fraction of 66% for the DHW-demand, 19% for the space heating demand and 28% for the total demand.

The system is designed to fit existing houses and the price is calculated to be 51.000 D.Crs. It is expected to be possible to reduce this price by further improvements of the system and the components, so that the system will have a sound economy. The system has been carefully modelled with the EMG 2 simulation programme (the simulation programme developed by the European Modelling Group). The results of this are described in chapter 4 of this report.

The last two years of operation have proved that the SPTF's are very valuable tools to obtain accurate and detailed measuring data of solar systems. Furthermore, the SPTF's are designed so that it is very easy to modify or change the solar systems installed on the SPTF's. The characteristics of the SPTF make it suitable for every kind of experimental work with solar systems.

Though the work of the SPTF group has found a form where the carrying out of the different tasks is a matter of routine some problems still have to be solved.

The group has already carried out some work as to which criteria the characteristics of the time series have to fulfil to be valid for data analysis. For example you must have some heat demand, some solar insulation etc.

The length of the time serie is also very important and some theoretical work has also been made about it. Any final conclusion has not yet been found so the group has to reconsider this question.

After the experience gained during the last years of operation it should also be worthwhile to reevaluate the working procedures which have been established.

For example the following questions could be considered:

a) Are the measurements accurate and uniform enough for the validation purposes?

   This question could be answered from the modelling group where the validation has been going on for some time.

b) Does the operation procedure secure maximum use of the SPTF installations?

   Until now the group has operated with a least six operation sequences per year.

   However, it has been proved that if you are making major changes on the systems (for example if you dismount a solar system and construct a new one) then half a year could easily pass before you are ready to make new measurements. On the other hand if you are only making modifications on the system then it could be carried out in less than a week.

A planned programme of action should therefore be flexible but it should also secure that results even though they are not coming in a regular order could be handled as effectively as possible.

A last question which is to be taken up is for what purposes the SPTF has to be operated in the future.

The two purposes, which has been considered, are the validation and the system development studies.

From the Danish point of view we agree with these purposes and think that they can easily go hand in hand.

Appendix 1

List of participants

Co-ordinator:	G. Olive Ministère de l'Urbanisme et du Logement Direction de la Construction 2 Avenue de Parc de Passy 45775 Paris Cedex 16
Belgium:	W.L. Dutré A. Debosscher Catholic University of Leuven Laboratorium voor Warmteoverdracht en Reaktorkunde Instituut voor Mechanica Celectijnenlaan, 300 A 3030 Heverlee
France:	R. Ployart CEN Cadarache BP 1 13115 Saint Paul Lez Durance
Germany:	R. Hanitsch K.D. Bergmann Institut für Elektrische Machinen Technische Universität Berlin Sekr. EM4 Einsteinufer 13-15 1000 Berlin
Ireland:	I.J. Cowan Institute for Industrial Research & Standards Energy Development & Promotion Dep. I.I.R.S. Ballymun Road Dublin 9
Italy:	L. Grassi Enel-Phoebus Via Leopardi 148 95127 Catania
The Netherlands:	C. den Ouden Institute of Applied Physics T.P.D. - T.N.O. Heat Instrumentation Department P.O. Box 155 2600 Delft

The Netherlands	E. Van Galen Van Amerongen Institute of Applied Physics Stieltjesweg 1 2628 CK Delft
United Kingdom	C.J. Baker N. Potter BSRIA Old Bracknell Lane West Bracknell, Berkshire, RG 12 4AH
Denmark	Klaus Ellehauge Ole Balslev-Olesen Nick Bjørn Andersen Thermal Insulation Laboratory Technical University of Denmark Building 118 DK-2800 Lyngby

Appendix 2

Data descriptors

Logsheets

Data descriptors

DDO: DD0.203

1 TOWN DAY MONTH YEAR HOUR NDAY NHOUR NMIN

2 HGR HDR CGR WV AT SH ILT

FORMAT

Each value is separated by a blank " "

1 A10, 2F3.0, F5.0, F3.0, F4.0, 2F3.0

2 3F8.3, F5.1, F7.1, 2F5.1

DDO.204

TOWN DAY MONTH YEAR HOUR NDAY NHOUR NMIN
HGR HDR CGR WV AT SH ILT

FORMAT

linie No.

1 C10, 2F3.0, F5.0, F3.0, F4.0, 2F3.0

2 3F8.3, F6.1, F7.1, 2F6.1

DD1: DD1.203

3 OCT1 CTD1 IPT1 PTD1 IIT1 ITD1 IHT1 HTD1

4 PCF1 SPF1 IIF1 FPF1 STT1 STT2 STT3 STT4 STT5

5 IL1 HP1 AHP1 SSG1 HOC1 HT1

FORMAT

Each value is separated by a blank " "

3 8F1.1

4 4F8.3, 5F6.1

5 6F6.2

DD1.204

OCT1 CTD1 IPT1 PTD1 OIT1 ITD1 IHT1 HTD1
PCF1 SPF1 IIF1 FPF1 STT1 STT2 STT3 STT4 STT5
IL1 HP1 AHP1 SSG1 HOC1 HH

FORMAT

linie No.

3 8F6.1

4 4F8.3, 5F6.1

5 6F7.2

```
00090 INPUT #1 TOWN $ DAY MONTH YEAR HOUR NDAY NHOUR NMIN
00100       #2 HGR HDR CGR WV AT SH ILT
00110       #3 OCT1 CTD1 IPT1 PTD1 OIT1 ITD1 IHT1 HTD1
00120       #4 PCF1 SPF1 IIF1 FPF1 STT1 STT2 STT3 STT4 STT5
00130       #5 IL1 HP1 AHP1 SSG1 HOC1 HH
00140       #6 OCT2 CTD2 IPT2 PTD2 OIT2 ITD2 IDT2 DTD2
00150       #7 T10 T11 T12 T13 T15 T16 T17 T18
00160       #8 T19 F1 F2 F3 Q1 Q2 Q3 Q1A
00170       #9 SIF1 SIT1 RDT1 X1 X2 SCL1
00180       #10  C2 C3 C4          ;
```

FORMAT:

#1 C10, 2F3.0, F5.0, F3.0, F4.0, 2F3.0

2 3F8.3, F5.1, F7.1, 2F5.1

3 8F6.1

4 4F8.3, 5F6.1

5 6F6.2

6 8F6.1

7 8F6.1

8 F61, 3F7.3, 4F7.2

9 F6.2, 2F6.1, 3F7.2

10 3F7.2

Data Descriptor: DD1.205

```
€3 OCT1 CTD1 IPT1 PTD1 OIT1 ITD1 IHT1 HTD1
€4 PCF1 SPF1 IIF1 FPF1 STT1 STT2 STT3 STT4 STT5
€5 IL1 QD1 QD2 SSG1 HOC1 HH ;
```

Format:

Line 3 : 8F6.1

4 : 4F8.3, 5F6.1

5 : 6F7.2

New variable

QD1 : Measured integrated DHW-draw off reset at midnight

QD2 : Requested integrated DHW-draw off reset at midnight

DD2: DD2.205

6 OCT2 CTD2 IPT2 PTD2 OIT2 ITD2 ODT2 DTD2

7 T10 T11 T12 T13 T15 T16 T17 T18

8 T19 FPF2 IIF2 FDHW2 HOC2 IL2 QDHW2 SSG2

9 SIIF1 SOIT1 RDT1 X1 X2 SCL1

10 C2 C3 C4

FORMAT

Each value is separated by a blank " "

6 8F6.1

7 F7.2, 2F6.1, 3F7.2

8 F6.1, 3F7.3, 4F7.2

9 3F7.2

Numenclature

Line 1

TOWN:	Name of town	
DAY, MONTH, YEAR, HOUR	Beginning of data storage sequence	
NDAY, NHOUR, NMIN	Data storage file	

Line 2

HGR:	Horizontal global radiation	[kWh/m^2]
HDR:	Horizontal diffuse radiation	[kWh/m^2]
CGR:	Collector global radiation	[kWh/m^2]
WV :	Wind velocity	[m/s]
AT :	Air temperature	[^oC]
SH :	Specific humidity, not measured	
ILT:	Interior laboratory temperature	[^oC]

Line 3 Data from SS1

OCT1:	Out of collector temperature	[^oC]
CTD1:	Collector temperature difference	[^oC]
IPT1:	Inlet primary temperature	[^oC]
PDT1:	Primary temperature difference	[^oC]
OIT1:	Out of interface temperature	[^oC]
ITD1:	Interface temperature difference	[^oC]
IHT1:	Inlet heat exchanger temperature in primary collector circuit	[^oC]
HTD1:	Heat exchanger temperature difference in primary collector circuit	[^oC]

Line 4, Data from SS1

PCF1:	Partial collector flowrate	[m^3/h]
SPF1:	Secondare collector flowrate	[m^3/h]
IIF1:	Interface flowrate	[m^3/h]
FPF1:	Primary collector flowrate	[m^3/h]
STT1:	Top storage tank temperature	[^oC]
STT2:	storage tank temperature	
STT3:	storage tank temperature	
STT4:	storage tank temperature	
STT5:	Bottom storage tank tamperature	

Line 5, Data from SS1

IL1 :	Interface losses	[kWh]
HP1 :	Heating power	[kWh]
AHP1:	Auxiliary heating power	[kWh]
SSG1:	Solar storage gain	[kWh]
HOC1:	Heat out of collector	[kWh]
HH :	Heat into heat exchanger	[kWh]

Line 8,	Data from SS2		
T19	:	Storage tank temperature	[^oC]
F1	:	Flow in collector circuit	[m^3/h]
F2	:	Flow in interface	[m^3/h]
F3	:	Domestic hot water flow	[m^2/h]
Q1	:	Heat gain from collector	[kWh]
Q2	:	Heat gain to interface	[kWh]
Q3	:	Heat gain for domestic hot water	[kWh]
Q1A	:	Heat storage gain	[kWh]
Line 9			
SIF1	:	Set interface flow, predicted by SIMUL	[m^3/h]
SIT1	:	Set interface temperature, predicted by SIMUL	[^oC]
RDT1	:	Requested distribution temperature predicted by SIMUL	[^oC]
X1	:	Control parameter	
X2	:	Control parameter	
SCL1	:	Space cooling load	
Line 10	Data from SS2		
C2	:	Integrated space heating load, predicted by SIMUL	[kWh]
C3	:	Integrated heat gain from solar system, predicted by SIMUL	[kWh]
C4	:	Integrated storage loss	[kWh]

PTF LOG SHEET LS

C	N			Y		D		M		Y	
2	0	3	4	8	1	2	2	0	7	8	1
cassette n°				year recorded		date sent					

DESCRIPTION OF SEQUENCES

S	START					CASE	DD						ID				END				
							DD0		DD1		DD2		ID1		ID2						
	M	D	H	m	F		C	V	C	V	C	V	C	V	C	V	M	D	H	m	F
1	7	4	13	0	100	3	2	03	2	03	2	05	2	04	2	05	7	20	8	0	479
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9																					
0																					

REMARKS

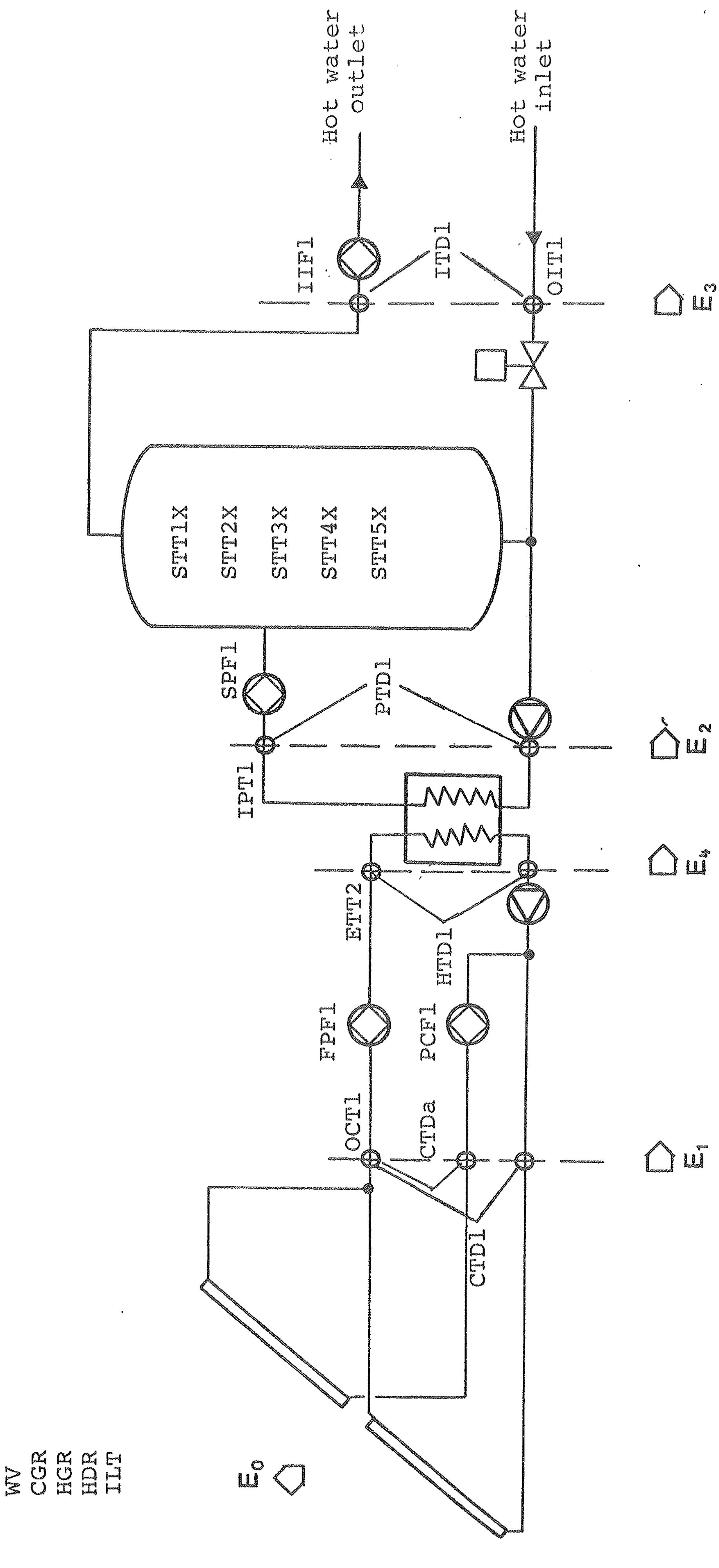
SS1: The value of HP1 and AHP1 is missing, but use x1 and x2 in line 9 instead

HP1 = x1 and AHP1 = x2

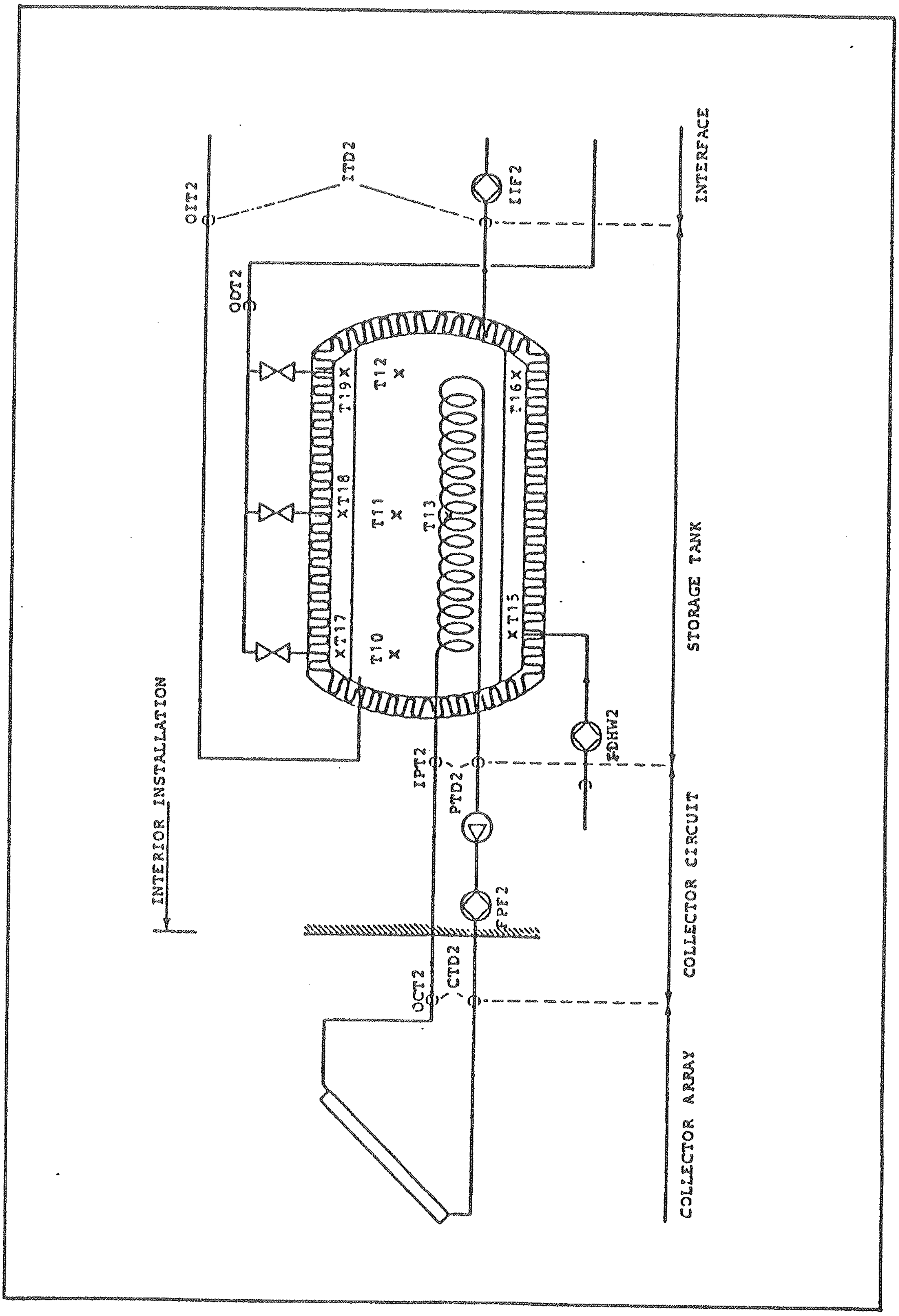
Appendix 3

Design Drawings

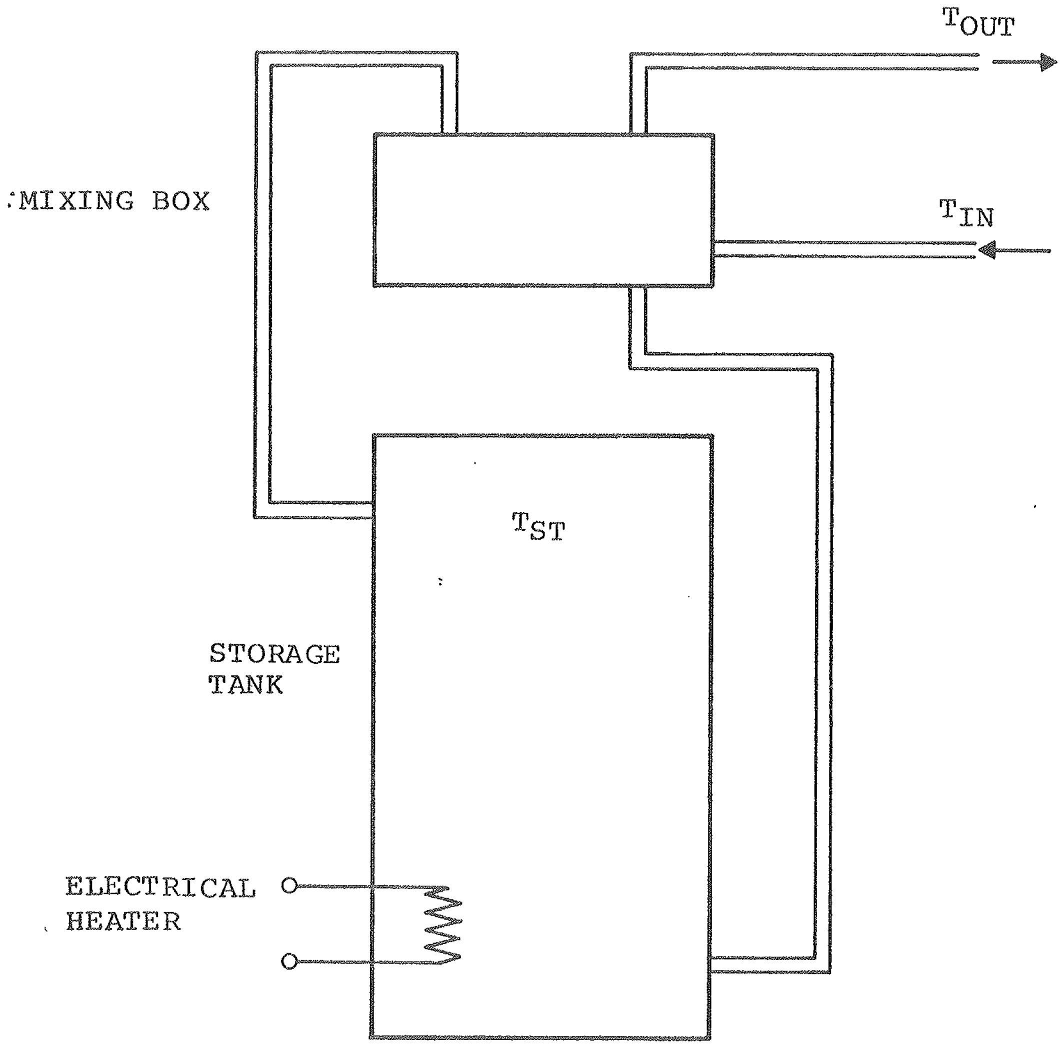
Schematic diagram of the solar system SS1



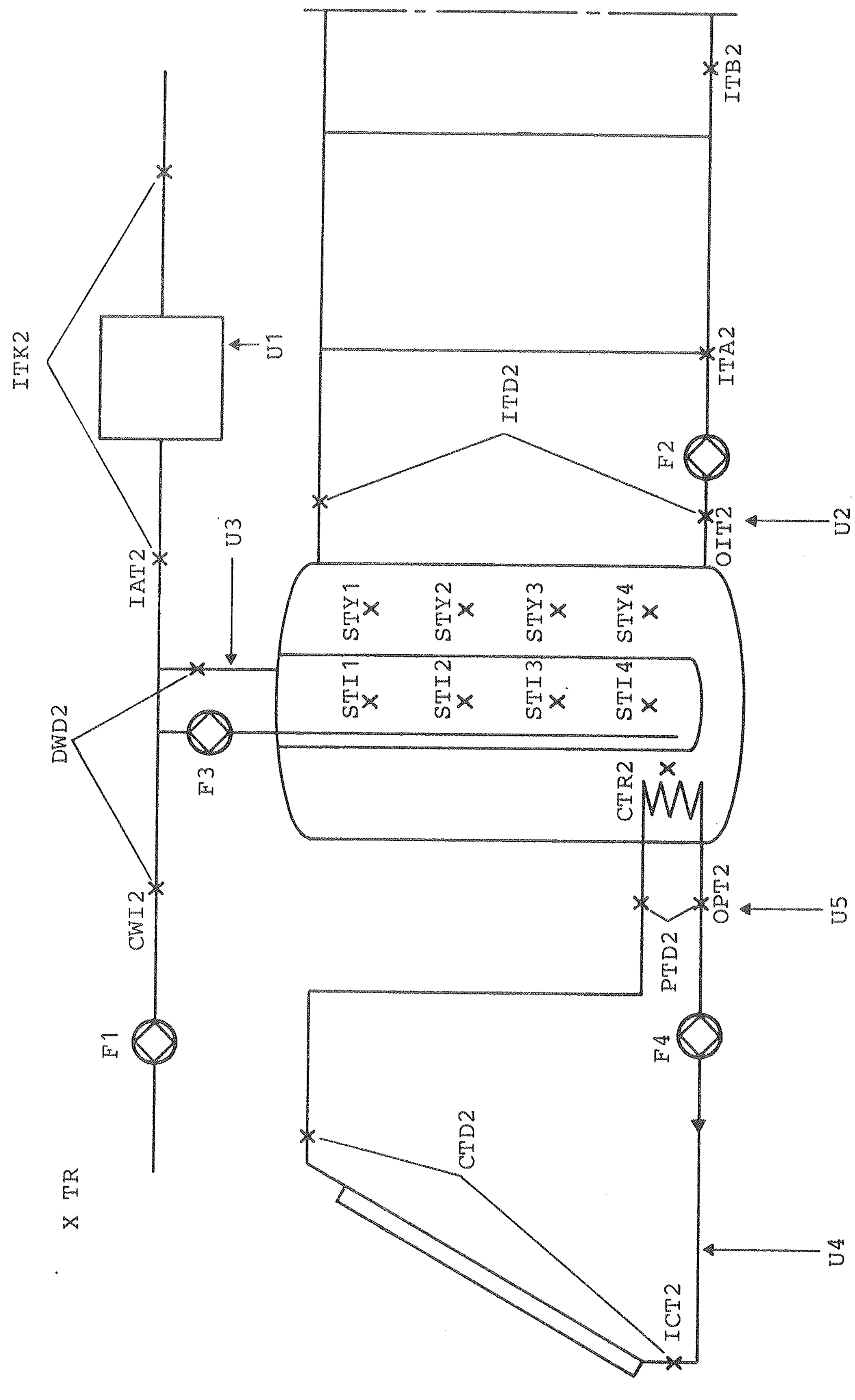
Schematic diagram of the solar system SS2.2



Schematic diagram of the solar system SS2.3



Schematic diagram of the solar system SS2.4



Appendix 4

Installation descriptors

The installation descriptors - solar system one

The installation descriptors each describing a certain system configuration are here presented:

Solar system one

Combined system

ID1.201*): Common configuration

ID1.202*): ID1.201 + lower heat demand and lower requested distribution temperature

ID1.203*): ID1.201 + ID1.202 + renewed collector control System and stratified storage tank

ID1.205 : ID1.204 + new control strategy

ID1.206 : ID1.205 + new heat exchange

Domestic hot water system

ID1.204*): ID1.201 + ID1.203 + domestic hot water production

ID1.207 : ID1.206 + another inlet position

ID1.208 : ID1.207 + new heat exchange

*) See ref (1)

Solar system two

ID2.201*): 30 m^2 black-painted solar collector 1.2 m^3 storage tank with an 0.2 m^3 preheating tank inside.

ID2.202*): ID2.201, but with 20 m^2 collector area.

ID2.203*): ID2.201, but with 10 m^2 collector area.

ID2.204*): ID2.201, but with renewed storage tank with an 0.1 m^3 preheating tank outside. Renewed control system with four sensors.

ID2.205*): ID2.204, but with renewed solar collector with selective absorber.

ID2.206: 16 m^2 selectiv absorber 1,0 m^3 storage tank with an 0.2 m^3 DHW-tank inside.

*) See ref (1)

Installation descriptor ID1.205:

The system configuration now differs from the original configuration. The requested distribution temperature and the house heating demand are lowered according to the installation descriptor ID1.202. Another control strategy for the collector circuits is introduced according to the ID1.203. These two modifications are also included in the installation descriptor ID1.205.

The installation descriptor ID1.205 comprises an investigation of the starting and the stopping temperature difference of the collector control system.

$$\Delta T_{on} = 8\ ^{o}C \pm 1\ ^{o}C$$

$$\Delta T_{off} = 0\ ^{o}C \pm 1\ ^{o}C$$

Installation descriptor ID1.206:

The heat exchanger between the two collector circuits is replaced by a counterflow heat exchanger. Besides the heat exchanger the installation descriptor ID1.206 also includes the modifications according to ID1.2o2, ID1.203 and ID1.205.

Because of wrong information given by the manufacturer, the pressure drops across the heat exchanger is greater than expected. To secure a reasonable flow rate in the collector circuits the pump power is increased.

Primary circuit: 600 W, 50% to the fluid
Secondary circuit: 345 W, 50% to the fluid

By using measurement obtained in May 1982 the heat exchanger effectiveness and the heat transfer coefficient is found.

The effectiveness is found by

$$\varepsilon = \frac{\dot{Q}_{actual}}{\dot{Q}_{maximum}}$$

$$= \frac{SPF1 \quad C_p \cdot \rho \cdot PTD1}{\dot{C}_{min} \quad (IHT1 - OPT1)}$$

Since the capacity flow rate in the secondary collector circuit is the minimum flow rate, the equation then becomes

$$\varepsilon = \frac{PTD1}{IHT1 - IPT1 + PTD1}$$

The overall heat transfer coefficient (UA) can be found by

$$\mathring{Q} = UA \cdot \theta_{en}$$

$\mathring{Q}$: heat transfer (SSG1)

θ_{ln} : logarithmic mean temperature difference

$$UA = \frac{SSG1}{\dfrac{HTD1 - PTD1}{\ln[(IHT1 - IPT1) / (IHTI - HTD1 - IPT1 - PTD1)]}}$$

A linear relation between ε and the temperature IHT1 is found:

$$\varepsilon = 1.16 \cdot 10^{-3} \cdot IHT1 + 0.553$$

A linear relation between UA and the temperature IHT1 is found:

$$UA = 5.22 \cdot 10^{-3} \cdot IHT1 + 1,814 \quad [kW/^{o}C]$$

The main results are listed in the table 1, and all the measurements used are listed in the appended list.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
FPF1	134	2.50513433	0.02786940	2.44800000	2.5610000
SPF1	134	1.45925373	0.01217892	1.41700000	1.4760000
IHT1	134	56.03507463	10.71416922	32.40000000	80.7000000
IPT1	134	50.99179104	10.80006299	29.70000000	77.9000000
HTD1	134	5.06492537	1.64573988	2.00000000	8.4000000
PTD1	134	8.17164179	2.65260864	3.30000000	13.5000000
E	134	0.61743574	0.01354223	0.57812500	0.6412214
UA	134	2.10676053	0.07029155	1.85892164	2.2101722

Table 1. UA: [kW/^{o}C]

Installation descriptor ID1.207

The system on the Danish solar pilot test facility is a domestic hot water system with a draw of profile according to a consumption of 20 dwellings.

The system is indicated on fig. 1. The cold water inlet is in the bottom of the storage tank and the outlet from the top. The water from the heat exchanger in the secondary collector circuit is returned into the middle layer of the storage tank.

The collector circuits are controled by a differential thermostat which starts the pumps when the temperature of the backside of the absorber plate is higher than the temperature at the bottom of the storage tank.

Parametre:

Collector:

Absorber area	46.47 m^2
Tilt	56.0 $^\circ \pm 1^\circ$
Azimut	0.0 $^\circ \pm 1^\circ$
Cover refractive index	1.52
Absorber absorptance	0.93
Absorber emittance	0.3
Space between cover and absorber	0.035 m
Back and side lasses incl. their connections	91.0 $\pm$ 5% W/K
Heat capacity for all collectors and their connections incl. fluid	1200 $\pm$ 13% kJ/K
Specific heat of fluid	3.91 $\pm$ 2% KJ/kg K
Density of fluid	1060 $\pm$ 2% kg/m^3
Optical factor of collector $(\alpha\tau)$	0.85

Piping (primary collector loop):

Length of cold side piping	32.4 $\pm$ 0.2 m
Outside length (cold side)	23.2 $\pm$ 0.2 m
Heat capacity incl. content	16.0 $\pm$ 20% kJ/K m
Heat loss	1.12 $\pm$ 20% W/K m
Electrical power of the pump	600 $\pm$ 5% W
Power delivered to the fluid	300 $\pm$ 20% W
Length of hot side piping	16.9 $\pm$ 0.2 m
Outside length (hot side)	11.6 $\pm$ 0.2 m

Controler:

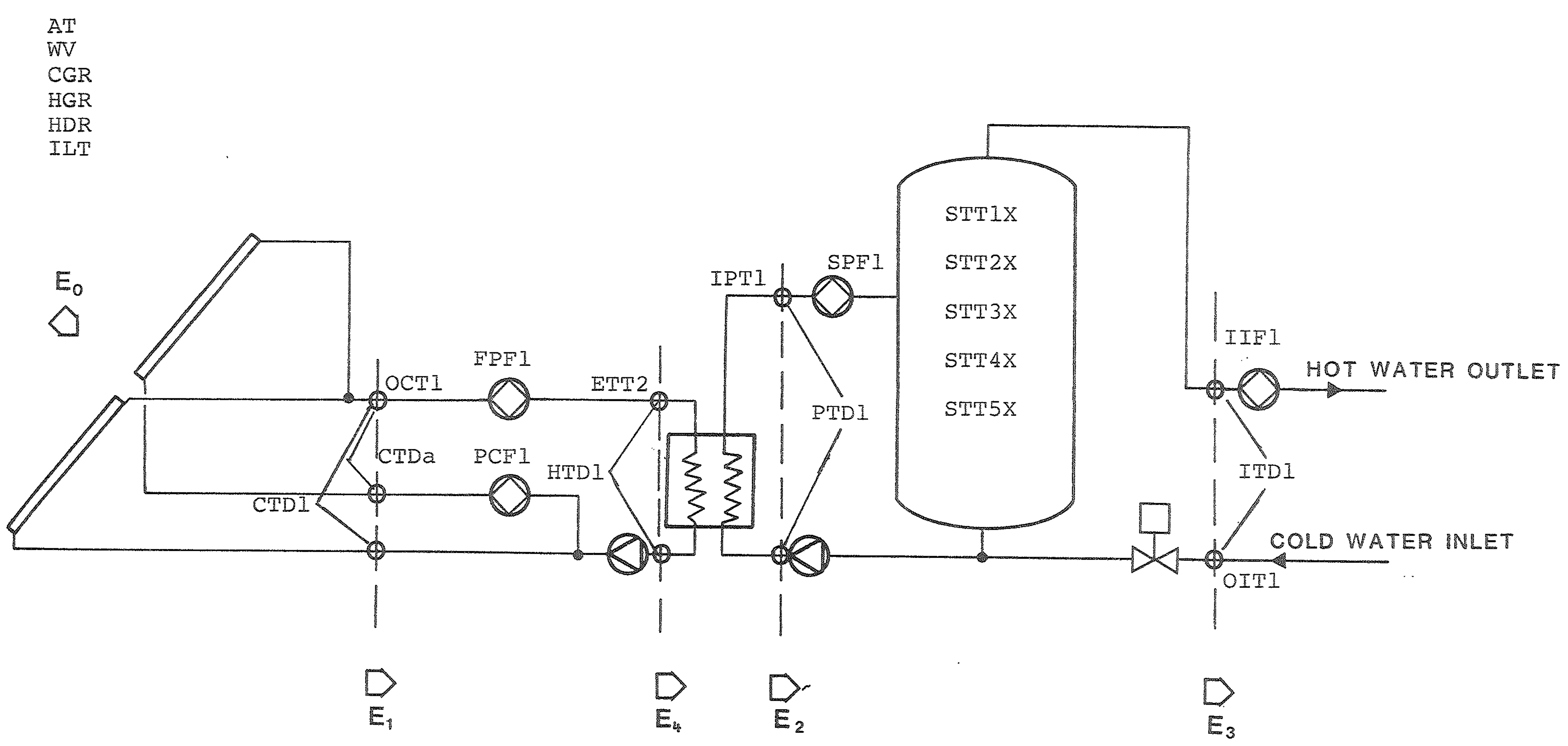
Start differential ΔT_{on}	8 $\pm$ $1^\circ C$
Stop differential ΔT_{off}	0 $\pm$ $1^\circ C$

Heat exchanger:

Heat exchanger effectiveness	0.62 $\pm$ 3%

Storage tank:

Volume of tank	3 m^3
Length of secondary circuit	7 $\pm$ 0.2 m
Specific heat of the fluid	4.2 kJ/kgK
Density of the fluid	1000 kg/m^3
Heat capacity of tank incl. secondary collector circuits	13400 $\pm$ 7% kJ/K
Heat loss coefficient of tank	15.4 $\pm$ 3% W/K
Heat loss coefficient of piping	3.5 $\pm$ 20%
Electrical power of pump	345 $\pm$ 5% W
Power delivered to the fluid	170 $\pm$ 20% W



Schematic diagram of the solar system SS1,ID1.207

Installation descriptor ID1.208

The heat exchanger used between the two collector circuits according to installation ID1.206 has now been replaced by the one originally used in the SS1-system (ID1.201-205). This means that the performance now can be expressed as:

Heat exchanger effectiveness 0,37 ±3%

Furthermore the $r_v(C_v)$ value of the controlled value A in the tapping pipe has been changed.

The system is still a domestic hot water system with a draw off profile according to the consumption of 20 dwellings.

System parameters

Collector:

Absorber area	46.47 (m^2)
Tilt	56.0^{o} $\pm 1^{o}$
Azimuth	0.0^{o} $\pm 1^{o}$ (south)
Cover refractive index	1.52
Absorber absorptance	0.93
Absorber emittance	0.30
Space between cover and absorber	0.035 (m)
Back and side losses incl. their connections	91.0 ±5% (W/K)
Heat capacity for all collectors and their connections incl. fluid	1200 ±13% (kJ/K)
Specific heat of fluid	3.91 ±2% (kJ/K kg)
Density of fluid	1060 ±2% (kg/m^3)
Optical factor of collector ($\alpha\tau$)	0.85

Piping (primary collector circuit):

Length of cold side piping	32.4 ±0.2 (m)
Outside length (cold side)	23.2 ±0.2 (m)
Heat capacity incl. content	16.0 ±20% (kJ/K m)
Heat loss	1.12 ±20% (W/K m
Electrical power of the pump	600 ±5% (W)
Power delivered to the fluid	300 ±20%
Length of hot side piping	16.9 ±0.2 (m)
Outside length (hot side)	11.6 ±0.2 (m)

Control:

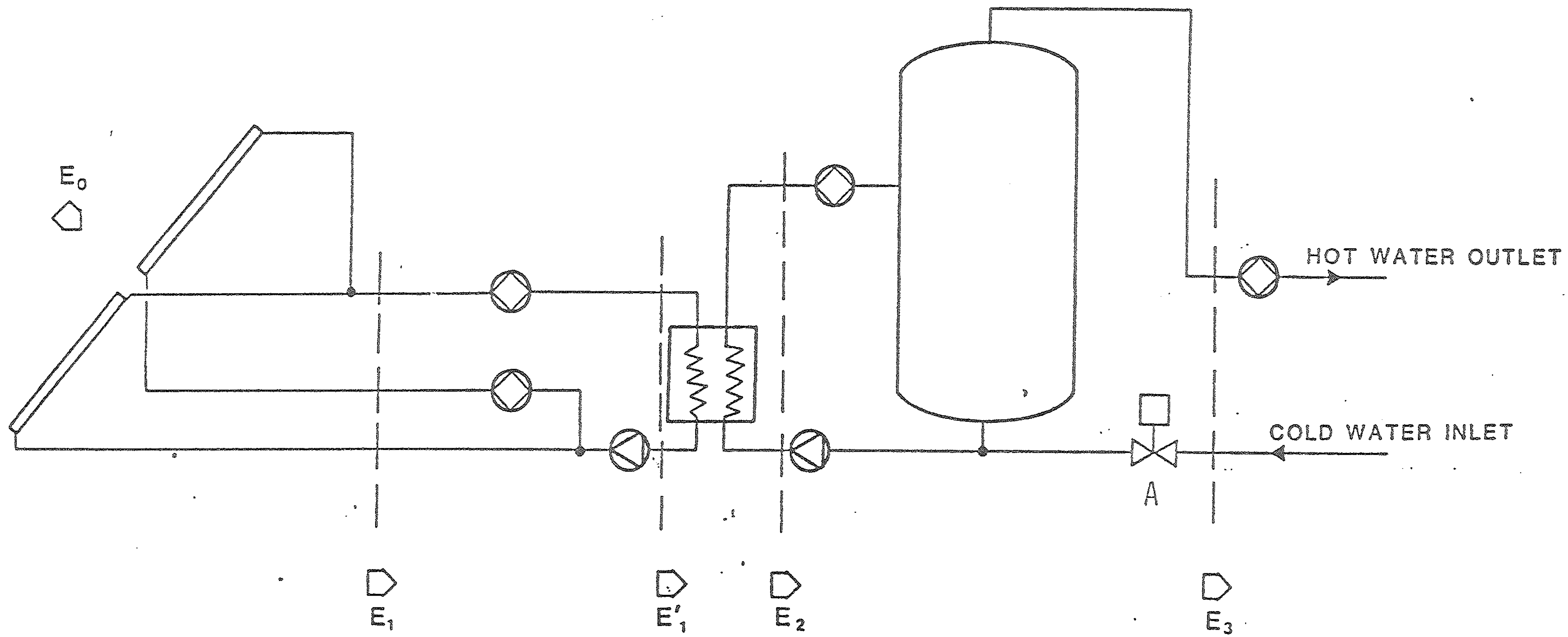
Start differential ΔT_{on}	8 $\pm 1^{o}C$
Stop differential ΔT_{off}	0 $\pm 1^{o}C$

Heat exchanger:

Heat exchanger effectiveness	0.37 ±3%

Storage tank:

Volume of tank	3	$(m)^3$
Length of secondary circuit	7 ± 0.2	(m)
Specific heat of the fluid	4.2 ±2%	(kJ/kg K)
Density of the fluid	1000 ±2%	(kg/m^3)
Heat capacity of tank incl. secondary collector circuit	13400±7%	(kJ/kg K)
Heat loss coefficient of tank	15.4 ±3%	(W/K)
Heat loss coefficient of piping	3.5 ±20%	(W/K)
Electrical power of the pump	345 ± 5%	(W)
Power delivered to the fluid	170 ±20%	(W)



SCHEMATIC DIAGRAM OF THE SOLAR SYSTEM SS1 ID1.208

Fig. 1

The installation descriptors - solar system two

Installation descriptor ID2.205

The collectors are replaced by collectors with selective absorber coating. The requested space heating load is the same as for SS1.ID1.203, calculated by SIMUL.

System parameters

Collector:

Absorber area for all collectors 18.84 m^2

Further information about the effectiveness of the collector can be found in ref (1) section 6.

Installation descriptor ID 2.206

On the SS2 installation, the system in question is a combined space-heating and domestic hot water supply system, which is designed for an ordinary dwelling 130 m^2 in size and with an energy consumption of 14.000 kWh for space heating and 3.500 kWh for the domestic hot water supply.

The DHW storage tank (0,2 m^3) is placed inside the SH storage tank (1,0 m^3) and it has nearly the same height as the SH tank. The solar collector system is liquid based and it is connected to the storage with a pipe heate exchanger placed in the bottom part of the SH-storage. The inlet of the cold water is placed at the bottom at the DHW-tank and the outlet is placed at the top. This storage configuration provides higher efficiences of the primary circuit because the cold inlet will cool down the bottom of the storage and give higher temperature differences between the fluid in the primary circuit and the water in the storage tank.

ABSORBERS	VALUE	UNIT	UNCERTAINTY	
			VALUE	ABS. or REL.
P (1,1) : ABSORBER AREA FOR ALL COLLECTORS	15,7	m^2	0.01	R
P (1,2) : TILT	56	°	1	A
P (1,3) : AZIMUTH	0	°	1	
P (1,4) : COVER ABSORPTANCE				
P (1,5) : COVER REFRACTIVE INDEX	1.52			
P (1,6) : ABSORBER ABSORPTANCE				
P (1,7) : ABSORBER EMITTANCE	0.1		0.1	R
P (1,8) : SPACE BETWEEN COVER AND ABSORBER	0.018	m	0.001	A
P (1,9) : BACK AND SIDE LOSS (FOR ALL COLLECTORS)	28.3	W/K	0.1	R
P (1,10): HEAT CAPACITY for all conllectors and their connections incl. fluid	160	kJ/K	0.15	R
P (1,11): FLUID CONTENT (FOR ALL CONNECTORS + CONNECTIONS)	0.044	m^3	0.05	R
P (1,12): SPECIFIC HEAT OF FLUID (20[°C])	3.515	kJ/kgK	0.01	R
P (1,13): DENSITY OF FLUID (20[°C])	1037	kg/m^3	0.01	R
P (1,14): OPTICAL FACTOR OF COLLECTOR WITH VARIABLE ($\tau\alpha$) OPTION				
P (1,15): OPTICAL FACTOR OF COLLECTOR WITH CONSTANT ($\tau\alpha$) OPTION	0.85	W/m^2K	0.02	R

ABSORBERS	VALUE	UNIT	UNCERTAINTY	
			VALUE	ABS. or REL.
P (1,16): CONSTANT THERM OF THE TOP HEAT LOSS COEFFICIENT	4.5	W/m^2K	0.02	R
P (1,17): TEMPERATURE COEFFICIENT OF THE TOP HEAT LOSS COEFFICIENT	0.015	W/m^2K^2	0.02	R
P				
P PIPING, COLD SIDE				
P (2,1) : TOTAL LENGTH OF COLD SIDE PIPING	25,0	m	0.3	ABS
P (2,2) : OUTSIDE LENGTH	21,5	m	0.25	ABS
P (2,3) : TOTAL VOLUME				
P (2,4) : HEAT CAPACITY (INSIDE PIPING)	6,8	kJ/K	0.1	R
P (2,5) : HEAT CAPACITY (OUTSIDE PIPING)	41,7	kJ/K	0.1	R
P (2,6) : HEAT LOSS COEFFICIENT (INSIDE PIPING)	0,88	W/K	0.05	R
P (2,7) : HEAT LOSS COEFFICIENT (OUTSIDE PIPING)	5,38	W/K	0.05	R
P (2,8) : ELECTRICAL POWER OF THE PUMP	77	W	0.05	R
P (2,9) : POWER DELIVERED TO THE FLUID	38	W	0.2	R
P (2,10): VOLUME OF THE BYPASS				
P				

PIPING, HOT SIDE	VALUE	UNIT	UNCERTAINTY	
			VALUE	ABS. or REL.
P (3,1) : TOTAL LENGTH OF HOTSIDE PIPING	32,5	m	0.5	ABS
P (3,2) : OUTSIDE LENGTH	29,0	m	0.4	ABS
P (3,3) : TOTAL VOLUME				
P (3,4) : HEAT CAPACITY (INSIDE PIPING)	6,8	kJ/K	0.1	R
P (3,5) : HEAT CAPACITY (OUTSIDE PIPING)	56,3	kJ/K	0.1	R
P (3,6) : HEAT LOSS COEFFICIENT (INSIDE PIPING)	0,88	W/K	0.05	R
P (3,7) : HEAT LOSS COEFFICIENT (OUTSIDE PIPING)	7,25	W/K	0.05	R
P				
P CONTROL				
P (4,1) : Δ T ON	3	K	1	ABS
P (4,2) : Δ T OFF	0	K	1	ABS
P				
P				
P				
P				

HEAT EXCHANGER	VALUE	UNIT	UNCERTAINTY	
			VALUE	ABS. or REL.
P(5,1) : HEAT TRANSFER COEFFICIENT				
P(5,2)' : HEAT TRANSFER AREA				
P(5,3) : HEAT EXCHANGER EFFICIENCY	0,7		0.07	R
P(5,4) : HEAT LOSS COEFFICIENT				
P				
P				
P				
P				
P				
P				
P				
P				
P				
P				
P				

STORAGE	VALUE	UNIT	UNCERTAINTY	
			VALUE	ABS. or REL.
P (6,1) : VOLUME OF TANK	1,1916	m^3	0.01	REL (beregn)
P (6,2) : VOLUME OF SECONDARY CIRCUIT				
P (6,3) : LENGTH OF SECONDARY LOOP				
P (6,4) : SPECIFIC HEAT OF THE FLUID (20[°C])	4,182	kJ/kgK	0.01	ABS
P (6,5) : DENSITY OF THE FLUID (20[°C])	998,2	kg/m^3	3	ABS
P (6,6) : HEAT CAPACITY OF TANK (INCL. FLUID)	5399	kJ/K	0.03	REL (målt)
P (6,7) : HEAT CAPACITY OF PIPING (INCL. FLUID)				
P (6,8) : HEAT LOSS COEFFICIENT OF TANK (TANK TEMP. T_L)	3,662 + 0,038983 . T_L	W/K	0.005	REL (målt)
P (6,9) : HEAT LOSS COEFFICIENT OF PIPING				
P (6,10): ELECTRICAL POWER OF THE PUMP				
P (6,11): POWER DELIVERED TO THE FLUID				
P (6,12): VOLUME OF TANK FOR DOMESTIC HOT WATER	0,206	m^3	0.01	REL (beregn)
P (6,13): HEAT TRANSFER COEFFICIENT BETWEEN TANKS	200	W/°C	0.3	REL
P				
P				

UNCERTAINTIES ON MEASURED QUANTITIES. ID1/1/02

		VALUE	σ	ABS.or REL.
1	Collector irradiance			
	- CGR	-	0.05	R
	- S(COLL) P1(1,1)	15,7 m^2	0.01	R
2	Collector heat withdrawal			
	- density	1037kg/m^3	0.01	R
	- specific heat	3,515kg/kgK	0.01	R
	- FPF1	340L/h	0.03	R
	- CTD1	-	0,1 °C	A
3	Solar storage gains			
	- density	998,2kg/m^3	0.003	R
	- specific heat	4,182 kg/kgK		R
	- SPF1	-	0.03	R
	- PTD1	-	0.1 °C	A
4	Interface losses			
	- density	998,2kg/m^3	0.003	R
	- specific heat	4,182 kg/kgK	0.01	R
	- OIF1	-	0.03	R
	- ITD1	-	0.1 °C	A
5	Climatic measurements			
	- HGR	-	0.05	R
	- HDR	-	0.05	R
	- CGR	-	0.05	R
	- AT	-	0,35 °C	A
	- ILT	-	0,35 °C	A
	- WV	-	0.05	R

ID1/1/02

EMGP1-INPUT DATA WHICH ARE NOT IN ID1.

	VALUE	UNIT	UNCERTAINTY VALUE	UNCERTAINTY ABS. or REL.
1. Collectors				
Initial Collector Temperature	5	°C	10.0	A
Cover emittance	0.94	-		A
Efficiency factor F'	0.98	-	0.005	A
First primary flow	340	L/h	0.03	R
Cover extinction coefficient	0.16	CM^{-1}	0.02	A
Cover thickness	0.4	CM	0.01	A
2. Storage				
Initial temperature	20	°C	0.5	A
Second Primary Flow	-	L/h	-	R

Appendix 5

Contents of the cassettes

Measurements obtained at the Danish SPTF:

1) 1 + 2 year (1979-81)

Cassette no.	DD0	DD1	DD2	ID1	ID2	N
2001	1	1	1	1	1	184
2	1	1	2	1	1	231
3	1	1	2	1	1	378
4	1	1	2	1	1	259
5	1	1	2	1	1	209
6	1	1	2	1	1	399
7	1	1	2	1	1	386
8	1	1	3	1	1	399
9	1	1	3	1	1	237
10	1	1	3	1	1	330
11	1	1	3	1	2	331
12	1	1	3	1	3	221
13	2	2	4	2	4	140
14	2	2	4	2	4	353
15	2	2	4	2	4	338
16	2	2	4	2	*	382
17	2	2	4	2	*	383
26	3	3	5	3	5	111
27	3	3	5	3	5	331
28	3	3	5	3	5	336
31	3	3	5	3	5	361
32	3	3	5	4	5	354
33	3	3	5	4	5	363
34	3	3	5	4	5	379

N: Number of hour-values

DD: Data descriptor

ID: Installation descriptor

2) 3 + 4 year (1981-83)

Cassette No.	DD0	DD1	DD2	ID1	ID2	N	FROM	TO	YEA
2036	3	3	5	5	5	332	4/9	18/9	81
37	3	3	5	5	5	183	23/9	1/10	81
38	3	3	5	5	5	327	5/10	19/10	81
39	3	3	5	5	5	188	20/10	1/11	81
40	3	3	5	5	5	362	2/11	23/11	81
41	3	3	5	5	5	309	24/11	13/12	81
42	3	3	5	5	5	150			
45	4	4		6		306	3/2	16/2	82
46	4	4		6		307	18/2	3/3	82
47	4	4		6		187	3/3	15/3	82
49	4	4		6		379	30/3	15/4	82
50	4	4		6		299	25/4	27/4	82
51	4	5		7		399	20/8	7/9	82
52	4	5		7		340	7/9	21/9	82
53	4	5		7		365	21/9	5/10	82
54	4	5		7		381	6/10	22/10	82
55	4	5		7		123	22/10	27/10	82

N: Number of hour-values

DD: Data describtor

ID: Installation descriptor