Report on Solar Combisystems Modelled in Task 26 (System Description, Modelling, Sensitivity, Optimisation)

A Report of IEA SHC - Task 26

Solar Combisystems

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A technical report of Subtask C

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APPENDICES (SYSTEM DESCRIPTIONS)

System #2	***Klaus Ellehauge, Ellehauge & Kildemoes, Denmark***
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System #15	***Dagmar Jaehnig, SOLVIS, Braunschweig, Germany***
System #19	***Richard Heimrath, IWT, Graz University of Technology, Austria***

Nomenclature

Q_{SH}	space heating demand
Q_{DHW}	domestic hot water demand
$Q_{loss,ref}$	reference system losses
$E_{ref,month} = \frac{Q_{SH} + Q_{DHW} + Q_{loss,ref}}{\eta_{boiler,ref}}$	monthly final energy demand of reference system boiler
$E_{ref} = \frac{Q_{SH} + Q_{DHW} + Q_{loss,ref}}{\eta_{boiler,ref}}$	annual final energy demand of reference system boiler
Q_{boiler}	thermal energy load of auxiliary boiler
η_{boiler}	mean annual efficiency of auxiliary boiler
$E_{boiler} = \frac{Q_{boiler}}{\eta_{boiler}}$	final energy consumption of auxiliary boiler
$W_{el.heater}$	thermal energy load of el. heating element
$\eta_{el.heater}$	mean annual efficiency of el. heating element
$E_{el.heater} = \frac{Q_{el.heater}}{\eta_{el.heater}}$	primary energy consumption of el. heating element
W_{par}	parasitic energy consumption of solar combisystem
η_{el}	electricity generation efficiency
$E_{par} = \frac{W_{par}}{\eta_{el}}$	primary parasitic energy consumption of solar combisystem
$W_{par,ref}$	parasitic energy consumption of reference system
η_{el}	electricity generation efficiency
$E_{par,ref} = \frac{W_{par,ref}}{\eta_{el}}$	primary parasitic energy consumption of reference system
$E_{aux} = E_{boiler} + E_{el.heater}$	combined auxiliary energy consumption of solar combisystem
$E_{total} = E_{aux} + E_{par}$	combined total[1] energy consumption of solar combisystem
$E_{total,ref} = E_{ref} + E_{par,ref}$	combined total energy consumption of reference system
A	collector area (m²)
V	storage volume (l)
$Q_{solar,usable}$	usable solar energy

[1] The losses from refining and transportation of the fuels were neglected.

1 Introduction

One of the targets of Task 26 was to compare different combisystem designs by means of annual system simulations. The following report summarises the simulation methodology and the results for nine systems following the guidelines presented in [1] and [2].

To describe the performance of solar combisystems and to carry out an adequate comparison with detailed simulation models, it needs to be recognized that the result of a comparison depends on:

1.) the chosen **reference conditions** concerning energy demands, energy sources, parameter settings, and standard components,
2.) the **output or target function** of the annual system simulation that serves as a measure of the combisystem performance (e.g. the saved gas consumption of a combisystem compared to the gas consumption of a non-solar reference heating system), and
3.) the **mathematical accuracy** of the system simulation and the choice of the same simulation models for identical parts of the systems

In order to carry out a comparison between combisystems that do not correspond to the reference conditions defined in [1], these non-complying combisystems were additionally characterised in a way that allows comparisons of different system designs for various climates and system sizes. A description of a **characterisation method** developed in the framework of Task 26 is given in [1] and [2].

2 Methodology of Modelling

2.1 Reference Conditions

The reference conditions are given in detail in [1]. They are summarised in the following:

- **Climate:** In order to cover the geographical range for the main markets of solar combisystems it was decided to choose a northern European (Stockholm, Sweden), a middle European (Zurich, Switzerland) and a southern European (Carpentras, France) climate for all further investigations and simulations. The hourly weather data was calculated with Meteonorm 3 [3] using long term average monthly values. Additionally the yearly temperature fluctuation of the mains water was taken into account.

- **Heat demand of buildings:** The heat demand of the buildings was defined by reference buildings with reference conditions for user behaviour, occupation, etc. These building models were also part of the TRNSYS model of each solar combisystems. Three single-family houses (SFH) with the same geometry but different building physics data were defined in a way that the specific annual space heating demand for the Zurich climate amounts to 30, 60 and 100 kWh/m^{2}a. Additionally, a multi-family house (MFH) with five apartments and a specific annual space heating demand for Zurich of 45 kWh/m^{2}a was defined. The room temperature was allowed to vary between 19.5 and 24°C during the heating season. In the reference case the heat was delivered via radiators (Non-standard TRNSYS type 162 radiator). The flow temperature was controlled via the ambient temperature and internal loads were accounted for by thermostatic valves (Non-standard TRNSYS type 120 PID-controller). Two systems used floor heating systems with additional reference values.

- **Domestic hot water (DHW):** The DHW demand was fixed with 200 litres/day per house or apartment. The daily distribution was calculated with a software tool developed by [4]. It is based on a statistical distribution of the occurrence of taking a bath, taking showers, washing hands, etc. coupled with weekday/weekend differences and vacation periods. Figure 1 show an example of the domestic hot water demand over a period of seven days.

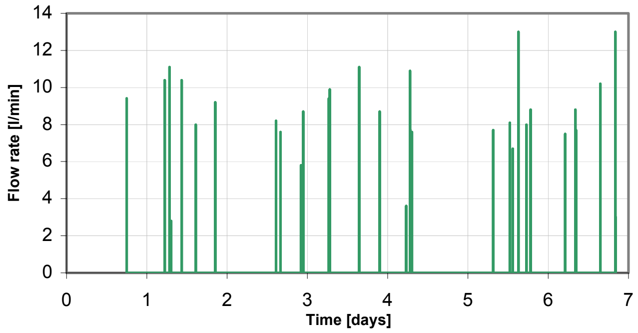


Figure 1: Domestic hot water demand for 72 hours and 200 litres/day [4]

- **Auxiliary heating device**: Two burner models, a gas and a biomass burner model, were defined by specific characteristics such as range of modulation, convective and radiation losses, standby temperature etc. as standard burner models. If burners were an integrated part of the solar combisystems, the burner model was adapted to its specific values. Non-standard TRNSYS Type 170 was used for the burner calculations, the controller for the burner was non-standard TRNSYS type 123.

- **Solar collector: A** typical flat plate collector with optically selective coated absorbers was used for the comparisons. The collector parameters are shown in [1]. The Non-standard TRNSYS type 132 was used as collector model. Additionally the connecting tubes of the collector loop were defined.

- **Electricity consumption:** The parasitic electricity demand of a combisystem, W_{par}, and of a reference heating system (see chapter 2.2), $W_{par,ref}$, was defined as the sum of the annual electricity consumption, other than for heating, of all electrical system components (pumps, burner devices, valves and controllers).

2.2 Target Functions

The target function for the optimisation is based on fractional energy savings f_{sav} of the solar Combisystem compared to a reference system. According to CEN/TC 312, ISO/TC 180, f_{sav} is related to the purchased auxiliary energy. The reference systems were defined with the reference buildings for each climate coupled with a gas-boiler driven radiator heating system. No space heating water storage was used, the volume of the DHW store was set to 150 litres. Three different indicators were used.

Fractional thermal energy savings ($f_{sav,therm}$)

This definition gives fractional energy savings based on the saved fuel input of the solar combisystem compared to the reference heating system.

equ.1: $$f_{sav,\,therm} = 1 - \frac{\dfrac{Q_{boiler}}{\eta_{boiler}} + \dfrac{Q_{el.heater}}{\eta_{el.heater}}}{\dfrac{Q_{boiler,\,ref}}{\eta_{boiler,\,ref}}} = 1 - \frac{E_{aux}}{E_{ref}}$$

with:

$\eta_{el.heater}$ = 40% for systems that do **not** apply solely renewable energy sources

$\eta_{el.heater}$ = 90% for systems that apply solely renewable electrical energy sources

Extended fractional energy savings ($f_{sav,ext}$)

In this definition, the above value takes into account the parasitic electricity W_{par} used by the system.

equ.2: $$f_{sav,\,ext} = 1 - \frac{\dfrac{Q_{boiler}}{\eta_{boiler}} + \dfrac{Q_{el.hetaer}}{\eta_{el.heater}} + \dfrac{W_{par}}{\eta_{el}}}{\dfrac{Q_{boiler,\,ref}}{\eta_{boiler,\,ref}} + \dfrac{W_{par,\,ref}}{\eta_{el}}} = 1 - \frac{E_{total}}{E_{total,\,ref}}$$

with:

$\eta_{el.heater}$ = 40% for systems that do **not** apply solely renewable energy sources

$\eta_{el.heater}$ = 90% for systems that apply solely renewable electrical energy sources

η_{el} = 40% for all systems

Fractional savings indicator (f_{si})

This last definition includes also a penalty $Q_{penalty,red}$ for not fulfilling the comfort criteria of domestic hot water (DHW) and room temperatures as described in [1].

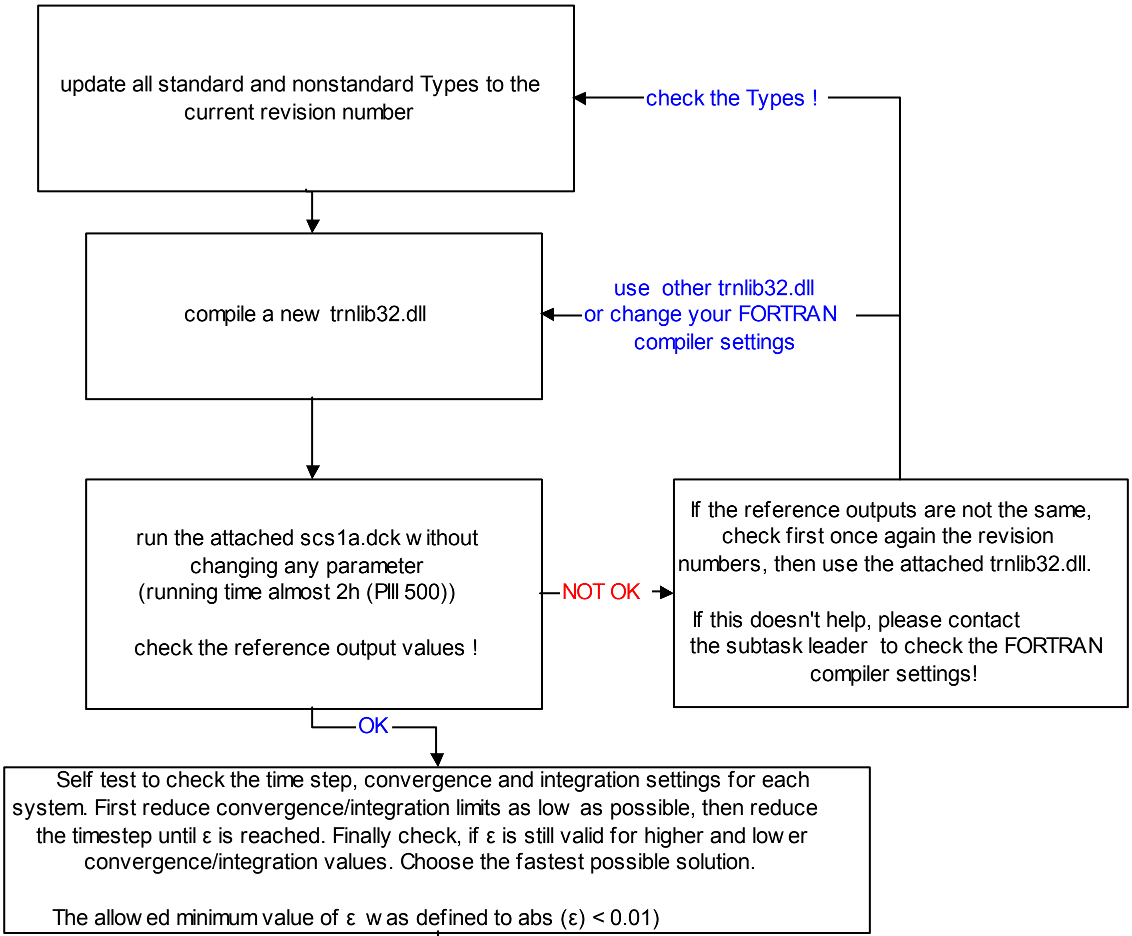
equ.3: $$f_{si} = 1 - \frac{E_{total} + Q_{penalty,\,red}}{E_{total,\,ref}}$$

2.3 Model calibration, optimisation, sensitivity analysis

All TRNSYS models of Task 26 had to be adjusted to reach the same mathematical **simulation accuracy**. Otherwise the simulation results would not have been comparable. This adjustment was performed in the following steps:

1) All TRNSYS types are the same for all participants (all current TYPE versions were collected at a specific website that was accessible for Task 26 workers) and the reference system has the same results on each computer and TRNSYS library used.
2) Simulation time step and the parameters for convergence and integration accuracy had to be adjusted in order to reach a given relative and absolute accuracy. The accuracy was defined as the relative difference of the $f_{sav,therm}$ – values between two iterative simulation runs.

Figure 2 illustrates this procedure:



maximum possible time step

Parameter			Results (example)		
Convergence	Integration	Time step	simulation runs	$f_{sav,therm}$	$\varepsilon=(f_s(i)-f_s(i-1))/f_s(i-1)$
0,1	0.1	1/20	yes	0.253	
0.01	0.01	1/20	yes	0.24	-0.051
0.005	0.005	1/20	yes	0.234	-0.025
0.001	0.001	1/20	no	-	-
0.005	0.005	1/20	yes	0.234	
0.005	0.005	1/32	yes	0.23	-0.017
0.005	0.005	1/40	yes	0.227	-0.013
0.005	0.005	1/64	yes	0.225	-0.008810573
0.01	0.01	1/64	yes	0.227	0.008888889
0.001	0.001	1/64	yes	0.224	-0.004444444

Convergence and integration values are not possible

ε < 0.01

choosen values ε < 0.01, short simul. time

Last convergence/ integration check (both compared to 0.005;0.005;1/64)

Figure 2: Procedure to ensure the same TRNSYS TYPES and the same accuracy for all simulation models of Task 26.

Most of the systems had to be modelled with small time steps in order to achieve the defined accuracy (see chapter 2.3). In the course of Task 26 it was found, that there were mistakes in the standard TRNSYS types 16 (radiation processor) and proc.for (a basic routine for TRNSYS) when small time steps not equal 1/(2^n) hours were used (TRNSYS Version 14.2). Both subroutines were improved by participants of Subtask C. The revised modules can be ordered from the author.

The **optimisation procedure** for the different systems was defined by a two step approach: In the first step the systems were optimised in itself as they are produced starting from a 'base case' with their typical collector areas and store volumes.

In the second step values for the FSC method (see [1] and [2]) are calculated for each system. The comparison of the systems based on these values are presented in [1] and [2].

The following steps are performed during the system optimisation

- Model the system in TRNSYS for the relevant climate (preferably Zurich) and the 60 kWh/m²a building with collector area and store volumes set by the participant.
- The target functions for the analysis are based on fractional energy savings. Three functions (ref. to chapter 2.2) are defined.
- Do a sensitivity analysis (and maybe optimisation) with this model. The parameters that should be varied are given in Table 1. Of course participants were free to perform a sensitivity analysis with more than the mandatory parameters. The model could also be changed, if it was found, that it is in the present form far away from the optimum.
- Optimise the system using the specified target function in chapter 2.2 (by hand and automatically). If available, cost functions can be included in the optimisation. The results of this last step are presented in [6]
- Besides: country or company specific calculations could be performed

It should be mentioned that each participant of Subtask C of Task 26 did as much as possible within the optimisation, but of course, was restricted by funding available for the Task.

The parameters to be generally included in the optimisation are defined as shown in Table 1. Table 2 shows as an example the actual parameters and the resulting $f_{sav,ext}$ values for the optimisation runs performed with System #19.

All results for the different systems are shown in the description of each system. The optimisation led to several changes in the lay-outs of the system during the Task. These changes are described in [5].

Table 1: Parameters for optimisation (values, boundaries and fixed parameters see [1])

		Ref.-Cond	Analysis/ optimisation	Comparison
Climate	**Four climates** Stockholm (northern Europe) Zürich (middle Europe) Carpentras (southern Europe)	 * * *	one	all
	Space heating system **a) Single- family house** **100 kWh/m²a** **60 kWh/m²a** **30 kWh/m²a** b) Multi-family house (45 kWh/m²a) c) Lay-Out temp. of heating system [°C]	 * * * * *	one only #19 if possible fixed	all fixed
System	**Collector** Type (η_0, a_1, a_2) (2 types in ref. cond.) Area [m²] Azimuth (-90 - +90°) Tilt angle (0 – 90°) Specific flow rate (kg/m²h) (8 – 50 l/m²h) Fixed/matched flow	 *	 one variable fixed fixed fixed fixed	 ? variable fixed (0) fixed (45) fixed fixed flow
	Pipe system (collector – storage unit) electricity consumption (pump) [W]	*		 fixed
	Storage unit(s) Volume [m³] Volume/diameter [m³/m] Position of heat exchangers Position of in/outlets Fixed position of in/outlets – stratification unit Position of sensors Thermal insulation [W/m²K]		free discussion for each system	 variable opt. fixed opt. fixed opt. fixed opt. fixed opt. fixed opt. fixed
	DHW – preparation Load Circulation loop (if necessary) Length of circul. loop [m] Heat loss (thermal insulation) [W/K] Electricity consumption (pump) [W]	 *	 fixed none none fixed fixed	 fixed (ref) none none fixed fixed
	Heat exchangers U*A [W/K]		 variable	 opt. fixed
	Control strategy		variable	opt. fixed
	Auxiliary heating Range of modulation (if possible) Fuel consumption (e.g. wood, gas) Electricity consumption (pump, control-unit)	 *	 ?	 fixed

opt. fixed: optimum from system analysis/optimisation taken.

Table 2: Parameters variation done for System #19 (base-case see annex of #19 system description)

Summary of Sensitivity Parameters			
Parameter	Variation	[1]Variation in $f_{sav,ext}$	
Base Case (BC)	-	38.97%	
Collector size [m^2] (fixed store size (5.5 m^3)	25 – 250	16.85 – 50.91%	Figure xx
Collector Size [m^2] (fixed store spec. vol. 0.05 m^3/m^2)	25 – 250	18.01 – 55.49%	Figure xx
Store Size [m^3] (fixed collector area of 100 m^2)	1.75 – 13.00	31.77 - 39.64%	Figure xx
Collector Azimuth [°] (fixed tilt of 60°)	-90 - 90	26.73 – 39.06%	Figure xx
Collector Tilt [°] (fixed azimuth of 0°)	15 – 90	29.46 – 39.45%	Figure xx
Specific Collector flow rate [kg/m²-h]	10 - 22	38.70 -39.22%	Figure xx
Climate (45 kWh MFH – Base Case (BC))	Carp. / Zur. / Stock.	67.0% / 39.0% / 34.4%	Figure xx
[2]Boiler Inlet Rel. Height [-]	0.940 – 0.999	38.97 – 39.10%	Figure xx
[2]Boiler Outlet Rel. Height [-]	0.87 – 0.98	38.48 – 40.37%	Figure xx
[2]Heating System Inlet Rel. Height [-]	0.00 – 0.60	31.04 – 38.97%	Figure xx
Collector Heat Exchanger UA [%] (variation from identified value)	-50 - +100	37.94 – 39.63%	Figure xx
DHW Heat Exch. UA [%] (variation from BC value)	-50 - +100	38.83 – 39.15%	Figure xx
[3]Store Insulation: top [cm]	4 – 34	36.84 – 39.45%	Figure xx
[3]Store Insulation: sides [cm]	4 – 34	28.69 - 41.21%	Figure xx
[3]Store Insulation: bottom [cm]	4 – 34	38.84 – 39.02%	Figure xx
[3]Store Insulation: whole store [cm]	4 – 34	25.59 – 41.73%	Figure xx
Collector Controller dT_{start} [K] (constant dTstart/dTstop)	4 – 12	38.94 – 39.06%	Figure xx
[4]Boiler Outlet Temperature [°C]	61 - 80	35.88 – 41.39%	Figure xx
[5]Store Charge Thermostat (off) [K]	0 - 2	38.80 – 38.97%	Figure xx
Store Charge Flow Rate [kg/h]	1500 - 5500	37.57 – 39.13%	Figure xx
Store Charge Controller Sensor Rel. Height [-]	0.85 – 0.96	36.85 – 38.97%	Figure xx
Collector Controller Sensor Rel. Height [-]	0.050 – 0.500	38.14 – 39.11%	Figure xx
DHW charge flow rate [kg/h]	100 - 200	38.24 – 42.00%	Figure xx
DHW Storage charging time (Day) [h]	9:00 – 13:00	38.90 – 39.14%	Figure xx
DHW Storage charging time (Night) [h]	0:00 – 4:00	38.80 – 38.97%	Figure xx
DHW Storage charging temperature [°C]	53 - 63	37.61 – 41.96%	Figure xx
DHW Storage Volume [m³]	0.15 – 0.30	38.65 – 40.29%	Figure xx

[1] The variation if fractional savings indicated in the table does not represent the values for the extremes of the range, rather the minimum and maximum values for the range indicated.

[2] **The thermostat settings for store charging and electrical heater were NOT changed for these variations. Adjusting the setting to just meet the demand of the period with the highest load would probably lead to different results.**

[3] **The insulation has a conductivity of 0.04 W/m-K and has a correction factor for "imperfection" of $C_{corrE}=MAX(1.2,(-0.1815*LN(V_{maiST})+1.6875))*2.5$.**

[4] **The settings for the controller for the charging of the store from boiler were kept constant for all variations (62°C start, 70°C stop).**

[5] **The boiler standby and supply set temperature were set to be 5K higher than the thermostat (off) setting. The thermostat had a constant hysteresis of 8K.**

2.4 Common Report Structure

A common report structure for the system simulation reports was defined in Subtask C in Task 26. It consists of the following parts:

1 General description of the system
2 Modelling of the system
  2.1 TRNSYS model
  2.2 Definition of the components included in the system and standard inputs data
  2.3 Validation of the system model
3 Simulations for testing the library and the accuracy
  3.1 Result of the TRNLIB.DLL check
  3.2 Results of the accuracy and the time step check
4 Sensitivity Analysis and Optimisation
  4.1 Presentation of results
  4.2 Definition of the optimised system
5 Analysis using FSC
6 Lessons learned
7 References
8 Appendix 1: Description of components specific to this system

3 Systems Modelled

The following 9 Systems were modelled within Subtask C of Task 26 and are described in detail the following appendices to this report. A comparison using the FSC-method is given in [1] and [2]. A more detailed analysis of the simulations can be found in [6].

Systems:

System #2	Klaus Ellehauge, Denmark
System #3a	Philippe Papillon, David Chèze,,Clipsol, Aix-les-Bains, France
System #4	Louise Jivan Shah, Denmark
System #8	Jacques Bony, Thierry Pittet, EIVD, Yverdon-les-Bains, Switzerland
System #9b	Markus Peter, University Oslo, Norway
System #11 oil, gas	Chris Bales, SERC, Borlänge, Sweden
System #12 base	Chris Bales, SERC, Borlänge, Sweden
System #15	Dagmar Jaehnig, SOLVIS, Braunschweig, Germany
System #19	Richard Heimrath, IWT Graz, University of Technology, Austria

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[4] Jordan, U., Vajen, K.: Influence of the DHW profile on the Fractional Energy Savings – A Case Study of a Solar Combisystem, in: CD-ROM of the Third ISES Europe Solar Congress EuroSun 2000, Copenhagen, Denmark.

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[6] Streicher, W., Heimrath, R., Analysis of System Reports of Task 26 for Sensitivity of Parameters, Technical Report, IEA SHC Task 26 Solar Combisystems, http://www.iea-shc.org, 2003