Validation of the CTSS Test Procedure by In-situ Measurements

A Report of IEA SHC - Task 26

Solar Combisystems

December 2002

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INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

Validation of the CTSS Test Procedure by In-situ Measurements

by

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A technical report of Subtask B

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1 Introduction

For the validation of the CTSS-Test procedure (component testing – system simulation) three-year in-situ measurements of a solar combisystem were carried out.
The investigated solar combisystem is mounted on a low energy single-family house in Böblingen (near Stuttgart), Germany. With an evacuated tube collector area of 6.6 m² and a storage volume of 550 litres the system yields yearly energy savings of about 25 % of the total annual energy demand of about 12000 kWh for space heating and hot water preparation. Before installation the system was tested by the CTSS test procedure to get the necessary data for the simulation.
Our aim was to compare the measured data with the results of simulation carried out with input data from measurements. If the simulated and measured data are in good agreement, one can be sure that the CTSS-Method produces correct system parameters and that the assumptions and boundary conditions for the simulation are justified.
The detailed in-situ measurements lasted for three years from October 1999 to June 2002

2 The investigated Solar Combisystem

The system under investigation is a Solar combisystem suited for use in single-family houses in Germany. The system has a collector area of 6.6 m² of a highly efficient evacuated tube collector with external CPC-reflectors. Figure 1 shows a view of the collector field mounted onto the roof. In figure 2 one can see the store (550 litres) with some measuring devices. The hot water preparation is realised by a thermosiphon heat exchanger. The solar loop is connected to the store via an internal spiral heat exchanger with a stratification device. The auxiliary heating is done by a condensing gas burner. It has a maximum power output of 24 kW and 8 kW at the minimum.

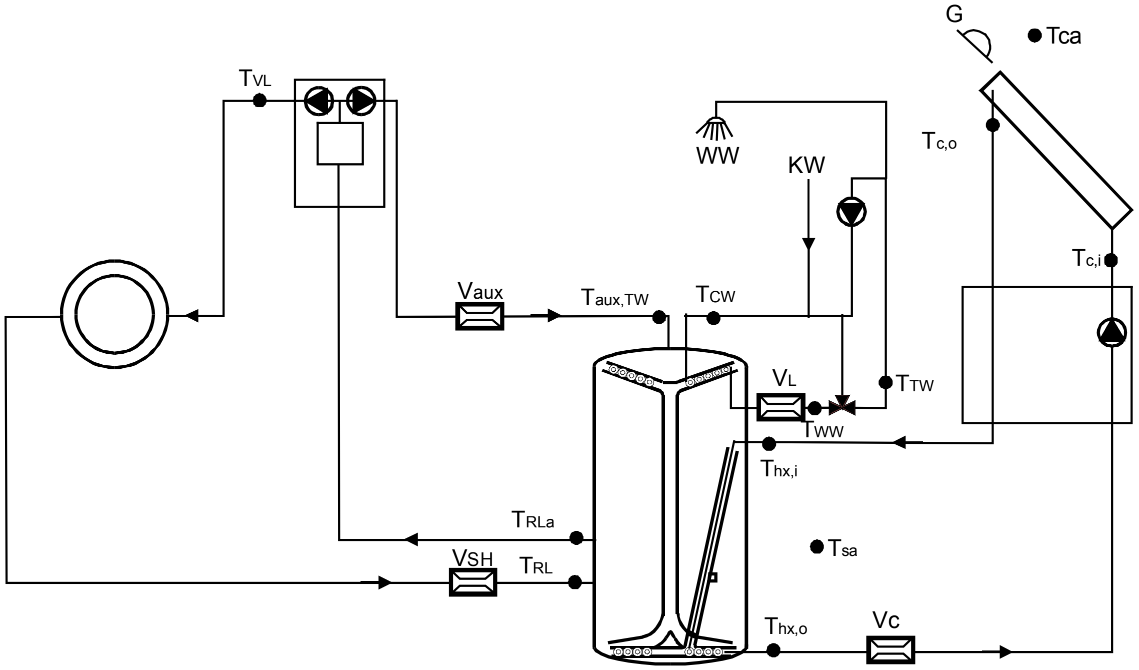
Figure 1: View of the collector field.

Figure 2: Storage with measurement equipment

3 Hydraulic scheme and measuring equipment

The following two pictures show two different hydraulic schemes for the system we derived during the test period of three years. Most of the measuring equipment is indicated in the sketches. For the time period from October 1999 to October 2000 we worked with the hydraulic scheme 1 shown in figure 3. Here the gas burner is in line with the space-heating loop (SH). The working fluid always passes through the burner when the space-heating loop is in operation.

Our investigation showed that this configuration has some disadvantages. We noticed a very high number of burner starts and found that the time periods during which the burner is in operation are often very short. On the one hand this behaviour results in a small reduction of the burner efficiency and on the other it produces high emissions of CO and HC during the start/stop process, which from our viewpoint is undesirable.

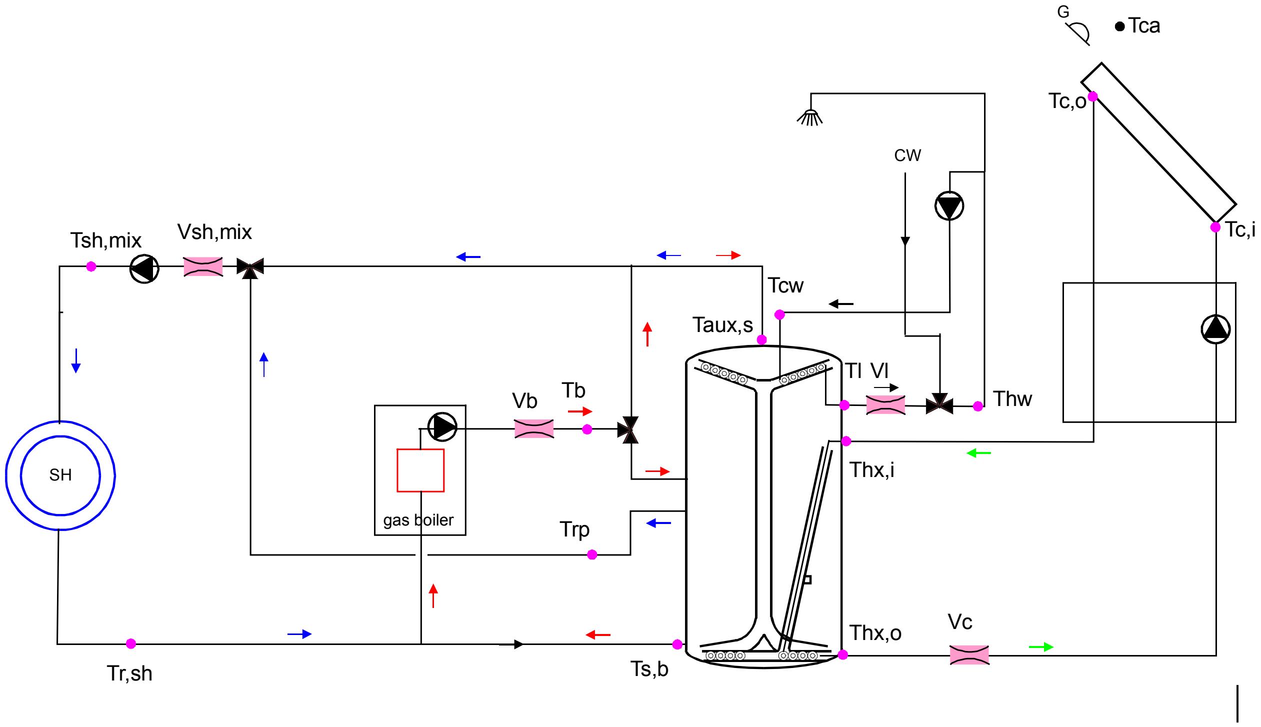


Sensor	Description	Sensor	Description
Tca	collector ambient temperature	Thw	hot water temperature
Tc,i	collector input temperature	Ttw	tap water temperature
Tc,o	collector output temperature	Taux,tw	aux. heating temperature
Thx,i	heat exchanger inlet temperature	Vaux	flow rate through auxiliary loop
Thx,o	heat exchanger outlet temperature	Trl	return temperature SH
Tsa	storage ambient temperature	Tvl	flow temperature SH
Vc	flow rate through collector loop	Trla	solar preheated temperature
Tcw	cold water temperature	Vsh	flow rate through space-heating loop

Figure 3: Hydraulic scheme 1

After operating the first scheme for one year we decided to rebuild the hydraulics according to scheme 2 shown in figure 4.

Here, the gas burner is directly connected to the storage and is no longer in line with the space-heating loop. With this configuration we achieve ten times less burner starts per year. The gas burner is also observed to work for longer time periods in the new arrangement.



Sensor	Description	Sensor	Description
Tca	collector ambient temperature	Vl	flow rate to load
Tc,i	collector input temperature	Taux,s	aux. temperature to storage
Tc,o	collector output temperature	Tb	aux. temperature from boiler
Thx,i	heat exchanger inlet temperature	Vb	flow rate through boiler
Thx,o	heat exchanger outlet temperature	Trlp	solar preheated temperature to SH
Tsa	storage ambient temperature	Tspu	return temperature to storage
Vc	flow rate through collector loop	Trlh	return temperature from SH
Tcw	cold water temperature	Ths,mix	temperature in space-heating loop after mixing
G	radiation in collector plane		
Thw	hot water temperature from store	Vhs,mix	flow rate through space heating loop after mixing
Tl	temperature delivered to load		

Figure 4: Hydraulic scheme 2

Measuring Equipment
All data necessary for a complete energy balance of the system were measured.
The measuring interval was 10 seconds. We used a Hewlett-Packard DMM with internal scanner connected to a Quick Basic programmed PC for data acquisition.
For temperature measurement we used calibrated PT100 sensors (accuracy 0.05 K).
In the beginning of the research we used magnetic flow meters to detect the flow rate in all loops. Within a short time we noticed uncertainty in the measurement of the mass flow rate through the space heating and auxiliary loop. The reason was the magnetite deposition at the magnetic sensor of the flow meter. For this reason we changed the magnetic flow meters for fully mechanical rotary flow meters. This kind of flow meters is less accurate but much more stable in magnetite-polluted water.

4 In-situ measurement results

The evaluation of the measured data shows that the installed solar combisystem works very well and meets the targeted energy saving of about 20 – 30 %.

Evaluation of the year 2000

The radiation in the collector plane was 1147 kWh/(m²a) and the collector output was 447 kWh/(m² a). As seen in figure 5 the collector efficiency was 39% on average.
The heat input into the store was 403 kWh/(m² a). Therefore the heat loss due to the pipes between collector and store was about 10 % of the total collector output.
Note lots of stagnation during the sunny June and the lack of data for a week during vacation. Barring these two time ranges the system worked within the expected efficiency limit. Compared to a total energy demand of 11574 kWh/a, the solar thermal system delivered 2663 kWh/a and thus effected energy savings of 23 %.

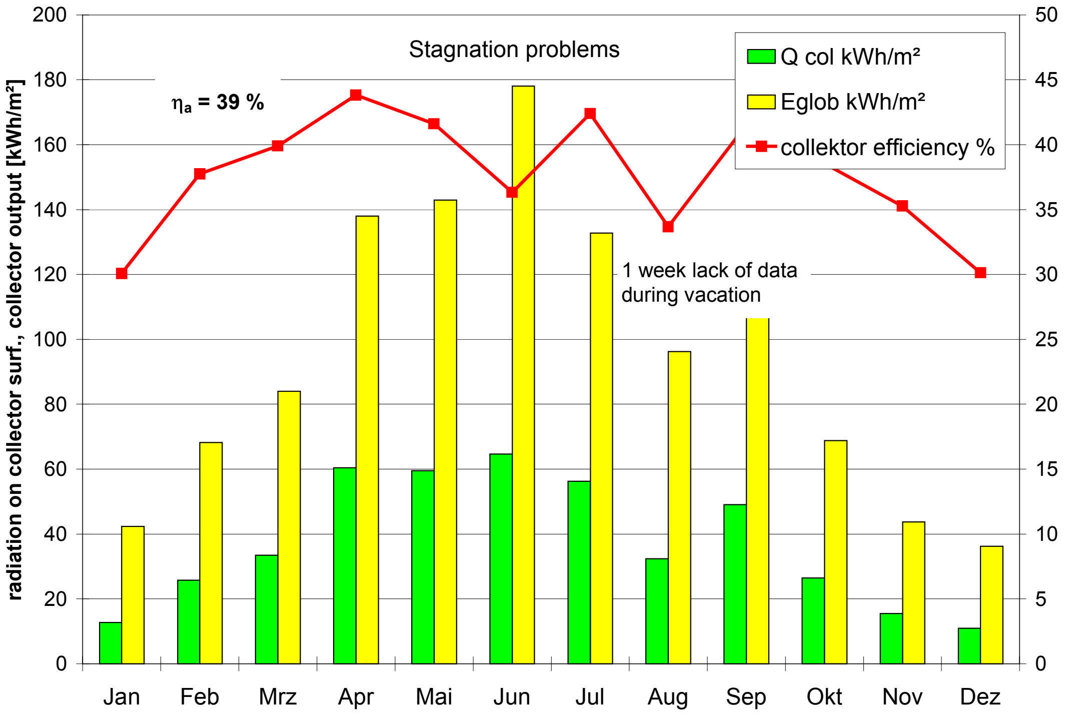


Figure 5: Radiation in the collector plane, collector output and efficiency in the year 2000

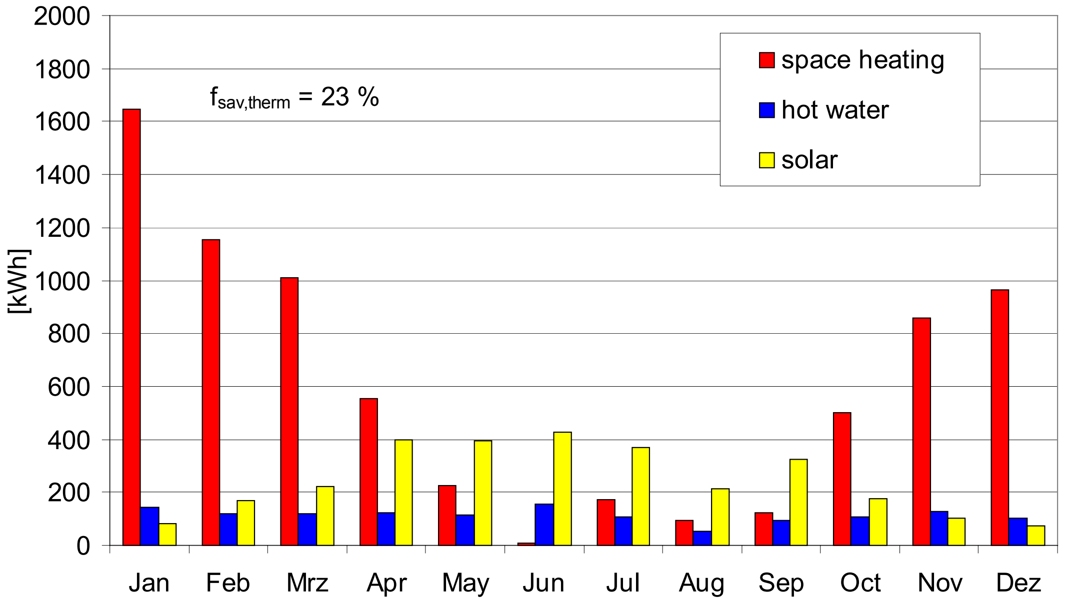


Figure 6: Energy demand for space heating and hot water in comparison with delivered solar energy for the year 2000.

Evaluation of the year 2001

During the year 2001 we changed the hydraulic scheme as mentioned above.
The radiation on the solar collector in this year was 1225 kWh/(m²a) and the collector output, 466 kWh/(m²a). Referring to figure 6 one can observe an average collector efficiency of

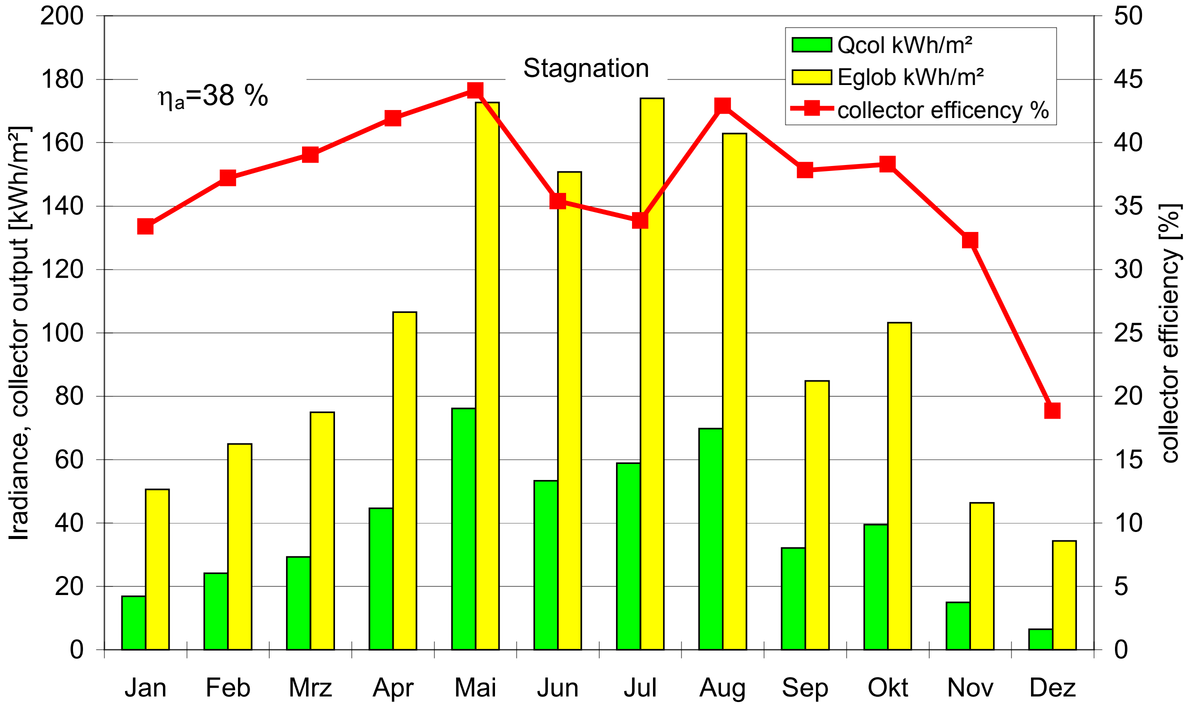


Figure 6: Radiation in collector plane, collector output and collector efficiency in the year 2001

38%. The heat input into the store was 413 kWh/(m²a). Here again we observed some stagnation periods during the months June and July.
Out of the total energy demand of 11082 kWh/a, the system delivered 2732 kWh/a and produced an energy saving of 24.6 %, nearly the same as that of the previous year.
With the new hydraulic scheme we were able to reduce the number of burner starts from 14126 in the year 2000 to 2371 in 2001.

Evaluation of the year 2002

We stopped our measurements at the beginning of June 2002. Therefore the results shown below are for the first five months of the year 2002.
The collector output in this period was 212 kWh/m². The radiation at the collector was 535 kWh/m² and the collector efficiency 40 % on an average. The total energy demand was 5570 kWh, the system delivered 1399 kWh which made an energy saving of 25 %. The number of burner-starts was 1439.

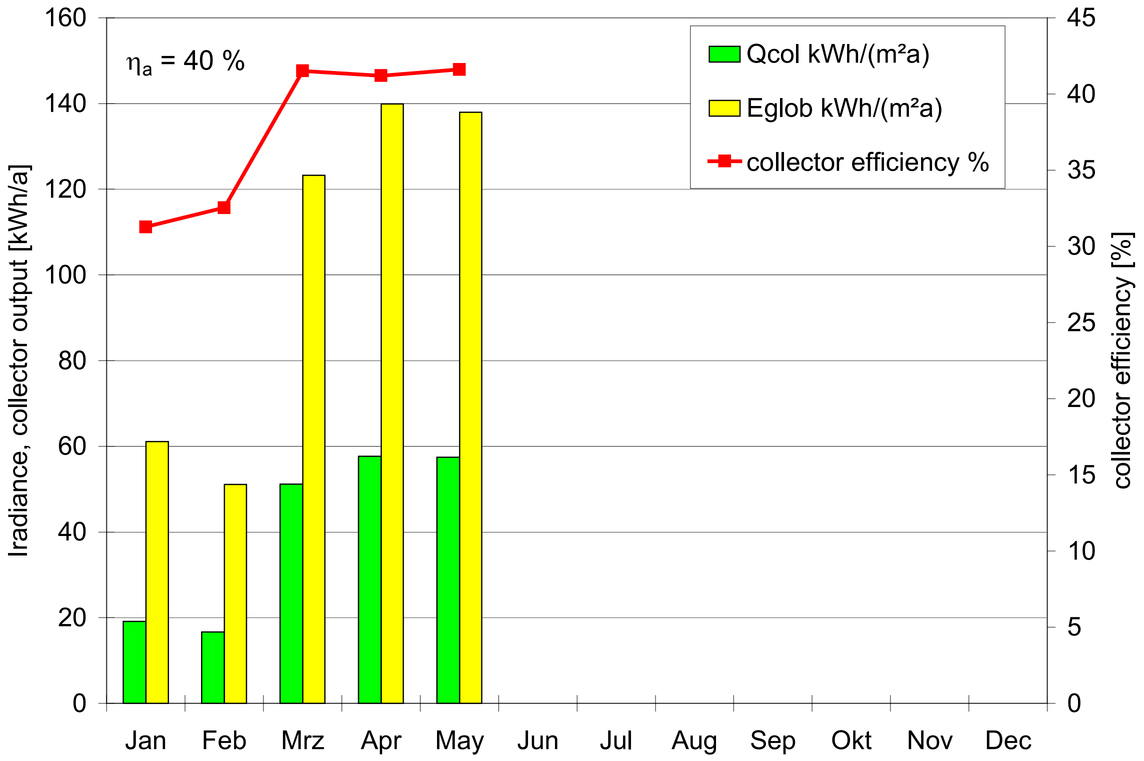


Figure 7: Radiation in collector plane, collector output and collector efficiency in the year 2002

5 Comparison between measurements and simulations

The validation of the CTSS test procedure by in-situ measurement of a solar combisystem was realised by comparing the measured and simulated energy output of the system.
The necessary parameters to describe the system under investigation were obtained from the CTSS-procedure. The simulation tool TRNSYS was used.

Measured data used as input values for the simulation include: radiation intensities, collector ambient temperature, mass flow rate to the load, temperatures of cold water (Tcw), the return temperature form the space heating loop (Trl) and the flow temperature from the gas boiler. With these measured input values we carried out the simulation of the system to predict the output temperatures and calculate the performance of the system numerically.

Figure 8 shows the total energy demand and a comparison between the measured and simulated auxiliary power data for the time period from November 1999 to October 2000. In table 1 some more detailed data are given which show that the difference between the calculated and the measured results is less than 5%..

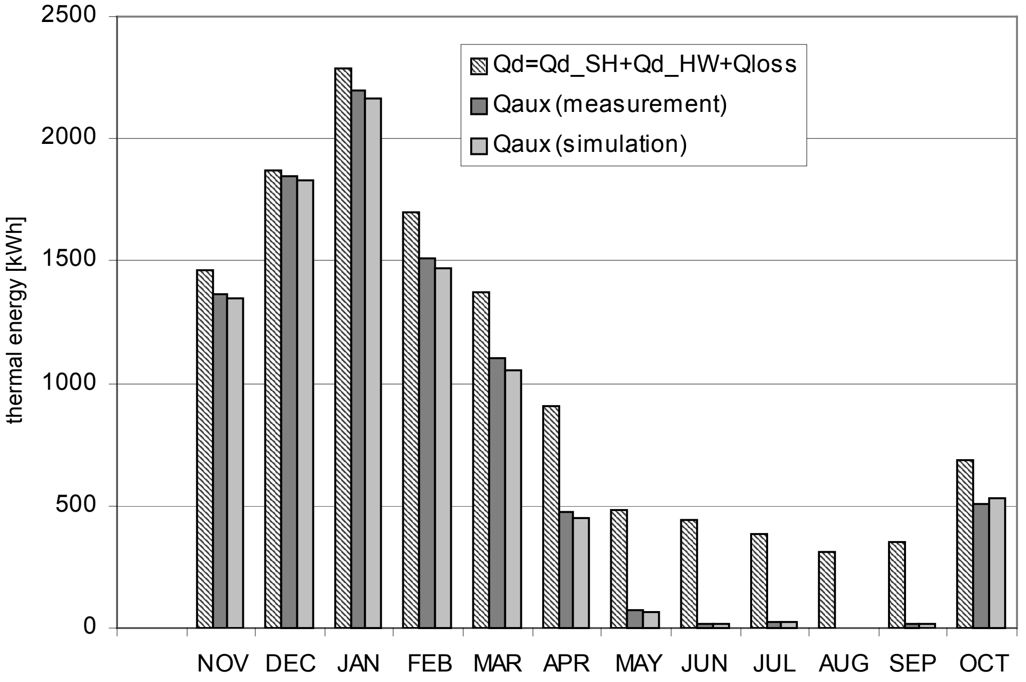


Figure 8: The total energy demand and comparison between measured and simulated auxiliary power data from November 1999 to October 2000

Table 1: Data of measurement and simulation from November 1999 to October 2000

	Qd_SH	Qd_HW	Qaux_SH	Qaux_HW	Qsol	Qloss
measurement	9816 kWh	1407 kWh	7690 kWh	1470 kWh	3126 kWh	n.n.
simulation	9994 kWh	1471 kWh	7607 kWh	1389 kWh	3122 kWh	615 kWh
error	1,8 %	4,3 %	1,0 %	5,8 %	0,1 %	-

Since we were in an experimental phase of determining a better system configuration during the year 2001 we did not simulate the system behaviour for that period.

Figure 9 shows the comparison between the measured and simulated auxiliary power data for the second hydraulic scheme used from January 2002 to May 2002. Here again the total energy demand and the necessary auxiliary power (measured and simulated) are shown. With the new concept the agreement between measurement and simulation is slightly better.

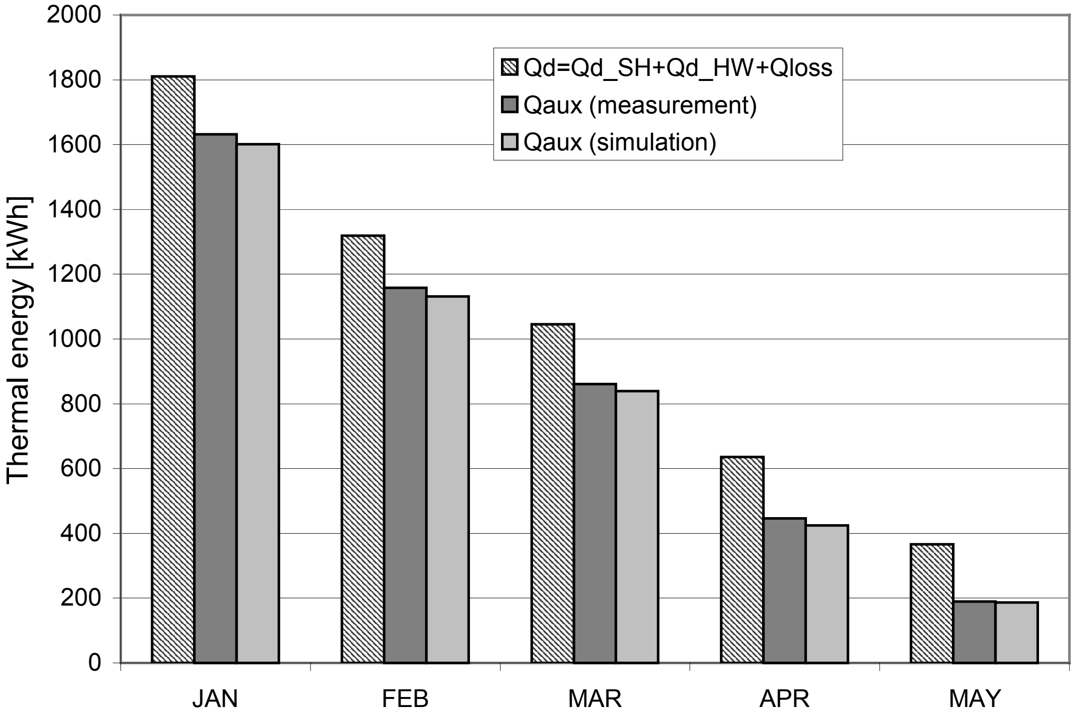


Figure 9: The total energy demand and comparison between the measured and simulated auxiliary power data for the first five months of 2002

6 Conclusion

Detailed in-situ measurements in conjunction with the system simulation based on the results of the component testing procedure were used to validate the whole CTSS-Method.
A comparison between measured and simulated data shows that the test method gives realistic parameters for a numerical simulation of the thermal behaviour of the system.

This suggests that the CTSS- method is able to deliver long term performance predictions of a solar combisystem with an error of about 5%.

Furthermore, we found that the reference conditions for both the energy demand and the weather-data used in the CTSS-method for long term performance predictions are very close to the in-situ data (see table 2). With these reference conditions we can generate realistic results of the annual energy savings of solar combisystems from a numerical simulation.

Table 2: Reference conditions for the long term performance prediction used with CTSS and calculated energy savings vs. measured data

	Radiation	Energy demand	$f_{sav,therm}$
CTSS reference conditions	1230 kWh/(m²a)	12020 kWh/(m²a)	22 %
In-situ measurements	1147 kWh/(m²a)	11574 kWh/(m²a)	23 %