Development of the Direct Characterisation test procedure for solar combisystems

A Report of IEA SHC - Task 26

Solar Combisystems

December 2002

Daniël Naron
Huib Visser

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

Development of the Direct Characterisation test procedure for solar combisystems

by

Daniël Naron* and Huib Visser*

A technical report of Subtask B

TNO Building and Construction Research
NL-2600 AA Delft, P.O. Box 49
The Netherlands

Contents

1 Introduction

For development of the Direct Characterisation (DC) test procedure, a reliable simulation model is a necessary tool. A large number of simulated tests was simulated with a numerical solar combisystem model based on the Dutch solar hot water system model VA115 ([1]). Prediction of annual system performance as outcome of the simulated tests was compared to direct simulations of the solar combisystem.

Starting point for the test procedure development, described here, is the status of the test procedure described in [2].

2 Test procedure

The test procedure to be developed is a 6-days test, preceded by two days of heat store conditioning. This 6-days core phase of the test procedure contains realistic climate and load conditions. Two days involve characteristic winter conditions (November – March); two days follow summer conditions (May – September) and two days contain spring/autumn conditions (March-May and September-November). Mean values of important weather and load variables (temperature, irradiation, domestic hot water draw-off and space heating) of each ‘season’ correspond to average values for the seasons in the whole year. All six days together represent the average weather and load conditions of a whole year.

Test results of the core phase are used to calculate the performance indicator, i.e. final energy (energy content of the fuel based on the lower heating value) used by the tested solar combisystem (E_{aux}), see also the description of the draft test procedure ([3]). The test procedure has been elaborated for European climate zone II (TRY Zürich) and the space heating loads according to Single Family House 60 (SFH60) and Single Family House 100 (SFH100) as defined in the IEA SHC Programme Task 26 work.

For investigation of the test conditions, the thermal energy load of the auxiliary heater of the solar combisystem (Q_{aux}) served as model for the thermal energy load of auxiliary boiler.

2.1 Solar combisystems

In order to check stability of the investigated (and chosen) test days, at first, two solar combisystems have been defined: a small one, rather typical for the Dutch market ([5]) and the other one larger, rather typical for the mid-European market ([4]). The test procedure should give reliable annual performance prediction for these two systems, further described below.

	I. Small combisystem		**II. Larger combisystem**	
Collector area	5.6 m^2		12 m^2	
Heat store	200 litres		600 litres	
Heat store segmentation	Auxiliary: Space heating: Solar part:	60 litres 90 litres 50 litres	Auxiliary: Space heating: Solar part:	140 litres 340 litres 120 litres

2.2 *Criteria for evaluation of quality of test procedure*

2.2.1 Accuracy of annual performance

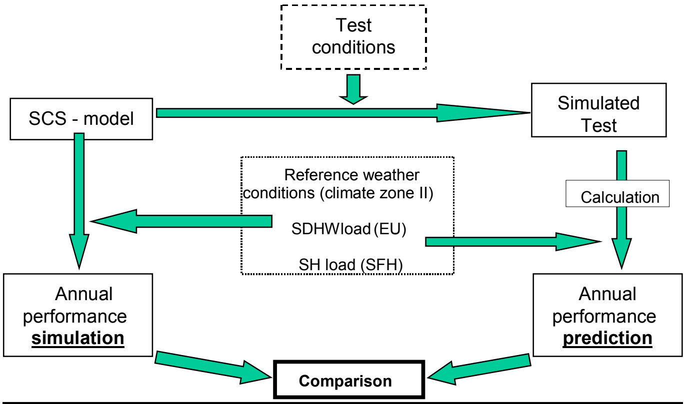


Figure 1: Scheme for evaluation of the test quality.

Figure 1 shows the process of evaluation of simulated tests. Towards the right hand side of the scheme, the solar combisystem model (i.e. SCS model) is used to carry out a simulated test for a chosen 6-days (core) sequence (i.e. test conditions). Results of this simulated test are used to calculate an annual performance prediction. On the other side of the scheme, the SCS model is used to carry out directly an annual performance simulation. The closer the value of prediction is to the value of simulation, the better the chosen conditions are.

2.2.2 Energy content of the heat store

For the second criterion for evaluation of the test, it is necessary to introduce the following two quantities:

- Energy content
  The energy content of the heat store is defined as energy of the water in the store (with a particular average temperature) compared to the cold water inlet temperature corresponding to the climate the test is performed for, e.g. for climate zone II, this is 9.7°C.
- Difference in energy content
  The difference in energy content (Δ Energy content) is defined as the energy content at the start minus the energy content at the end of the core phase.

In order to minimise the need for corrections in calculation of performance prediction of the tested system, start and end conditions of the heat store for the core phase have to be as close to each other as possible. Therefore, minimum difference in energy content of the heat store is another, second criterion for evaluation.

Hence, summarised:
1. Annual performance prediction must be close to the annual performance simulation.
2. Difference in energy content must be as small as possible.

3 Single Family House SFH60

As described above and in the present version ([3]), the test procedure consists of initial conditioning of the heat store at 20°C, followed by a secondary conditioning of two days and the core phase afterwards. The secondary conditioning is divided into:

a. Initial charge of ‘hot top’ using auxiliary heating.
b. Constant space heating discharge of 8 hours.
c. Domestic hot water draw-off.
d. One day of final stage of secondary conditioning.

First three steps are well described in the draft test procedure ([3]). Step (d), final stage of secondary conditioning, has been taken into consideration during development of the test procedure. This final stage of secondary conditioning is a normal test day that brings the store in such condition that requirement 2 (see Section 2.2.2 above) is valid.

3.1 Selection of test sequence

Table 1 describes the starting point for development.

Table 1: Starting point: test sequence Bales ([2]).

Day	**Day in year**	**T-ambient** [°C]	**Irradiation** [MJ/d]	**DHW load** [MJ]	**SH load** [MJ]	**Total energy load** [MJ]
Precond. II	280	11.25	19.4	29.5	33.1	62.6
1	7	-2.4	1.7	20.7	275.2	295.8
2	32	5.0	10.0	38.4	117.6	155.9
3	280	11.25	19.4	20.7	33.1	53.8
4	168	14.7	25.1	38.4	0	38.4
5	154	16.8	10.6	20.7	0	20.7
6	281	7.5	11.9	38.4	52.1	90.5

Season	**Weather conditions for performance simulation**				DHW load [MJ]	**Test**			
	T-amb. [°C]	Irradiation [MJ/d]	SH load [MJ]	Total load [MJ]		T-amb [°C]	Irradiation [MJ/d]	SH load [MJ]	Total load [MJ]
Winter	1.2	6.4	194.9	224.5	29.5	1.3	5.8	196.4	222.8
Spring / Autumn	8.9	12.5	60.4	89.9	29.5	9.4	14.6	42.6	90.3
Summer	16.8	17.4	0	29.5	29.5	15.8	17.8	0	29.5
Average	9.0	12.1	84.8	114.3	29.5	8.8 (-2.2%)	12.8 (+5.8%)	79.7 (-6.1%)	109.2 (-4.5%)

Table 2 - calculation 1 presents the test results for the two solar combisystems using the test sequence described in Table 1. Fulfilling requirement 1 implies a minimum ‘prediction error’; fulfilling requirement 2 implies a minimum ‘Δ Energy content’. Calculation 1 shows that neither of these two requirements has been fulfilled. Although prediction error and difference in energy content are very reasonable for the small system I, these two quantities are much larger for the prediction of the larger system II.

Table 2: Simulations and simulated tests on the small and the larger solar combisystem.

No.	**I. Small system**				**II. Larger system**			
	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	∆ Energy content	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	∆ Energy content
1.	34.15	32.8	-3.8%	-0.1 MJ	29.9	25.5	-14.8%	3.5 MJ
2.	34.15	33.3	-2.4%	1.8 MJ	29.9	26.9	-10.2%	0.3 MJ

In case ∆ Energy content is too large, one should correct the test result for this value. A ∆ Energy content of 3.5 MJ leads to an inaccuracy of about 0.2 GJ, i.e. approx. 0.8%, in prediction of the thermal energy load of auxiliary boiler. However, one does not know the difference in energy content in real testing as this is not a direct outcome of the test. Therefore, it is recommended to take an average winter day as final stage of secondary conditioning (i.e. precond. II in Table 1) instead of an average spring/autumn day. Moreover, the core phase should also end with a winter day in order to have an equal energy content at end of the test. Calculation 2 in Table 2 reports the result of a test sequence in which the described changes have been introduced.

This leads to the following conclusions:

- Idea of an average winter day as final stage of secondary conditioning combined with a winter day as last test day of the core phase is good. Prediction error decreases and requirement 2 is reasonable good.
- Prediction error for system II (3.0 GJ – 10.2%) is still too large.

The question now is whether it would be possible to reduce prediction error for both the small system I and the large system II to less than 2% without abandoning the philosophy for the choice of test days.

The test reported in calculation 2 (Table 2) appears to underestimate final energy *in the 6-days core phase* by about 10 MJ for the small system I and by about 50 MJ for the larger system II. Solar contribution in the test is too large compared to the reality for both systems. A second observation is the large exchange of energy collected during the two summer days into the autumn and winter days. Indirectly this implies that there is an energy exchange from the summer into autumn and winter during the whole year. It is obvious that this is not a realistic situation and can be the reason for under-prediction of the thermal energy load of auxiliary boiler. On the other hand, exchange of energy towards the following day(s) is a very common and even desirable behaviour of solar combisystems in general. Hence, when testing a solar combisystem with a 6-days core phase, a zero exchange of energy from the summer days into the following autumn and winter day is a not very realistic demand either.

Searching for better test conditions, the following guidelines have been followed:

- For the first part of the core phase (three days), the solar input needs to be relatively high and the domestic hot water load and space heating load need to be relatively low.
- In the second half of the core phase it is the other way around. The solar input needs to be relatively low and the energy load needs to be relatively high.
- It is obvious that the principle for selection of the test days does not change. The average weather and load variables (temperature, solar irradiation and energy loads) of the two winter days, two spring/autumn days and two summer days need to be similar to the corresponding season in the reference year.

Table 3 presents the optimum test sequence, both core phase and final stage of preconditioning. Compared to the Table 1 test sequence, the following changes in the choice of the test days have been carried out:

- An average winter day (23) as preconditioning II; this was an autumn day.
- The end of the core phase is a winter day; this was an autumn day.
- Solar irradiation has been slightly decreased: 11.7 MJ/d instead of 12.8 MJ/d.
- Space heating load has been slightly increased: 85.5 MJ/d instead of 79.7 MJ/d.
- For the first three days of the core phase, a low domestic hot water load was chosen; for the last three days of the core phase, a high domestic hot water load was chosen.

Table 3: Optimum test sequence for Climate II and SFH60.

Day	**Day in year**	**T-ambient** [°C]	**Irradiation** [MJ/d]	**DHW load** [MJ]	**SH load** [MJ]	**Total energy load** [MJ]
Precond. II	23	4.2	11.0	29.5	159.9	198.2
1	50	2.4	6.8	20.7	172.2	192.9
2	304	9.4	17.3	20.7	55.9	76.6
3	208	18.2	21.0	20.7	0	38.4
4	239	15.5	12.2	38.4	0	20.7
5	114	8.0	8.0	38.4	65.7	104.0
6	20	-1.0	5.0	38.4	218.9	257.3
Mean	-	8.8 (-2.9%)	11.7 (-3.1%)	29.5	85.5 (+0.8%)	115.0 (+0.6%)

Table 4 shows the substantial improvement of prediction results from this sequence. The discrepancy between performance prediction and simulation has disappeared for small system I. The prediction error for the large system II has been reduced to 1.8 GJ, i.e. about 6%.

Table 4: Performance simulations and predictions from simulated tests on the small and larger solar combisystem for the optimised test sequence.

No.	**I. Small system**				**II. Larger system**			
	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	Δ Energy content	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	Δ Energy content
3.	34.15	34.0	-0.3%	0.3 MJ	29.9	28.1	-6.0%	-0.4 MJ

3.2 Discussion

The test reported in calculation 3 (Table 4) for the small system I hardly shows any discrepancy of the final energy when compared to the corresponding simulated quantity. For the larger system II, the final energy in the 6-days core phase is underestimated by about 30 MJ. It is not possible with a 6-days core phase to reduce the prediction error to zero for both the small and the larger solar combisystem, without leaving the philosophy for the choice of the test days. For the optimum test sequence presented in Table 3, collection of energy during the summer days is so high for system II, that in the following autumn and winter day it is not possible to compensate for this surplus.

There is an indication that underestimation of performance prediction is related to the heat store volume. In that case, it might be possible to compensate for this effect by a volume-related correction. In order to formulate this correction, simulated test results should be available for more combisystems and dimensions.

3.3 Verification

For verification of the developed test sequence described in Table 3 and to formulate a correction formula, nine other solar combisystems have been simulated. These systems have different dimensions and different internal layouts. The IEA SHC-Task 26 brochure 'Solar Combisystems – Overview 2000' ([5]) was basis for the choice. Table 5 shows results of all simulations carried out.

A first quick look into prediction results and prediction errors in Table 5 reveals that the larger the system, the larger the underestimation.

Table 5: Simulations and predictions of simulated tests for several solar combisystems using the aspirant test method for climate II and SFH60.

No.	Collector-area (CA)	Heat store volume (V)				V / CA	$Q_{aux,sim}$	$Q_{aux,predict}$	Prediction error		Δ Energy content
		Total	'Hot top'	SH-part	Solar part						
	[m^2]	[litres]	[litres]	[litres]	[litres]	[litres/m^2]	[GJ]	[GJ]	[GJ]	[%]	[MJ]
1*	5.6	200	60	90	50	35.7	34.2	34.1	-0.1	-0.3	0.3
2	5.6	280	140	90	50	50	35.1	35.0	-0.1	-0.2	0.1
3	5.6	280	60	140	80	50	33.7	33.5	-0.2	-0.6	-0.7
4	8.4	600	200	260	140	71.4	32.2	31.4	-0.9	-2.7	-0.5
5	8.4	800	200	400	200	95.2	31.9	30.8	-1.1	-3.6	-0.3
6*	12	600	140	340	120	50	29.9	28.1	-1.8	-6.0	-0.4
7	12	720	240	312	168	60	30.6	28.7	-1.8	-5.9	0.1
8	12	1200	400	520	280	100	30.3	27.7	-2.6	-8.4	0.4
9	18	1080	360	450	270	60	27.8	22.9	-4.9	-17.6	3.7
10	18	2000	600	900	500	111	27.7	20.4	-7.3	-26.4	1.9
11	30	2400	800	1000	600	80	24.2	10.4	-13.8	-57.0	5.9

* System no. 1 and 6 are the combisystems I and II respectively used before in order to develop the test sequence.

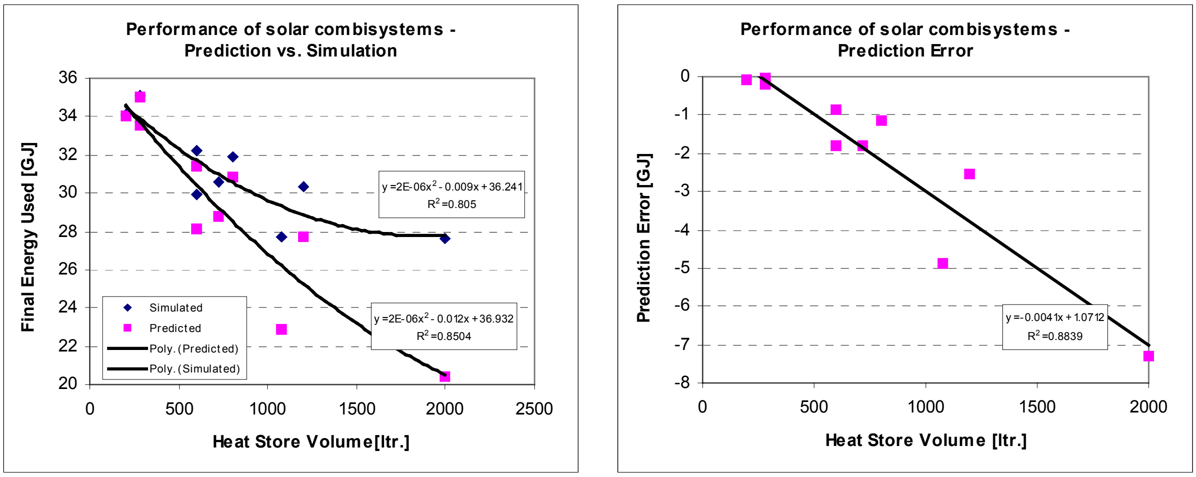


Figure 2: Comparison of test result and performance simulation for a variety of solar combisystems.

The left graph in Figure 2 shows performance prediction and performance simulation as a function of the heat store volume; the right graph shows prediction error as a function of heat store volume. The 30m^2 - 2400 litres system has not been considered because of its too large discrepancy.

3.3.1 Observations

Based on the results in Table 5 and Figure 2, the following observations can be made:

- Prediction error increases when heat store volume increases. This result was expected from findings in Table 4.
- For solar combisystems with collector areas of 18 and 30 m^2, the prediction error is large: larger than 4.5 GJ, i.e. 15%.
- For systems with dimensions smaller than about 15 m^2 - 1500 litres, prediction error is limited to about 10%. To be on the safe side, these dimensions set the boundary of the application range of the test procedure, using the sequence described in Table 3. For systems with dimensions larger than 15 m^2 - 1500 litres, a 9- or 12-days core phase should be developed. This is outside the scope of the present test procedure development.
- The difference in energy content is fairly stable and remains low for all simulated tests. For large solar combisystems, the quantity is increasing, however, a maximum observed 'Δ-Energy-Content' of 5.9 MJ causes an error in performance prediction of 0.4 GJ. Hence, the optimum test sequence yields a stable energy content of the heat store.

3.4 Correction calculation

One observation was that there is a clear relation between heat store volume and prediction error of the 'tested' solar combisystem. It is found that equation (1) below is a statistically well-founded formula for correction of the performance prediction:

equ 1:

$$\text{Prediction} - \text{Correction}\ \ [\text{GJ}] = 0.00615 * \text{Heat Store Volume} - 0.0538 * \frac{\text{Heat Store Volume}}{\text{Collector Area}} + 0.973$$

Correction of prediction of the thermal energy load of auxiliary boiler is not only related to heat store volume, but also to the ratio of heat store volume and collector area. There is a physical explanation for this dependency. A combisystem with a large collector area in relation to the heat store volume is able to transfer more energy from summer into autumn/winter than a system with a large heat store volume in relation to collector area.

Statistics Correction Formula

$R^2 = 0.98$
Prediction error < 0.34 GJ
Parameters:
a1: +0.00615 ± 0.0004
a2: -0.0538 ± 0.008
cst: +0.973 ± 0.36

Table 6 shows results of the corrections using equation (1) for predictions reported in Table 5. The 'New prediction error' is reduced to 0.5 GJ. Within the applicability range of solar combisystems smaller than 15m^2 – 1500 litres, prediction error of the thermal energy load of auxiliary boiler is reduced to 2%.

Table 6: Simulations and predictions of simulated tests for several solar combisystems using the aspirant test method for climate II and SFH60 after a heat store volume dependent correction.

No.	Collector Area (CA)	Heat Store Volume (V)	V / CA	$Q_{aux,sim}$	$Q_{aux,predict}$	Correction (formula)	$Q_{aux,corrected}$	New prediction error	
	[m2]	[litres]	[litres/m^2]	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[%]
1	5.6	200	35.7	34.2	34.1	0.28	34.3	0.18	0.5
2	5.6	280	50	35.1	35.0	0.01	35.0	-0.05	-0.2
3	5.6	280	50	33.7	33.5	0.01	33.5	-0.20	-0.6
4	8.4	600	71.4	32.2	31.4	0.82	32.2	-0.04	-0.1
5	8.4	800	95.2	31.9	30.8	0.77	31.6	-0.37	-1.2
6	12	600	50	29.9	28.1	1.97	30.1	0.16	0.5
7	12	720	60	30.6	28.7	2.17	30.9	0.36	1.2
8	12	1200	100	30.3	27.7	2.97	30.7	0.41	1.4
9	18	1080	60	27.8	22.9	4.39	27.3	-0.49	-1.8
10	18	2000	111	27.7	20.4	7.30	27.7	0.0	0.0
11	30	2400	80	Outside applicability range					

4 Single Family House SFH100

It is expected that solar combisystems perform better in less insulated houses with a more substantial space heating load during spring and autumn[1]. The SFH100 is a reference house with more heat losses and a higher space heating load. This is the main reason that the test sequence has also been developed for the SFH100 house.

4.1 Selection test sequence

Compared to the characteristic year data presented in Table 1, only the space heating load has been changed. Table 7 presents the starting point of the development. For the first test sequence analysed, the same test days have been chosen as for the optimum test sequence for the SFH60 house. Performance of this sequence is presented in Table 8 - calculation 1.

Table 7: Starting point for development of the test sequence for the SFH100 house, including annual average data for the SFH100 house.

Day	Day in year	T-ambient [°C]	Irradiation [MJ/d]	DHW load [MJ]	SH load [MJ]	Total energy load [MJ]
Precond. II	23	4.2	11.0	29.5	283.0	312.5
1	50	2.4	6.8	20.7	276.1	296.8
2	304	9.4	17.3	20.7	119.5	140.2
3	208	18.2	21.0	20.7	0	20.7
4	239	15.5	12.2	38.4	0	38.4
5	114	8.0	8.0	38.4	120.8	159.2
6	20	-1.0	5.0	38.4	335.0	373.4

[1] This was a suggestion from the Dutch solar combisystem steering committee.

Continuation of Table 7: Comparison weather conditions throughout year versus test (core phase)

Season	Weather conditions for performance simulation				DHW load [MJ]	Test			
	T-amb. [°C]	Irradiation [MJ/d]	SH load [MJ]	Total load [MJ]		T-amb [°C]	Irradiation [MJ/d]	SH load [MJ]	Total load [MJ]
Winter	1.2	6.4	311.0	340.5	29.5	0.7	6.0	305.6	335.1
Spring / Autumn	8.9	12.5	113.9	143.4	29.5	8.7	12.7	120.1	149.7
Summer	16.8	17.4	0.5	30.0	29.5	16.9	16.6	0	29.5
Mean	9.0	12.1	141.3	170.8	29.5	8.8 (-2.9%)	11.7 (-3.1%)	141.9 (+0.4%)	171.4 (+0.3%)

Table 8: Simulations and simulated tests of the small and the larger solar combisystem for the SFH100 house.

No.	I. Small system				II. Larger system			
	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	Δ Energy content	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	Δ Energy content
1.	54.4	53.9	-0.9%	0.4	50.1	47.3	-5.6%	1.1

At first sight, this result looks quite reasonable. However, further look into the test results *in the 6-days core phase* reveals a quite substantial underestimation of thermal energy load of auxiliary boiler in the test. For system I, it is about 8 MJ and for system II, it is about 47 MJ. Again, the solar contribution is too large compared to reality. The exchange of energy from the two summer days into the autumn and winter day is large. It is expected that for system I this underestimation in the test can be reduced to zero. For system II, it can be reduced as well but not to zero.

Searching for better test conditions, the same guidelines as for test development for the SFH60 house have been followed. Table 9 presents the optimum test sequence, both the core phase and the final stage of preconditioning. Compared to the test sequence mentioned in Table 7, following changes in the choice of the test days have been carried out:

- A slightly colder winter day (40) with lower solar irradiation as preconditioning II.
- The winter day at end of the core phase has been changed. For this day, space heating load is slightly higher as well as solar irradiation.
- The autumn day (day 5 of the core phase) has been changed; the solar irradiation has been decreased.
- Solar irradiation has been slightly decreased: 11.5 MJ/d instead of 11.7 MJ/d.
- Space heating load has been slightly increased: 146.6 MJ/d instead of 141.9 MJ/d.

Table 9: Optimum test sequence for climate II and the SFH100 house.

Day	Day in year	T-ambient [°C]	Irradiation [MJ/d]	DHW load [MJ]	SH load [MJ]	Total energy load [MJ]
Precond. II	40	3.9	10.0	29.5	239.0	312.5
1	50	2.4	6.8	20.7	276.1	296.8
2	304	9.4	17.3	20.7	119.5	140.2
3	208	18.2	21.0	20.7	0	20.7
4	239	15.5	12.2	38.4	0	38.4
5	272	9.5	6.2	38.4	123.9	162.2
6	60	0.0	6.2	38.4	360.2	398.6
Mean	-	9.20 (+1.8%)	11.5 (-5.3%)	29.5	146.6 (+3.7%)	176.1 (+3.1%)

Table 10 shows that prediction results for this sequence have improved substantially. Discrepancies between performance prediction and simulation have disappeared for small system I. Prediction error for large system II has been reduced to 1.7 GJ, i.e. about 3.5%.

Table 10: Performance simulations and predictions from simulated tests on the small and larger solar combisystem for the optimum test sequence for the SFH100 house.

No.	**I. Small system**				**II. Larger system**			
	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	Δ Energy content	$Q_{aux, sim}$ [GJ]	$Q_{aux, predict}$ [GJ]	Prediction error [%]	Δ Energy content
2.	54.4	54.4	+0.1%	+0.2 MJ	50.1	48.4	-3.5%	+0.4 MJ

4.2 Discussion

Discussion points raised here are similar to those raised for development of test conditions for the SFH60 house:

- The test reported in calculation 2 (Table 10) for small system I hardly shows any discrepancy of the thermal energy load of auxiliary boiler in the test. For larger system II, underestimation in the 6-days core phase is reduced to about 30 MJ.
- It is not possible with a 6-days core phase to reduce this prediction error to zero for both the small and the larger solar combisystem, without abandoning the philosophy for the choice of the test days.
- For the optimum test sequence presented in Table 9, collection of energy during the summer days is so high for system II, that in the following autumn and winter day it is not possible to compensate for this surplus.
- There is an indication that the underestimation of the performance prediction is related to the heat store volume. In that case, again, it might be possible to compensate for this effect.
- For verification reasons and in order to be able to formulate this correction, simulated test results should be available for more combisystems and dimensions.

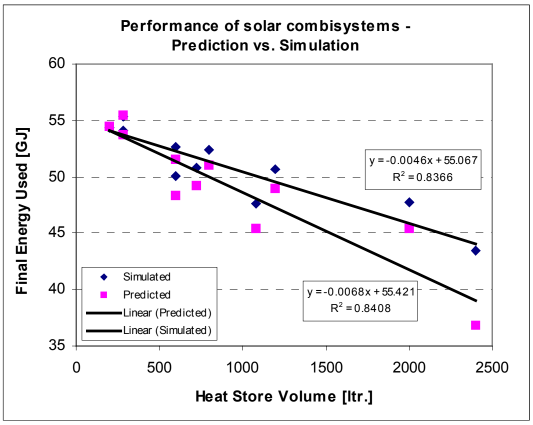
4.3 Verification

Identically to the development of the SFH60 test, this sequence has been verified by performing a series of simulated tests on nine different solar combisystems. These simulations and calculations will set again the application range of the procedure. Table 11 presents results of all calculations and simulated tests. A first look to prediction results show again that the larger the system, the larger the underestimation. However, magnitude of the underestimation is lower than for the SFH60 house.

Table 11: Simulations and predictions of simulated tests on several solar combisystems using the aspirant test method for climate II and SFH100.

No.	Collector-area (CA)	Heat store volume (V)				V / CA	$Q_{aux,sim}$	$Q_{aux,predict}$	Prediction error		Δ Energy content
		Total	'Hot top'	SH-part	Solar part						
	[m^2]	[litres]	[litres]	[GJ]	[GJ]	[litres/m^2]	[GJ]	[GJ]	[GJ]	[%]	[MJ]
1	5.6	200	60	90	50	35.7	54.4	54.4	0.0	0.1%	0.2
2	5.6	280	140	90	50	50	55.4	55.4	0.0	0.1%	0.5
3	5.6	280	60	140	80	50	54.1	53.8	-0.3	-0.6%	1.7
4	8.4	600	200	260	140	50	52.7	51.6	-1.1	-2.1%	1.1
5	8.4	800	200	400	200	71.4	52.4	51.1	-1.3	-2.5%	1.4
6	12	600	140	340	120	95.2	50.1	48.4	-1.8	-3.5%	0.4
7	12	720	240	312	168	60	50.8	49.2	-1.6	-3.2%	-0.9
8	12	1200	400	520	280	100	50.7	49.0	-1.7	-3.4%	1.3
9	18	1080	360	450	270	60	47.7	45.4	-2.3	-4.8%	0.0
10	18	2000	600	900	500	111	47.7	45.5	-2.2	-4.7%	-1.9
11	30	2400	800	1000	600	80	43.4	36.9	-6.5	-15.1%	-1.1

The left graph in Figure 3 shows performance prediction and performance simulation as a function of the heat store volume; the right graph shows prediction error as a function of heat store volume.



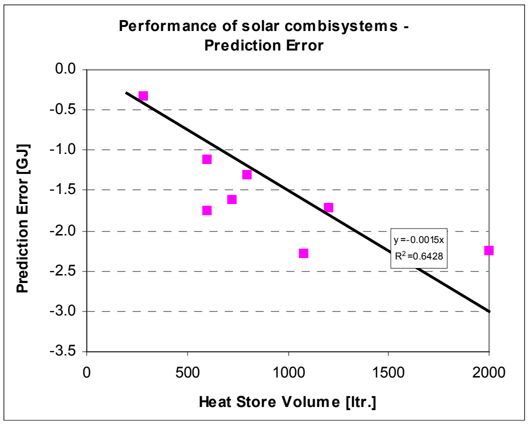


Figure 3: Comparison of test result and performance simulation for a variety of solar combisystems for climate zone II and the SFH100 house.

4.3.1 Observations

Based on Table 11 and Figure 3, the following observations can be made:

- Also for the SFH100 house, prediction error increases when heat store volume increases. However, discrepancy is lower than for predictions (without correction) of solar combisystems for the SFH60 loads.
- For the 30 m^2 - 2400 litres combisystem, prediction error is still large: larger than 6.5 GJ, i.e. 15%.
- The difference in energy content is fairly constant and remains low for all simulated tests. However, for large combisystems, the observed Δ Energy content is slightly increasing. A (maximum) difference of 1.9 MJ would oblige a correction of 0.11 GJ on prediction of the thermal energy load of auxiliary boiler. Therefore, test conditions described in Table 9 lead to a stable energy content of the heat store.

- For systems smaller than about 18 m^2 - 2000 litres, prediction error is limited to about 5%. To be on the safe side, these dimensions set boundary to the application range of the test procedure (using the sequence described in Table 9). For systems larger than 18 m^2 - 2000 litres, a 9- or 12-days core phase should be developed. This is outside the scope of the present test procedure development.

4.4 Correction calculation

Already earlier in this technical report, it is stated that there is a clear correlation between heat store volume and prediction error of the ‘tested’ solar combisystems. A similar expression has been tried for defining a correction formula that is able to correct for this systematic prediction error for the SFH100 case:

equ. 2:

$$\text{Prediction} - \text{Correction} \quad [\text{GJ}] = a_1 * \text{Heat Store Volume} + a_2 * \frac{\text{Heat Store Volume}}{\text{Collector Area}} + \text{cst}$$

Although prediction error becomes relatively low, standard deviation is large. Frame ‘Statistics of Correction Formula’ shows that two the parameters a_2 and cst appear to be not significant. There is a physical explanation for a_2 to be not significant: because of the high(er) space heating load of the SFH100 house, energy transfer from one day into the next, especially from the summer days into the autumn and winter day, is lower. Therefore, there is a lower correlation between prediction correction and the ratio Volume / Collector area.

Statistics of Correction Formula

R^2 = 0.64
Prediction error < 0.5 GJ
Parameters:
a_1: +0.0015 ± 0.0002
a_2: (-0.012 ± 0.018) – not significant
cst: (+0.22 ± 0.31) – not significant

The new correction formula is as follows:

equ. 3: $\text{Prediction} - \text{Correction} \quad [\text{GJ}] = 0.0015 * \text{Heat Store Volume}$ *(3)*

Table 12 shows how accurate this correction of the systematic prediction errors works. The 6-days core phase of Table 9 combined with equ. (3) results in prediction of thermal energy load of auxiliary boiler with an accuracy better than 0.9 GJ, i.e. within 2% for the applicability range of about 18 m^2 - 2000 litres.

Table 12: Simulations and predictions of simulated tests for several solar combisystems using the aspirant test method for climate II and SFH100 after a heat store volume dependent correction.

No.	Collector Area (CA)	Heat Store Volume (V)	V / CA	Q_{aux} simulated	Q_{aux} predict	Correction (formula)	Q_{aux} corrected	New Prediction Error	
	[m^2]	[ltr.]	-	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[%]
1	5.6	200	35.7	54.4	54.4	0.300	54.73	0.33	0.6%
2	5.6	280	50	55.4	55.4	0.420	55.85	0.46	0.8%
3	5.6	280	50	54.1	53.8	0.420	54.22	0.09	0.2%
4	8.4	600	71.4	52.7	51.6	0.900	52.47	-0.22	-0.4%
5	8.4	800	95.2	52.4	51.1	1.200	52.25	-0.10	-0.2%
6	12	600	50	50.1	48.4	0.900	49.26	-0.86	-1.7%
7	12	720	60	50.8	49.2	1.080	50.29	-0.54	-1.1%
8	12	1200	100	50.7	49.0	1.800	50.81	0.08	0.2%
9	18	1080	60	47.7	45.4	1.620	46.99	-0.67	-1.4%
10	18	2000	111	47.7	45.5	3.000	48.45	0.76	1.6%
11	30	2400	80	Outside applicability range					

5 Extrapolation

An attempt has been made to extrapolate a test result for a SFH60 load to a prediction for a SFH100 load. Observed discrepancies were large. However, it could be possible to define a correction factor for these discrepancies as well. A scientific basis for such a correction factor is not available.

6 Conclusions

A procedure for testing solar combisystems has been developed. Investigation of test conditions for SFH60 and SFH100 loads leads to the following conclusions:

- The principle for selection of the test days works well. Average weather and load variables, i.e. temperature, solar irradiation and energy loads for the two winter days, two spring/autumn days and two summer days need to be similar to the corresponding season in the whole reference year.
- The choice of an average winter day as final stage of secondary conditioning combined with a fairly strong winter day as last test day of the core phase results or can result into a reliable test sequence for solar combisystems.
- During the first three days of the core phase, solar input needs to be relatively high and energy load to domestic hot water and space heating needs to be relatively low.
- In the second half of the core phase, it is the other way around. Solar input needs to be relatively low and energy load relatively high.
- It is not possible with a 6-days core phase to reduce the prediction error to zero for the whole spectrum of solar combisystems, without leaving the philosophy for choice of test days. Even for the optimum test sequence, collection of energy during the summer days is so high for large combisystems that in the following autumn and winter day it is not possible to compensate for this surplus.
- For the SFH60 load, the presented test sequence is applicable for solar combisystems up to about 15 m^2 - 1500 litres. The presented test sequence for the SFH100 load has an applicability range up to about 18 m^2 – 2000 litres. For systems larger than this, a 9- or

12-days core phase should be developed. This is outside the scope of test method development described in this technical report.
- Underestimation of performance prediction is related to heat store volume. It is possible to define a heat store volume dependent correction formula to reduce this discrepancy.
- It is not possible to extrapolate a test result of (e.g.) a SFH60 load to a prediction for a SFH100 load.

7 Recommendations

Recommendations for further research are:
- to develop a 9- or 12-days core phase for large solar combisystems.
- to develop test conditions for European reference climates I and III.
- to develop a model for extrapolation of a test result into other climates and loads.

8 References

[1] VABI. Solar hot water systems (VA115). Delft, the Netherlands, September 1999.
[2] Bales, C. Report on combitest. SERC, Sweden, February 2001.
[3] Visser, H. Direct Characterisation test procedure for solar combisystems - 5th draft. Technical report IEA - SHC Task 26, TNO Building and Construction Research, Delft, the Netherlands, March 2003.
[4] Drück, H. and S. Bachmann. Performance testing of solar combisystems – comparison of the CTSS and ACDC test procedure. Technical report IEA - SHC Task 26, ITW, Stuttgart, Germany, November 2002.
[5] Suter, J.-M., T. Letz, W. Weiss and J. Inäbnit (ed.) Solar Combisystems in Austria, Denmark, Finland, France, Germany, Sweden, Switzerland, the Netherlands and the USA - Overview 2000, IEA SHC - Task 26, Switzerland, 2000.