Direct Characterisation test procedure for solar combisystems – 5th draft

A Report of IEA SHC - Task 26

Solar Combisystems

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by

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A technical report of Subtask B

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1 Introduction

1.1 Scope

The Direct Characterisation (DC) test method is for solar combisystems, providing heat for domestic hot water (DHW) and space heating. It is to be used for small factory made systems as well as for small custom built systems as specified in present CEN test procedures. Solar domestic hot water systems should be tested according to the already existing European DST method (EN 12976-2, [1] or CTSS method (ENV 12977-2, [2]).

Systems to be tested shall include an auxiliary heater, either integrated in the store or separate. Preferably, possible external auxiliary heater is the choice of the manufacturer of the solar combisystem. If not available, the auxiliary heater at the test institution can be used. Auxiliary heating can be performed with electricity, oil, gas or wood. Internal auxiliary heating may include direct and indirect (through a heat exchanger) heating.

Heat demands, both for domestic hot water and space heating are emulated by the test facility. The test does not take into account a specific heat distribution system and its control. The heat distribution system emulator simulates the return temperature of the heat distribution system.
For this test procedure, sizes of the solar combisystem being tested are limited to heat stores up to 1500 litres and heating power from the collector up to 15 kW.

1.2 Course of development

Starting point for description of the DC test method was a short test for solar combistores developed at SERC in Sweden [3]. Heat store properties from these tests were used to compare a variety of solar combisystems. Comparison of this test method with the CTSS (Component Testing – System Simulation) method [2] revealed different ways to go in development of a test procedure for characterisation, assessment and comparison of solar combisystems:

1. Performance indicator is direct result from testing. There is no processing into annual performance prediction. Hence, this involves direct comparison of test results if more systems are tested.
2. Performance indicator from testing is processed in a simple way to deliver annual performance prediction, but only for the conditions during the test, being average values for the whole year. Extrapolation into other climates and heat demands than used in the test is not possible.
3. Test results are processed with a numerical solar combisystem model revealing annual performance predictions for all climates and loads possible.

Option 3 is favourable with respect to its expected accuracy. However, test sequences might be more extensive in order to determine all necessary parameters accurately enough. If no model is available, data processing also requires additional modelling work. This all makes the test more expensive. On the other hand, the test is considered to be cheaper than CTSS testing and probably also more accurate with respect to annual performance prediction due to measuring the whole system, i.e. including system control. This option has been explored at SPF in Switzerland [4]. Option 1 was considered as a too limited result. Without investigation of accuracy of the annual performance prediction, it is difficult to estimate how accurate the method is for the large variety of solar combisystems.

Option 2 has been investigated at ITW in Germany and at TNO in the Netherlands. ITW applied an early version (second draft) of the test method on two solar combisystems and compared the outcome with CTSS results [5]. TNO investigated simulated test results for composition of solar combisystem test conditions [6]. The present technical report describes the preliminary end result of these latter investigations.

2 Apparatus

This Section gives a description of the test facility and describes requirements for mounting and location of the solar combisystem being tested.

2.1 Safety

Mounting of system components and connection of the system to the test facility shall be carried out in a manner ensuring safety to personnel. Due consideration shall be given to likelihood of glass failure and leakage of hot liquids.

2.2 Test facility

2.2.1 Scheme of the test facility

Figure 1 shows two diagrams for possible layout of the test facility for solar combisystems. The hardware shall consist of the following parts:

1. Auxiliary Heating Emulator (AHE) that can emulate a standard external natural gas, oil, wood or electric auxiliary heater. However, it is strongly recommended that the manufacturer provides a solar combisystem including auxiliary heater for testing. The AHE is only used if the manufacturer does not supply an auxiliary heater. Possible use of the AHE including all settings is stated in the test report. The AHE shall fulfil requirements matching the two situations sketched in Figure 1:
   a) the AHE can provide modulating power to the solar combisystem based on the signal from the auxiliary heated part of the solar combisystem and from the outdoor temperature sensor that is integrated in the Solar Collector Emulator (situation b of the SCE description below) or in a small box simulating ambient air temperature.
   b) the AHE can also act as additional heater to the solar combisystem providing modulating power to the domestic hot water and space heating load based on signals from these loads and from the outdoor temperature sensor that is integrated in the SCE (situation b of the SCE description below) or in a small box simulating ambient air temperature.

   Situation b dictates the specifications of the AHE with respect to the power, i.e. the AHE shall be able to deliver power to the space heating load up to 6 kW at a temperature up to 65°C and power to DHW up to 25 kW at a temperature of at least 45°C. For an AHE operating on fuels, minimum modulation is 40% or less and efficiency under full load is higher than 100%, including heat of condensation. The AHE can also be heated electrically.

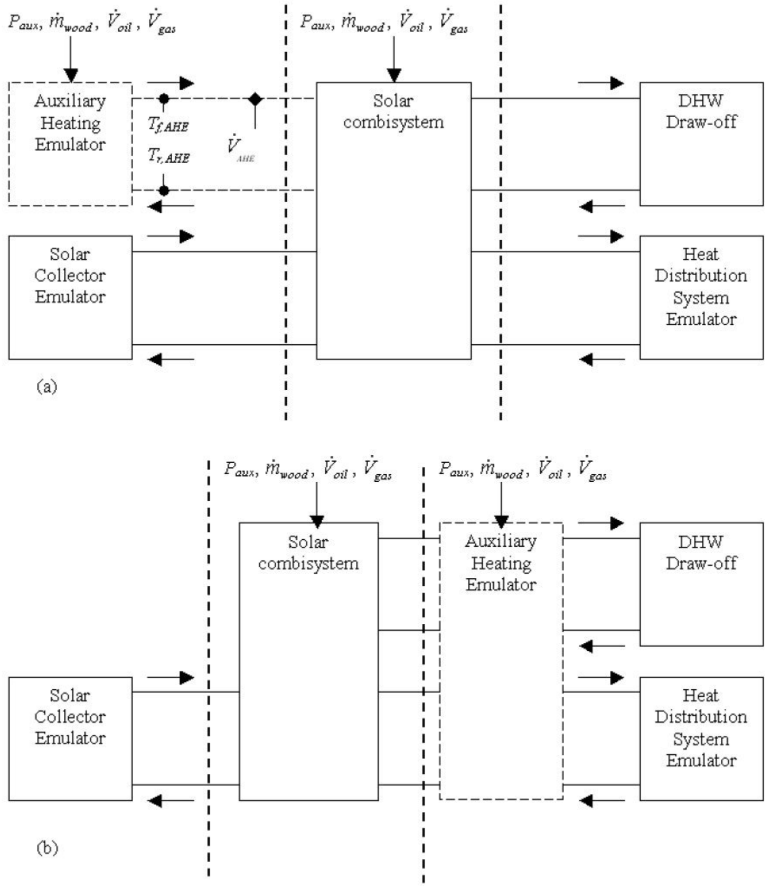

Figure 1: Two possible layouts of the test facility for solar combisystems.

2. Solar Collector Emulator (SCE) that:
   a) can emulate any collector up to a peak power of 15 kW. The SCE controls stagnation temperature (i.e. internal SCE temperature if the collector pump is not in operation) and flow temperature based on specifications of the solar collector usually delivered with the solar combisystem, meteorological data in the test and the signal from the collector loop controller indicating the status of the collector pump. The SCE shall be able to emulate the stagnation temperature of the collector when the collector pump is not in operation, and the collector flow temperature when the pump is running. The regular collector sensor is used for measuring both the stagnation and flow temperature for the collector loop controller. See Figure 2a.
   b) can emulate the solar irradiance and ambient air temperature on the built-in collector to extremes of 0 to1000 W/m^2 collector area and -5 to + 25°C respectively. Surrounding air velocity is 3.0 m/s. The signal of the regular collector temperature sensor is used for the collector loop controller. Optionally, power from the built-in collector can be multiplied in order to emulate larger collector fields composed out of parallel-connected solar collectors of the same type as in the SCE. See Figure 2b. Long wave radiation in the collector plane shall not exceed 50 W/m^2 for solar irradiance of 1000 W/m^2. Reflection of solar irradiation from surfaces inside the test facility onto the solar collector shall be prevented as well. An open mounting structure is provided for installation of the solar collector(s). This structure shall in no way

obstruct the aperture of collectors and shall not significantly affect the back or side insulation of the collector(s).

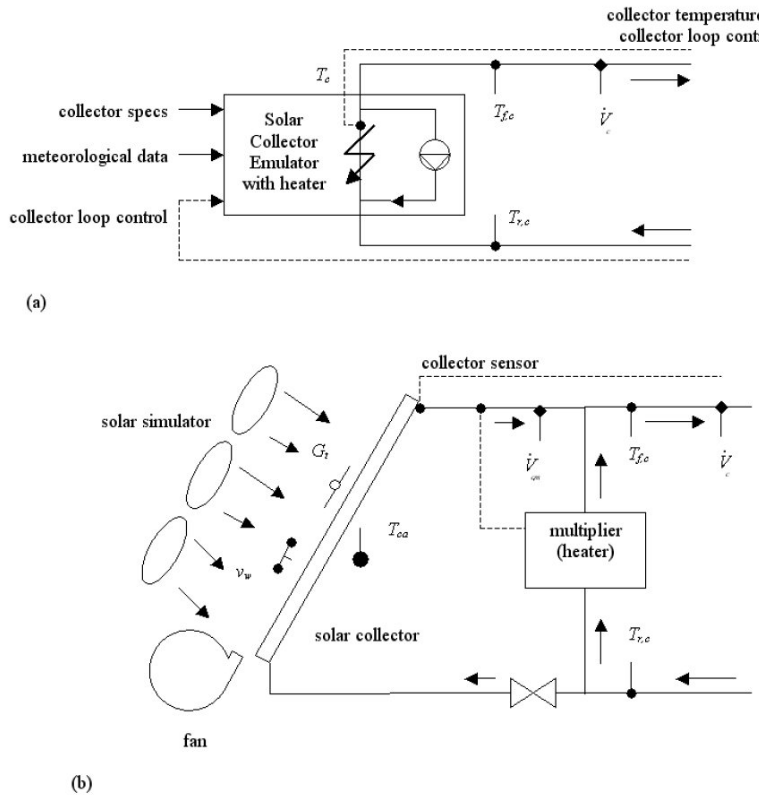

Figure 2: Two possible layouts of the Solar Collector Emulator.

The SCE in situation b can be used for mounting the (possible) outdoor ambient air temperature sensor of the AHE or solar combisystem. For situation a, the sensor shall be placed in a small box wherein outdoor ambient air temperature shall be simulated.

3. Heat Distribution System Emulator (HDSE) that can emulate space heating loads. The HDSE controls heat distribution system flow rate and return temperature into the solar combisystem based on reference values of flow rate, flow and return temperature in a low temperature heating system. Maximum cooling power is at least 6 kW. See Figure 3.

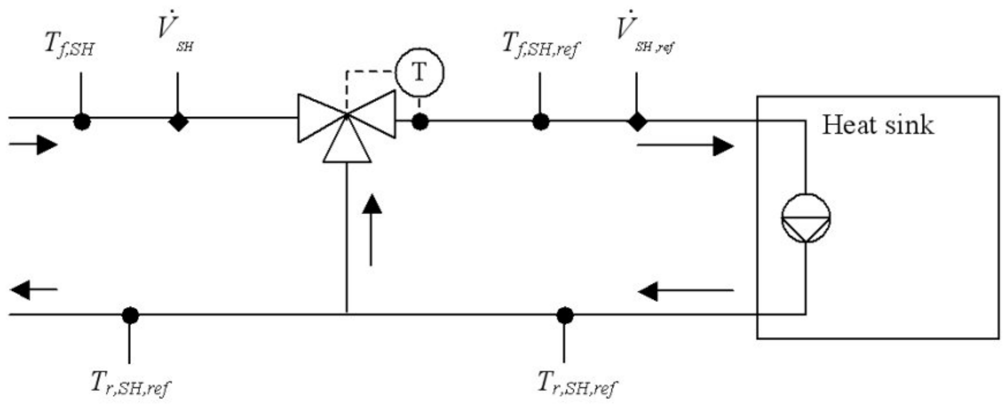

Figure 3: The Heat Distribution System Emulator.

4. Domestic Hot Water Draw-off that shall be able to perform discharges at a defined flow rate and draw-off pattern. See Figure 4. This part of the facility shall be prepared to perform energy rather than volumetric draw-offs.
5. A climate test chamber with constant ambient air temperature and without direct solar irradiation and infrared radiation sources.

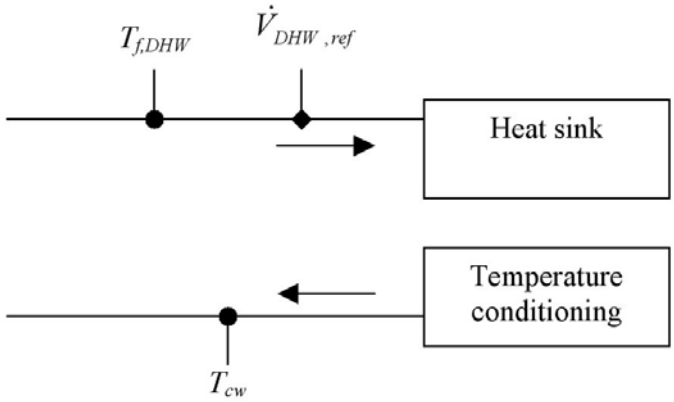

Figure 4: Domestic Hot Water Draw-off.

All piping in the test facility shall be resistant to corrosion and suitable for operation at temperatures up to at least 95°C with the exception of the piping in the SCE loop: this shall be able to even withstand temperatures up to at least 160°C.

Pipe lengths between AHE and the solar combisystem shall be kept short. Pipe length between solar combisystem (and AHE in case of situation Figure 1b) and other emulators should be fixed: see Section 2.3 for further information. In particular, the piping between coldwater source with constant temperature and inlet to the heat store shall be minimized in order to reduce effects of the environment on the water inlet temperature. If distance between cold water supply and heat store is substantial, the inlet pipe shall be rinsed directly before each draw-off in order to provide constant coldwater temperature.

All pipes and connections shall be insulated. Special attention shall be paid to insulation of the piping between temperature sensors and the heat store. The calculated temperature gain or loss along either pipe shall not exceed 0.01 K under test conditions, i.e. the pipe heat loss coefficient shall not exceed 0.15 W/K for each pipe.

If the flow in a certain pipe is not turbulent, mixing devices shall be installed directly upstream of the temperature sensor.

The test facility shall allow continuous operation of the test procedure described in Section 3.2, i.e. for about 9 days.

2.2.2 Overview of sensors

Test facility sensors can be subdivided into sensors for checking the test conditions and sensors for thermal performance measurements.

Sensors for checking the test conditions involve:

1. (a) For the possible Auxiliary Heating Emulator of Figure 1a, flow temperature $T_{f,AHE}$ and volume flow rate $\dot{V}_{AHE}$ into and return temperature $T_{r,AHE}$ from the solar combisystem. (b) For the possible Auxiliary Heating Emulator of Figure 1b, flow temperature $T_{f,SH}$ and volume flow rate $\dot{V}_{SH}$ into the HDSE as well as flow temperature $T_{f,DHW}$ and volume flow rate $\dot{V}_{DHW}$ to DWH draw-off; see Figures 3 and 4.
2. (a) For the Solar Collector Emulator with the heater of Figure 2a, flow temperature $T_{f,c}$ and volume flow rate $\dot{V}_c$ into and return temperature $T_{r,c}$ from the solar combisystem as well as the collector temperature T_c.
   (b) For the Solar Collector Emulator with the solar simulator and possible multiplier of Figure 2b, solar irradiance G_t, collector ambient air temperature $T_{c,a}$, surrounding air velocity v_w, flow temperature $T_{f,c}$ into and return temperature $T_{r,c}$ from the solar combisystem, volume flow rate from one collector module $\dot{V}_{c,m}$ and volume flow rate after multiplication $\dot{V}_c$.
3. For the Heat Distribution System Emulator of Figure 3, reference flow temperature $T_{f,SH,ref}$, reference volume flow rate $\dot{V}_{SH,ref}$ and reference return temperature $T_{r,SH,ref}$.
4. For the Domestic Hot Water Draw-off of Figure 4, reference volume flow rate $\dot{V}_{DHW,ref}$ and cold water temperature T_{cw}.

Sensors for checking the test conditions are optional, as test conditions may be assured in other ways.

Sensors for thermal performance measurements involve:

1. For the possible Auxiliary Heating Emulator, the electric power P_{aux}, mass flow rate of wood $\dot{m}_{wood}$ or volume flow rate of oil $\dot{V}_{oil}$ or gas $\dot{V}_{gas}$, whatever applicable for the external auxiliary heater.
2. For the solar combisystem (including auxiliary heating), the electric power P_{aux}, mass flow rate of wood $\dot{m}_{wood}$ or volume flow rate of oil $\dot{V}_{oil}$ or gas $\dot{V}_{gas}$, whatever applicable.
3. For heat delivered to space heating, flow temperature $T_{f,SH}$, volume flow rate $\dot{V}_{SH}$ into and reference return temperature $T_{r,SH,ref}$ from the HDSE.
4. For heat delivered to domestic hot water draw-off, flow temperature $T_{f,DHW}$, volume flow rate $\dot{V}_{DHW,ref}$ into and cold water temperature T_{cw} from the DHW-draw-off.

Sensors mentioned under 3 and 4 can also used for checking the test conditions as described above.

Figures 1 – 4 indicate roughly the location of sensors.

2.3 Mounting of the solar combisystem

2.3.1 General

The complete heat store part of the system, if possible with auxiliary heating, shall be mounted in the climate chamber of the test facility according to the manufacturer's installation instructions. The heat store(s) shall then be connected to the possible Auxiliary Heating Emulator (AHE), the Solar Collector Emulator (SCE), Heat Distribution System Emulator (HDSE) and Domestic Hot Water Draw-off. In order to support efficient mounting of the system to be tested connections into possible AHE, SCE, HDSE and domestic hot water draw-off are in specific positions, either on the wall(s) or on mobile test equipment. A grid drawn on floor and wall(s) might be helpful to establish space requirements for the solar combisystem.

There shall be a uniform ambient air temperature in the vicinity of the heat store(s) and piping, i.e. the part of the system that is indoors according to the manufacturer's installation instructions. The ambient air temperature shall be according to Section 3.2.3.1.

The climate chamber (or climatised area) might be prepared for quick and efficient installation.

2.3.2 Connection to the Auxiliary Heating Emulator

Pipes connected to the possible AHE shall be properly insulated so that thermal losses are minimized, and the measured energy corresponds to the actual auxiliary energy supply. The possible AHE shall be located below the connections into the heat store(s) or the pipes between the AHE and the heat store(s) shall have a downward bend of at least 300 mm deep, as close to the store as possible, in order to avoid reverse thermosiphon convection.

The possible temperature sensor in the heat store(s) for the external auxiliary heater shall be connected to the control unit of the AHE. The outdoor ambient air temperature sensor of the AHE shall be mounted in the SCE (situation b in Section 2.2.1) or in a small box wherein outdoor ambient air temperature shall be simulated. The sensor shall be protected from direct solar and infrared radiation.

2.3.3 Connection to the Solar Collector Emulator

2.3.3.1 Piping and insulation

Pipes connected to the SCE shall have the longest length allowed by the published installation instructions for the solar combisystem. If there are no such instructions, the pipe length shall be 15.0 ± 0.1 m for the collector flow pipe and 15.0 ± 0.1 m for the collector return pipe. The environment for these pipes shall be the same as for the heat store(s) as far as possible, in order to increase the reproducibility of the test results. The pipe length used shall be stated in the test report.

The diameter and insulation of the pipes shall be in accordance with the manufacturer's installation instructions. If not prescribed by the manufacturer, the insulation shall be chosen according to common installation practice such that maximum insulation thickness is 30 mm.

All pipes and pipe connections shall be properly insulated so that thermal losses are minimized. The SCE shall be located below the connections into the heat store(s) or the pipes between the SCE and the heat store(s) shall have a downward bend of at least 300 mm deep, as close to the store as possible, in order to avoid reverse thermosiphon convection.

2.3.3.2 Heater as SCE

If the SCE is a heater like in Figure 2a, not only the collector pipes shall be connected to the SCE but also the collector loop controller shall be connected to the ‘collector’ sensor in the heater. Connection to the signal indicating the collector pump status shall also be made.

2.3.3.3 Solar simulator as SCE

If the SCE is a solar simulator like in Figure 2b, collector pipes as well as the collector loop controller are connected to the solar collector and regular collector sensor as in usual practice.

The whole solar collector or the smallest module available shall be installed on the open mounting system of the test facility. For roof integrated collectors, the heat loss coefficient of the mounting system shall be set according to the manufacturer’s installation instructions or shall have a value of 0.35 ± 0.05 $W/(m^2K)$ if not prescribed by the manufacturer. If a specific mounting system is prescribed, then that structure shall be provided by the manufacturer and used. The way of mounting the collector(s) shall be stated in the test report.

The height between the lower edge of the collector(s) and the ground of the test facility shall be at least 0.50 m, unless specified otherwise by the manufacturer. Natural ventilation of the collector surface shall not be restricted through the mounting.

The collector shall be mounted at a collector tilt angle of 45°.

2.3.3.4 Heat transfer fluid and flow rate

The heat transfer fluid used in the collector loop during testing shall be as delivered by the manufacturer.

The flow rate in the collector loop as result of system operation shall be as indicated in the manufacturer’s installation instructions.

Both heat transfer fluid and flow rate shall be stated in the test report.

2.3.3.5 Collector loop controller

The collector loop controller shall be set in accordance with the manufacturer’s installation instructions. If no instructions are given and settings can be adjusted, for a ΔT controller, switch-on temperature difference shall be 7 K or another value selected by the test engineer, and switch-off temperature difference shall be 2 K. The controller settings shall be stated in the test report.

2.3.4 Connection to the Heat Distribution System Emulator

Pipes connected to the HDSE can lead from the solar combisystem as indicated in Figure 1a, or from the AHE as in Figure 1b. The pipe length shall be 5.0 ± 0.1 m for the flow pipe and 5.0 ± 0.1 m for the return pipe. The environment for these pipes shall be the same as for the heat store(s). The diameter and insulation of the pipes shall be in accordance with the manufacturer's installation instructions. If not prescribed by the manufacturer, the insulation shall be chosen according to common installation practice such that maximum insulation thickness is 30 mm. All pipes and pipe connections shall be properly insulated so that thermal losses are minimized. The HDSE shall be located below the connections of the heat store(s) or AHE or the pipes between the HDSE and the heat store(s) or AHE shall have a downward bend of at least 300 mm deep, as close to the store as possible, in order to avoid reverse thermosiphon convection.

2.3.5 Connection to the domestic hot water draw-off

Pipes connected to the DHW draw-off equipment can lead from the solar combisystem as indicated in Figure 1a, or from the AHE as in Figure 1b. The pipe length shall be 5.0 ± 0.1 m for the flow pipe and 5.0 ± 0.1 m for the return pipe. The environment for these pipes shall be the same as for the heat store(s). The diameter and insulation of the pipes shall be in accordance with the manufacturer's installation instructions. If not prescribed by the manufacturer, the insulation shall be chosen according to common installation practice such that maximum insulation thickness is 30 mm. All pipes and pipe connections shall be properly insulated so that thermal losses are minimized. The DHW draw-off equipment shall be located below the connections of the heat store(s) or AHE or the pipes between the DHW draw-off equipment and the heat store(s) or AHE shall have a downward bend of at least 300 mm deep, as close to the store as possible, in order to avoid reverse thermosiphon convection.

3 Thermal performance testing

This section describes the measurement procedure and processing of the measured data.

3.1 Principle

The Direct Characterisation (DC) test procedure involves a dynamic indoor test directly related to realistic operating conditions during winter, spring, summer and autumn weather conditions. Final energy use of the solar combisystem measured during the test is transformed into an annual value[1].

1 Determination of the final energy use rather than fractional savings prevents the ever disputable choice of reference combisystems (without solar energy) and efficiency of burners. On the other hand, it means that solar combisystems shall always be tested in combination with the auxiliary heater. Presentation of the system performance does not only include final energy use but also heat demand.

Test conditions described in Section 3.2 constrain to choose one out of two reference houses for a specific climate[2]. Section 3.3 describes derivation of annual final energy used and annual parasitic electricity as unambiguous performance indicators from the test.

3.2 Test procedure

3.2.1 Mounting of the system and additional information from the manufacturer

The complete collector circuit including possible heat exchanger, expansion vessel, pump, pipes, drainback facilities and control equipment shall be installed into the test facility by the manufacturer or designated installer. With respect to the collector there are three possibilities:

(1) The collector is not included. Then, the manufacturer shall supply details of the collector to be used with the system, including area. The collector shall be emulated by the test facility.

(2) The collector is delivered by the manufacturer and part of the solar collector emulator. In this case, a solar simulator is used.

(3) As (2) but only one collector module is delivered as well as additional information on the number of collector modules forming the solar collector. The test facility multiplies the heat output from this collector module by the number of modules in order to emulate the total heat from the collector.

The heat store, including equipment for preparation of domestic hot water shall be installed by the manufacturer or designated installer. The manufacturer shall also install the auxiliary heater including control equipment. Preferably, possible external auxiliary heater is the choice of the manufacturer of the solar combisystem. If not available, the auxiliary heater (AHE) at the test institution can be used.

The test institution shall indicate where and how to build in the sensors between the various system components, i.e. collector circuit, store(s), auxiliary heater and emulated heat distribution system as well as in the domestic hot water draw-off pipes. The manufacturer or designated installer shall connect the components and take care of connections to the solar collector emulator, heat distribution system emulator and mains water.

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2 The DC test procedure does not allow for extrapolation into other climates and/or other heat demands than tested for. Hence, in order to prevent solar combisystems to be tested for a large number of countries (with specific climate and reference houses) in fact three climate zones and three reference houses have been defined as basis for choice by the manufacturer. By doing so, threshold for selling solar combisystems abroad is lowered.
Climate zones and reference houses refer to choices made in Task 26 of the IEA Solar Heating and Cooling programme. With respect to meteorological data, climate zone I refers to TRY Stockholm, climate zone II to TRY Zurich and climate zone III to TRY Carpentras. Borders of climate zones have not (yet) been fixed. The three reference houses involve the so-called SFH30, SFH60 and SFH100 dwellings having an annual heating load of about 30, 60 and 100 kWh/m2 floor area respectively for climate zone II.
In this draft of the DC test procedure, test conditions have only been elaborated for climate zone II in combination with reference houses SFH60 and SFH100. Further investigations should reveal test conditions for the seven other combinations of reference climate and reference house.

3.2.2 General description of the test procedure

The DC test sequence consists of the following consecutive phases:

(1) Initial conditioning of the heat store at a uniform temperature of 20°C. During this phase, auxiliary heating is switched off.

(2) Two days secondary conditioning. Auxiliary heater is in normal operation from this point onwards until the final discharge in phase (4).

(3) Core phase consisting of six days of realistic climate and load conditions. Two days involve characteristic winter conditions (November – March), two days follow summer conditions (May – September) and two days spring/autumn conditions (March – May and September – November), i.e. mean values of the important weather variables for each ‘season’ are similar to the mean values for the season in a whole year. Test results from the core phase are used to calculate the performance indicators.

(4) Determination of the energy contents of the heat store at the end of the core phase through final conditioning. During this phase, auxiliary heating is switched off.

Secondary conditioning has the following subdivision:

(2a) Initial charge using auxiliary heating.

(2b) Constant space heating discharge.

(2c) Domestic hot water draw-off.

(2d) One day final stage of secondary conditioning.

If there are different auxiliary heaters for different seasons, the appropriate heater is used for the different seasons in the core phase of the test, i.e. winter auxiliary heater for winter and spring/autumn test sequences and summer auxiliary heater for the summer test sequence. In this case, for the secondary conditioning phase, the winter auxiliary heater is in operation.

Informative note on the core phase test sequence

Start and end conditions in the heat store for the core phase are as similar to one another as possible in order to minimise need for corrections in calculation of the final energy used. Initial and secondary conditioning together are used to get the heat store into nearly the same state as at the end of the core phase. Initial conditioning alone reveals information on whether the solar combisystem can fulfil specific requirements with respect to space heating load and domestic hot water draw-off.

During the core phase, the heat store is driven into a range of operating conditions addressing the following functions:

- For the winter sequence, heat store capacity during discharge, time between charges (i.e. a measure for heat store capacity of the auxiliary heated part), interaction with the auxiliary heater under high load and ability to use little solar energy.
- For the summer sequence, heat store capacity for solar energy and heat loss at high temperatures.
- For the spring/autumn sequences, ability to use varying solar energy with varying space heating load.

3.2.3 Test conditions

3.2.3.1 Ambient air temperature of the heat store

The ambient air temperature of the heat store(s) and piping, i.e. the part of the system that is indoors according to the manufacturer's installation instructions, shall be 20 ± 2°C standard deviation during the whole test.

3.2.3.2 Initial conditioning of the heat store

At the beginning of the test, the heat store shall be brought to a uniform temperature of 20°C ± 1°C standard deviation during at least the last hour of the initial conditioning. This temperature involves the average temperature of water measured at the inlet and outlet of the heat store.

The required temperature shall be achieved by applying continuous domestic hot water draw-off or flow via the space heating loop. Choice for either domestic hot water draw-off or space heating loop depends on the height of the outlet pipes of the store, i.e. the loop with the highest outlet shall be used for initial conditioning. With respect to the flow rate, 10 ± 1 litres/min shall be used or otherwise the maximum flow rate possible.

There is no solar energy input to the heat store and no auxiliary heating during this phase.

3.2.3.3 Secondary conditioning of the heat store

3.2.3.3.1 General

If there are different auxiliary heaters for different seasons, the winter auxiliary heater shall be used during the secondary conditioning phase.

Possible internal time control of the auxiliary heater(s) shall be deactivated for the first 24 hours of secondary conditioning. After that, possible internal time control of the auxiliary heater(s) shall be reactivated. The set temperature of the auxiliary heater shall be as specified by the manufacturer. The same applies to the dead band temperature difference[3] [4]. These controls and settings shall be stated in the test report. For indirect auxiliary heating, the flow rate in the auxiliary heating loop shall be as specified by the manufacturer.

3.2.3.3.2 Initial charge using auxiliary heating

The heat store shall be charged for 8.0 ± 0.1 hours using the auxiliary heater, i.e. from 0 to 8 h.

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3 Set temperature and dead band temperature difference of the auxiliary part of the solar combisystem are considered to be a characteristic system property. National regulations may require minimum temperature values, e.g. for microbiological safety of domestic hot water, but system design has to account for that.
4 Both final energy use and hot water comfort are closely linked to the set temperature of the auxiliary part of the solar combisystem, i.e. the higher the set temperature, the higher the final energy use and the hot water comfort. In order to compare systems properly figures on both aspects should be available. The present test procedure only considers the final energy use.

There is no solar energy input to the heat store and no discharge of heat during this phase.

3.2.3.3.3 Constant space heating discharge

The heat store shall be discharged for 12.0 ± 0.1 hours using the space heating loop, i.e. from 8 to 20 h.

The space heating load P_{SH} is constant to 3.0 ± 0.1 kW for the SFH60 reference house and 5.5 ± 0.1 kW for the SFH100 reference house[5]. Table 1 gives more details on the flow rate, flow temperature and return temperature for the heat distribution system emulator.

Table 1: Test conditions for the constant space heating discharge during the first day of the secondary conditioning phase

reference house	P_{SH} [kW]	$\dot{V}_{SH,ref}$ [l/h]	$T_{f,SH,ref}$ [°C]	$T_{r,SH,ref}$ [°C]
SFH60	3.0	356	35.2	28.0
SFH100	5.5	205	60.2	37.2

There is no solar energy input to the heat store and no domestic hot water draw-off during this phase.

If the required space heating load is not met, the test is stopped and the manufacturer is contacted. The realised load shall be stated in the test report.

3.2.3.3.4 Domestic hot water draw-off

The heat store shall be discharged through multiple domestic hot water draw-offs according to Table 2. Mains temperature is 9.7°C. Discharged energy $Q_{L,DHW}$ shall be delivered at specific times *t* at a temperature of at least 45°C. Domestic hot water volume flow rate is 600 l/h, or as indicated by the manufacturer. Domestic hot water volume flow rate shall be stated in the test report.

[5] The space heating load for the SFH30 reference house should be constant to 1.5 ± 0.1 kW.

Table 2: Test conditions for domestic hot water discharges during the first day of the secondary conditioning phase for climate zone II.[6][7]

t [h]	$Q_{L,DHW}$ [MJ]
20.00	5.41
21.40	5.41
21.80	21.24
22.30	5.41

There is no solar energy input to the heat store and no space heating demand during this phase.

If the test conditions are not met, i.e. if domestic hot water temperature drops below 45°C, the test is stopped and the manufacturer shall be contacted. The discharged energy until the moment that the domestic hot water drops below 45°C shall be stated in the test report.

3.2.3.3.5 Final stage of secondary conditioning

The heat store shall be charged additionally with solar energy while auxiliary heating is in operation as prescribed in Section 3.2.3.3.1, among others, possible internal time control of the auxiliary heater(s) shall be reactivated. At the same time, the heat store shall be discharged through multiple domestic hot water draw-off and using the space heating loop. Final stage of secondary conditioning lasts for 24 ± 0.1 hours, i.e. from 24 to 48 h.

Test conditions for climate, domestic hot water load $Q_{L,DHW}$ and space heating load $Q_{L,SH}$ have been listed in Tables A1 and A2 in Appendix A for the SFH60 and SFH100 reference house respectively. Additionally, surrounding air velocity is 3.0 m/s. Start time indicates the start of the prescribed test conditions. Irradiance, ambient air temperature and surrounding air velocity continue for the whole time interval between two start times. The same applies to the test conditions for space heating.

6 Table 2 corresponds with Table 3.2 of [3]. However, corrections were carried out for the (climate zone dependent) mains temperature, hence, discharged energy was multiplied by 35.3/35, 35 being the difference between 45oC demand temperature and 10oC mains temperature in Chris Bales' report. Moreover, volume flow rate has been simplified into one value.

7 Mains temperature depends on the climate zone for which the solar combisystem is tested and so does the discharged energy. Mains temperature for climate zones I and III should be 8.5°C and 13.5°C respectively, and discharged energies should be 5.59 MJ and 21.96 MJ for climate zone I and 4.83 MJ and 18.95 MJ for climate zone III.

Test conditions for domestic hot water draw-off are valid for the time needed to fulfil the requirements with respect to the discharged energies. Mains temperature is 9.7°C. Discharged energy shall be delivered at a temperature of at least 45°C. Domestic hot water volume flow rate is 600 l/h, or as indicated by the manufacturer. Domestic hot water volume flow rate shall be stated in the test report.[8]

If the required load is not met, the test is stopped and the manufacturer is contacted. The realised space heating load and the discharged energy until the moment that the domestic hot water drops below 45°C shall be stated in the test report.

3.2.3.4 Core phase

3.2.3.4.1 General

If there are different auxiliary heaters for different seasons, the appropriate heater is used for the different seasons in the core phase of the test, i.e. winter auxiliary heater for winter and spring/autumn test sequences (i.e. days 1, 2, 3 and day 6 of the core phase) and summer auxiliary heater for the summer test sequence (i.e. days 4 and 5).

Possible internal time control of the auxiliary heater(s) shall be activated. The set temperature of the auxiliary heater shall be as specified by the manufacturer. The same applies to the dead band temperature difference. These controls and settings shall be stated in the test report. For indirect auxiliary heating, the flow rate in the auxiliary heating loop shall be as specified by the manufacturer.

3.2.3.4.2 Climate, domestic hot water and space heating load

The heat store shall be charged with solar energy while auxiliary heating is in operation as prescribed in Section 3.2.3.4.1. At the same time, the heat store shall be discharged through multiple domestic hot water draw-off and using the space heating loop. The core phase lasts for 144 ± 0.1 hours, i.e. from 48 to 192 h.

Test conditions for climate, domestic hot water and space heating load have been listed in Tables A3 and A4 in Appendix A for the SFH60 and SFH100 reference house respectively. Additionally, surrounding air velocity is 3.0 m/s. Start time indicates the start of the prescribed test conditions. Irradiance, ambient air temperature and surrounding air velocity continue for the whole time interval between two start times. The same applies to the test conditions for space heating.

Test conditions for domestic hot water draw-off are valid for the time needed to fulfil the

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8 Mains temperature depends on the climate zone for which the solar combisystem is tested and so does the discharged energy. Mains temperature for climate zones I and III should be 8.5°C and 13.5°C respectively, and discharged energies should be adapted accordingly. Domestic hot water draw-off is based on European standard EN13203. However, draw-off pattern has been adapted to suit the solar combisystem test and so have the draw-off quantities. For the final stage of secondary conditioning, domestic hot water draw-off is 200 litres based on 45°C domestic hot water demand temperature.

requirements with respect to the discharged energies[9]. Mains temperature is 9.7°C. Discharged energy shall be delivered at a temperature of at least 45°C. Domestic hot water volume flow rate is 600 l/h, or as indicated by the manufacturer. Domestic hot water volume flow rate shall be stated in the test report.

Note that specific hours contain space heating load as well as domestic hot water draw-off. These hours have been divided into a first part with only domestic hot water draw-off and a second part with only space heating load.

If the required load is not met, the test is stopped and the manufacturer is contacted. The realised space heating load and the discharged energy until the moment that the domestic hot water drops below 45°C shall be stated in the test report.

3.2.3.5 Final conditioning

After the end of the core phase, the heat store shall be brought back to a uniform temperature of 20°C ± 1°C standard deviation during at least the last hour of the final conditioning.

The required temperature shall be achieved by applying continuous domestic hot water draw-off or flow via the space heating loop. Choice for either domestic hot water draw-off or space heating loop depends on the height of the outlet pipes of the store, i.e. the loop with the lowest inlet shall be used for initial conditioning. With respect to the flow rate, 10 ± 1 litres/min shall be used or otherwise the maximum flow rate possible.

There is no solar energy input to the heat store and no auxiliary heating during this phase.

3.3 Determination of performance indicators

3.3.1 Final energy used

The annual final energy use shall be calculated according to[10]:

equ. 1: $$E_{aux,y} = (Q_{L,y} / Q_{L,test}) \cdot E_{aux,test} \cdot F_{system}$$

with:

- $Q_{L,y}$: annual domestic hot water and space heating load;
- $Q_{L,test}$: measured domestic hot water and space heating load during the core phase of the test;
- $E_{aux,test}$: measured final energy use during the core phase of the test;
- F_{system}: system and load dependent prediction correction.

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[9] Domestic hot water draw-off is based on European standard EN13203. However, draw-off pattern has been adapted to suit the solar combisystem test and so have the draw-off quantities. For the core phase, there are two different draw-off quantities: 140 litres and 260 litres based on 45°C domestic hot water demand temperature.

[10] Test conditions were investigated based on Q_{aux}, the heat input into the solar combisystem. However, for systems with direct auxiliary heating, Q_{aux} cannot be measured, only E_{aux} (the energy content of the fuel based on the lower heating value). That is why the final energy use is the major performance indicator for all systems. It is assumed that test conditions based on Q_{aux} also hold for E_{aux}.

The annual domestic hot water and space heating load shall be calculated according to:

equ. 2: $Q_{L,y} = Q_{L,DHW,y} + Q_{L,SH,y}$

with:

$Q_{L,DHW,y}$: annual domestic hot water load;
$Q_{L,SH,y}$: annual space heating load.

Values for $Q_{L,DHW,y}$ and $Q_{L,SH,y}$ have been listed in Table 3[11].

Table 3: Annual domestic hot water and space heating loads the SFH60 and SFH100 reference houses in climate zone II.

$Q_{L,DHW,y}$ [GJ/year]	$Q_{L,SH,y}$ [GJ/year]	
	SFH60 house	SFH100 house
10.77	30.76	51.27

The prediction correction for the SFH60 reference house is [6]:

equ. 3: $F_{system} = 0.00615 \cdot V_s - 0.0538 \cdot V_s/A_c + 0.973$

and for the SFH100 reference house:

equ. 4: $F_{system} = 0.0015 \cdot V_s$

3.3.2 Parasitic electricity use

The annual parasitic electricity used for pumps and control is the second performance indicator that shall be calculated according to:

equ. 5: $W_{par,y} = 365 / 6 \cdot W_{par,test}$

with:

$W_{par,test}$: measured parasitic energy use during the core phase of the test.

[11] For all climates and reference houses, values for $Q_{L,DHW,y}$ and $Q_{L,SH,y}$ would be as follows:

Climate zone	$Q_{L,DHW,y}$ [GJ/year]	$Q_{L,SH,y}$ [GJ/year]		
		SFH30 house	SFH60 house	SFH100 house
I	11.14	22.48	43.78	70.96
II	10.77	15.50	30.76	51.27
III	9.61	5.63	12.90	24.87

4 Outlook and recommendations

The presented test method is intended to be passed on to CEN as work item for Technical Committee 312 on thermal solar components and systems. However, definition of such a work item means that:

- there is a clear document to work on;
- there is a prospect of having an EN or ENV (standard or draft standard) within 3 to 5 years;
- there should be sufficient support from industry.

For the DC test method, presently, this time has not come yet as:

- more practical experience is needed with DC testing;
- the DC test method should be validated against CTSS;
- industry should confirm the need for solar combisystem testing and elaborating the present work into a standard.

After that, the work item can be presented to CEN. Still open then, is what the work item should contain, probably CTSS and DC but maybe more.

5 References

[1] CEN, Thermal solar systems and components - Factory made systems - Part 2: Test methods, EN 12976-2, National standardisation bodies, 2001.

[2] CEN, Thermal solar systems and components - Custom built systems - Part 2: Test methods ENV 12977-2, National standardisation bodies, 2001.

[3] Bales, C. Combitest - initial development of the AC/DC test method. Technical report IEA SHC - Task 26, Chalmers University of Thechnology, Göteborg, Sweden, October 2002.

[4] Vogelsanger, P. The Concise Cycle Test method - a twelve day system test. Technical report IEA SHC - Task 26, SPF, Rapperswil, Switzerland, November 2002.

[5] Drück, H. and S. Bachmann. Performance testing of solar combisytems - comparison of the CTSS and ACDC test procedure. Technical report IEA SHC - Task 26, ITW, Stuttgart, Germany, November 2002.

[6] Naron, D. and H. Visser. Development of the Direct Characterisation test procedure for solar combisystems. Technical report IEA SHC - Task 26, TNO Building and Construction Research, Delft, the Netherlands, December 2002.

6 Appendix A: TEST CONDITIONS FOR THE SECOND DAY OF THE SECONDARY CONDITIONING PHASE AND THE SIX DAYS OF THE CORE PHASE

6.1 Second day of the secondary conditioning phase

Table A1: Test conditions for climate zone II and domestic hot water and space heating loads for the SFH60 reference house during the second day of the secondary conditioning phase.

	Climate		DHW draw-off	Space heating			
t [h]	G_t [W/m^2]	$T_{c,a}$ [°C]	Q_{DHW} [MJ]	$\dot{V}_{SH,ref}$ [litres/hour]	$T_{f,SH,ref}$ [°C]	$T_{r,SH,ref}$ [°C]	Q_{SH} [MJ]
24	0	-1.1	0	342	35.3	27.9	10.58
25	0	-1.5	0	356	35.2	28	10.73
26	0	-0.6	0	367	35.1	28.2	10.59
27	0	-0.2	0	382	34.7	28.2	10.37
28	0	0.1	0	396	34.5	28.2	10.43
29	0	0.6	0	410	34.3	28.3	10.29
30	0	0.9	0	425	34	28.3	10.12
31	0	1.3	7.38	414	33.8	28.2	9.69
32	75	2	0	338	33.5	27.7	8.20
33	313	2.3	0	173	33.2	26	5.20
34	434	3.1	2.11	130	32.9	24.3	4.66
35	417	4.4	0	148	32.3	23.7	5.31
36	353	5.9	2.95	162	31.4	23.7	5.21
37	543	7.3	0	54	30.5	22.6	1.78
38	453	8.3	0	43	29.8	21.4	1.52
39	404	8.9	0	0	29.3	20.5	0.00
40	54	7.7	0	104	29.5	21.3	3.58
41	0	7.1	0	205	30	22.8	6.18
42	0	6.5	1.69	212	30.4	23.9	5.77
43	0	7	0	227	30.4	24.3	5.78
44	0	6.8	8.64	241	30.3	24.5	5.85
45	0	7.6	6.75	256	30.2	24.7	5.88
46	0	7.3	0	270	30	24.8	5.87
47	0	7.9	0	306	29.9	25.1	6.14

Table A2: Test conditions for climate zone II and domestic hot water and space heating loads for the SFH100 reference house during the second day of the secondary conditioning phase.

	Climate		DHW draw-off	Space heating			
t [h]	G_t [W/m^2]	$T_{c,a}$ [°C]	Q_{DHW} [MJ]	$\dot{V}_{SH,ref}$ [litres/hour]	$T_{f,SH,ref}$ [°C]	$T_{r,SH,ref}$ [°C]	Q_{SH} [MJ]
24	0	2.9	0	227	45.5	32.9	11.95

25	0	2.4	0	227	45.9	33	12.23
26	0	2.5	0	227	46.1	33.2	12.23
27	0	1.7	0	230	46.5	33.4	12.62
28	0	1.8	0	230	46.9	33.6	12.81
29	0	1.6	0	230	47	33.7	12.81
30	0	1.2	0	234	47.3	33.9	13.11
31	0	0.5	7.38	234	48	34.1	13.60
32	15	1.4	0	230	47.9	34.2	13.19
33	44	2.2	0	223	46.9	33.9	12.13
34	315	3.7	2.11	158	45.5	32.3	8.74
35	621	5.8	0	79	43.3	29.2	4.67
36	688	7.4	2.95	58	41.1	26.2	3.59
37	425	8	0	101	39.7	25.3	6.07
38	261	8	0	126	39.3	25.9	7.06
39	288	8.3	0	79	39.1	25.6	4.47
40	124	7.7	0	68	39.3	24.5	4.23
41	6	6.5	0	162	40.4	25.9	9.82
42	0	5	1.69	166	42.1	28	9.76
43	0	3.6	0	169	43.9	29.1	10.47
44	0	3.4	8.64	169	44.8	29.9	10.54
45	0	2.6	6.75	173	45.4	30.4	10.83
46	0	2.6	0	176	45.9	30.8	11.13
47	0	2.1	0	180	46.2	31.1	11.36

Remarks and further test conditions as addition to Tables A1 and A2:

- Start time indicates the start of the prescribed test conditions. Irradiance, ambient temperature and surrounding air velocity continue for the whole time interval between two start times. The same applies to the test conditions for space heating. Test conditions for domestic hot water draw-off are valid for the time needed to fulfil the requirements with respect to the discharged energies.
- Surrounding ambient air velocity is 1.0 m/s.
- Mains temperature is 9.7°C.
- Domestic hot water volume flow rate is 600 l/h.
- Discharged energy to domestic hot water has been calculated as follows: mass of domestic hot water x specific heat x 35.3 where the latter value has been specified as 35.3 = 45 – 9.7 with 9.7°C the yearly average value of mains temperature in climate zone II. Discharged energy shall be delivered at a temperature of at least 45°C.

6.2 Six days of the core phase

Table A3: Test conditions for climate zone II and domestic hot water and space heating loads for the SFH60 reference house during the six days of the core phase.

		Climate		DHW draw-off	Space heating			
t [h]	*Type of day; type of DHW draw-off*	G_t [W/m²]	$T_{c,a}$ [°C]	Q_{DHW} [MJ]	$\dot{V}_{SH,ref}$ [litres/hour]	$T_{f,SH,ref}$ [°C]	$T_{r,SH,ref}$ [°C]	Q_{SH} [MJ]
48	W;L	0	-1	0	216	35.1	25.5	8.67
49	W;L	0	-1.4	0	227	35.2	25.8	8.91
50	W;L	0	-0.6	0	234	35.1	26	8.90

51	W;L	0	-0.4	0	245	34.8	26.1	8.90
52	W;L	0	-0.4	0	256	34.7	26.3	8.97
53	W;L	0	-1.3	0	266	35	26.5	9.47
54	W;L	0	-1.3	0	274	35.2	26.7	9.72
55	W;L	0	-0.5	8.06	259	35	26.7	8.99
56	W;L	77	0	1.45	220	34.6	26.2	7.71
57	W;L	53	1	0	241	34.2	25.9	8.37
58	W;L	122	2	2.07	212	33.6	25.6	7.10
59	W;L	124	3.7	0	209	32.8	25.2	6.63
60	W;L	344	4.7	2.89	133	32	24.2	4.34
61	W;L	449	6	0	90	31.3	23	3.12
62	W;L	366	6.7	0	97	30.7	22.3	3.41
63	W;L	230	6.4	1.03	126	30.6	22.3	4.37
64	W;L	123	5.9	0	158	30.8	22.9	5.23
65	W;L	14	5.3	0	212	31.2	23.8	6.57
66	W;L	0	4.7	1.65	220	31.5	24.4	6.52
67	W;L	0	4.6	0	227	31.7	24.7	6.64
68	W;L	0	4	3.51	238	31.9	25	6.85
69	W;L	0	3.1	0	245	32.4	25.2	7.37
70	W;L	0	2.9	0	248	32.7	25.5	7.48
71	W;L	0	2.5	0	274	32.9	25.8	8.12
72	S/A;L	0	8.6	0	281	29.5	24.7	5.63
73	S/A;L	0	8.8	0	288	29.2	24.7	5.42
74	S/A;L	0	8.2	0	302	29.3	24.8	5.69
75	S/A;L	0	7.5	0	310	29.7	25	6.08
76	S/A;L	0	7.6	0	313	29.9	25.2	6.15
77	S/A;L	0	7.5	0	320	29.9	25.3	6.16
78	S/A;L	0	7.3	0	324	30	25.4	6.23
79	S/A;L	75	7.3	8.06	250	30.1	25.1	4.74
80	S/A;L	387	7.2	1.45	0	30.1	22	0.49
81	S/A;L	604	7.5	0	0	30.1	20.5	0
82	S/A;L	519	8.6	2.07	0	29.6	20.4	0
83	S/A;L	620	9.7	0	0	28.9	20.5	0
84	S/A;L	805	10.3	2.89	0	28.3	20.8	0
85	S/A;L	804	12.4	0	0	27.4	21	0
86	S/A;L	552	12.4	0	0	26.7	21.1	0
87	S/A;L	352	12.8	1.03	0	26.6	21	0
88	S/A;L	100	13.4	0	0	26.2	20.9	0
89	S/A;L	0	11.9	0	0	26.5	20.6	0
90	S/A;L	0	10.9	1.65	0	27.4	20.5	0
91	S/A;L	0	10.2	0	0	28	20.7	0.27
92	S/A;L	0	9.6	3.51	45	28.4	20.5	1.21
93	S/A;L	0	9.5	0	59	28.6	20.7	1.96
94	S/A;L	0	9	0	75	28.8	21	2.43
95	S/A;L	0	8.5	0	108	29.2	21.5	3.46
96	S;L	0	16.9	0	0	26.1	25.2	0
97	S;L	0	16.4	0	0	26.4	25.1	0
98	S;L	0	15.1	0	0	27	25	0
99	S;L	0	14.4	0	0	27.4	24.9	0
100	S;L	0	13.5	0	0	27.7	24.8	0
101	S;L	19	12.4	0	0	27.7	24.9	0
102	S;L	91	12.3	0	0	27.2	25	0
103	S;L	185	12.8	8.06	0	26.8	25.1	0

104	S;L	255	14.2	1.45	0	26.5	25.2	0
105	S;L	541	15.4	0	0	26	25.3	0
106	S;L	776	16.7	2.07	0	25.4	25.5	0
107	S;L	939	18.9	0	0	24.3	25.6	0
108	S;L	776	21.4	2.89	0	22.8	25.7	0
109	S;L	773	22.3	0	0	21.4	25.9	0
110	S;L	577	23.6	0	0	20.3	26	0
111	S;L	438	24.5	1.03	0	20	26.1	0
112	S;L	219	24.5	0	0	20	26.2	0
113	S;L	164	23.8	0	0	20.6	26.2	0
114	S;L	64	23.5	1.65	0	22	26.2	0
115	S;L	26	22.3	0	0	23.4	26.1	0
116	S;L	0	20.3	3.51	0	25.2	25.9	0
117	S;L	0	18.7	0	0	26.8	25.7	0
118	S;L	0	17.8	0	0	27.8	25.6	0
119	S;L	0	16.2	0	0	28.8	25.4	0
120	S;H	0	13.2	0	0	24.8	24.7	0
121	S;H	0	13.4	0	0	25	24.6	0
122	S;H	0	13.5	0	0	25.3	24.5	0
123	S;H	0	13.5	0	0	25.6	24.4	0
124	S;H	0	12.1	0	0	25.8	24.4	0
125	S;H	0	11.9	0	0	25.8	24.3	0
126	S;H	41	12	0	0	25.6	24.4	0
127	S;H	161	12.5	13.43	0	25.1	24.6	0
128	S;H	272	13.3	1.49	0	24.2	24.7	0
129	S;H	345	14.3	0	0	23.4	24.8	0
130	S;H	374	14.9	2.13	0	22.9	24.9	0
131	S;H	560	16	0	0	22.2	24.9	0
132	S;H	358	16.9	2.98	0	21	24.9	0
133	S;H	407	18.5	0	0	20	25	0
134	S;H	437	18.7	0	0	20	25.1	0
135	S;H	226	18.8	1.07	0	20	25.2	0
136	S;H	155	19.3	0	0	20.2	25.3	0
137	S;H	32	19.1	0	0	21.1	25.1	0
138	S;H	20	19.2	1.71	0	21.9	25	0
139	S;H	0	17.4	0	0	22.7	24.9	0
140	S;H	0	16.7	8.74	0	23.1	24.8	0
141	S;H	0	16	6.82	0	23.5	24.8	0
142	S;H	0	15.8	0	0	23.8	24.7	0
143	S;H	0	15.1	0	0	23.8	24.6	0
144	S/A;H	0	8.3	0	119	29.5	22	3.74
145	S/A;H	0	8.1	0	126	29.7	22.2	3.94
146	S/A;H	0	7.8	0	131	29.7	22.4	4.01
147	S/A;H	0	8	0	140	30	22.6	4.34
148	S/A;H	0	6.9	0	146	30.2	22.8	4.51
149	S/A;H	0	7.3	0	152	30.2	22.9	4.64
150	S/A;H	37	6.8	0	139	30.6	23	4.40
151	S/A;H	63	6.2	13.43	105	30.6	22.6	3.53
152	S/A;H	149	6.9	1.49	68	30.2	21.8	2.38
153	S/A;H	155	7.2	0	79	30.2	21.3	2.54
154	S/A;H	358	7.1	2.13	0	29.9	20.6	0.41
155	S/A;H	381	8.2	0	0	29.2	20.2	0

156	S/A;H	346	9.3	2.98	0	28.7	20.3	0
157	S/A;H	208	9.7	0	0	28.6	20.2	0
158	S/A;H	65	9.6	0	55	28.4	20.4	1.30
159	S/A;H	157	10.1	1.07	0	28.4	20.3	0.55
160	S/A;H	211	9.8	0	0	28.4	20.2	0.11
161	S/A;H	73	9.9	0	42	28.4	20.3	1.43
162	S/A;H	7	9.8	1.71	77	28.8	20.7	2.60
163	S/A;H	0	8.9	0	96	29.6	21.2	3.36
164	S/A;H	0	7.2	8.74	106	30.3	21.7	3.80
165	S/A;H	0	6.8	6.82	114	30.8	22	4.21
166	S/A;H	0	5.6	0	121	31.2	22.3	4.49
167	S/A;H	0	5.6	0	146	31.3	22.7	5.25
168	W;H	0	-2.2	0	277	35.7	27.1	9.96
169	W;H	0	-2.9	0	281	35.9	27.2	10.21
170	W;H	0	-2.9	0	284	36.1	27.4	10.34
171	W;H	0	-3.2	0	288	36.2	27.5	10.47
172	W;H	0	-2.4	0	292	36.1	27.5	10.48
173	W;H	0	-2.6	0	295	35.9	27.5	10.37
174	W;H	0	-2.2	0	302	35.8	27.6	10.37
175	W;H	0	-2.2	13.43	284	35.7	27.5	9.75
176	W;H	4	-2.4	1.49	292	35.8	27.4	10.24
177	W;H	24	-1.5	0	288	35.6	27.4	9.87
178	W;H	126	-1.7	2.13	248	35.4	26.9	8.83
179	W;H	235	-1.1	0	205	35.3	26.2	7.81
180	W;H	368	0.4	2.98	155	34.7	25.1	6.21
181	W;H	334	1.6	0	151	33.9	24.3	6.07
182	W;H	186	1.7	0	191	33.5	24.5	7.18
183	W;H	100	1.5	1.07	220	33.5	25	7.80
184	W;H	23	2	0	245	33.5	25.5	8.19
185	W;H	0	1.2	0	263	33.5	25.9	8.35
186	W;H	0	0	1.71	263	34.1	26.2	8.68
187	W;H	0	-0.4	0	266	34.6	26.4	9.13
188	W;H	0	-0.6	8.74	270	34.8	26.6	9.25
189	W;H	0	-1.5	6.82	274	35.1	26.8	9.49
190	W;H	0	-1.6	0	277	35.4	27	9.73
191	W;H	0	-2	0	302	35.5	27.3	10.37

Table A4: Test conditions for climate zone II and domestic hot water and space heating loads for the SFH100 reference house during the six days of the core phase.

		Climate		DHW draw-off	Space heating			
t [h]	*Type of day; type of DHW draw-off*	G_t [W/m^2]	$T_{c,a}$ [°C]	Q_{DHW} [MJ]	$\dot{V}_{SH,ref}$ [l/h]	$T_{f,SH,ref}$ [°C]	$T_{r,SH,ref}$ [°C]	Q_{SH} [MJ]
48	W;L	0	-1	0	166	50.2	31.4	13.01
49	W;L	0	-1.4	0	169	50.3	31.8	13.08
50	W;L	0	-0.6	0	173	50.1	32.1	13.00
51	W;L	0	-0.4	0	184	49.5	32.3	13.20
52	W;L	0	-0.4	0	187	49.4	32.6	13.15
53	W;L	0	-1.3	0	194	49.9	32.9	13.81
54	W;L	0	-1.3	0	198	50.4	33.3	14.15
55	W;L	0	-0.5	8.06	202	50	33.5	13.90

56	W;L	77	0	1.45	180	49.2	33.1	12.11
57	W;L	53	1	0	198	48.4	32.8	12.91
58	W;L	122	2	2.07	187	47.2	32.5	11.50
59	W;L	124	3.7	0	187	45.6	31.9	10.72
60	W;L	344	4.7	2.89	151	44	30.8	8.34
61	W;L	449	6	0	126	42.6	29.2	7.06
62	W;L	366	6.7	0	133	41.4	28.2	7.35
63	W;L	230	6.4	1.03	155	41.1	28.2	8.35
64	W;L	123	5.9	0	176	41.6	28.8	9.44
65	W;L	14	5.3	0	212	42.3	30	10.92
66	W;L	0	4.7	1.65	216	43	31	10.83
67	W;L	0	4.6	0	223	43.5	31.6	11.10
68	W;L	0	4	3.51	230	43.9	32	11.46
69	W;L	0	3.1	0	234	44.8	32.5	12.03
70	W;L	0	2.9	0	234	45.4	32.9	12.23
71	W;L	0	2.5	0	238	45.8	33.2	12.51
72	S/A;L	0	8.6	0	266	38.9	31.1	8.69
73	S/A;L	0	8.8	0	277	38.4	31	8.57
74	S/A;L	0	8.2	0	284	38.7	31.1	9.03
75	S/A;L	0	7.5	0	284	39.5	31.4	9.63
76	S/A;L	0	7.6	0	284	39.9	31.7	9.75
77	S/A;L	0	7.5	0	284	39.9	31.8	9.63
78	S/A;L	0	7.3	0	288	40.1	31.9	9.87
79	S/A;L	75	7.3	8.06	238	40.2	31.8	8.34
80	S/A;L	387	7.2	1.45	86	40.2	29.2	3.97
81	S/A;L	604	7.5	0	0	40.1	25.5	1.32
82	S/A;L	519	8.6	2.07	82	39.2	23.3	3.59
83	S/A;L	620	9.7	0	0	37.8	22.3	1.63
84	S/A;L	805	10.3	2.89	0	36.7	21	0.21
85	S/A;L	804	12.4	0	0	34.9	20.6	0
86	S/A;L	552	12.4	0	0	33.4	20.6	0
87	S/A;L	352	12.8	1.03	0	33.2	20.5	0
88	S/A;L	100	13.4	0	0	32.4	20.5	0.02
89	S/A;L	0	11.9	0	59	33.1	21.3	2.89
90	S/A;L	0	10.9	1.65	82	34.8	22.3	4.29
91	S/A;L	0	10.2	0	95	36	23.3	5.03
92	S/A;L	0	9.6	3.51	103	36.8	24.2	5.44
93	S/A;L	0	9.5	0	109	37.3	24.8	5.72
94	S/A;L	0	9	0	116	37.7	25.3	6.01
95	S/A;L	0	8.5	0	122	38.3	25.8	6.38
96	S;L	0	16.9	0	0	26.1	25.2	0
97	S;L	0	16.4	0	0	26.4	25.1	0
98	S;L	0	15.1	0	0	27	25	0
99	S;L	0	14.4	0	0	27.4	24.9	0
100	S;L	0	13.5	0	0	27.7	24.8	0
101	S;L	19	12.4	0	0	27.7	24.9	0
102	S;L	91	12.3	0	0	27.2	25	0
103	S;L	185	12.8	8.06	0	26.8	25.1	0
104	S;L	255	14.2	1.45	0	26.5	25.2	0
105	S;L	541	15.4	0	0	26	25.3	0
106	S;L	776	16.7	2.07	0	25.4	25.5	0
107	S;L	939	18.9	0	0	24.3	25.6	0
108	S;L	776	21.4	2.89	0	22.8	25.7	0

109	S;L	773	22.3	0	0	21.4	25.9	0
110	S;L	577	23.6	0	0	20.3	26	0
111	S;L	438	24.5	1.03	0	20	26.1	0
112	S;L	219	24.5	0	0	20	26.2	0
113	S;L	164	23.8	0	0	20.6	26.2	0
114	S;L	64	23.5	1.65	0	22	26.2	0
115	S;L	26	22.3	0	0	23.4	26.1	0
116	S;L	0	20.3	3.51	0	25.2	25.9	0
117	S;L	0	18.7	0	0	26.8	25.7	0
118	S;L	0	17.8	0	0	27.8	25.6	0
119	S;L	0	16.2	0	0	28.8	25.4	0
120	S;H	0	13.2	0	0	24.8	24.7	0
121	S;H	0	13.4	0	0	25	24.6	0
122	S;H	0	13.5	0	0	25.3	24.5	0
123	S;H	0	13.5	0	0	25.6	24.4	0
124	S;H	0	12.1	0	0	25.8	24.4	0
125	S;H	0	11.9	0	0	25.8	24.3	0
126	S;H	41	12	0	0	25.6	24.4	0
127	S;H	161	12.5	13.43	0	25.1	24.6	0
128	S;H	272	13.3	1.49	0	24.2	24.7	0
129	S;H	345	14.3	0	0	23.4	24.8	0
130	S;H	374	14.9	2.13	0	22.9	24.9	0
131	S;H	560	16	0	0	22.2	24.9	0
132	S;H	358	16.9	2.98	0	21	24.9	0
133	S;H	407	18.5	0	0	20	25	0
134	S;H	437	18.7	0	0	20	25.1	0
135	S;H	226	18.8	1.07	0	20	25.2	0
136	S;H	155	19.3	0	0	20.2	25.3	0
137	S;H	32	19.1	0	0	21.1	25.1	0
138	S;H	20	19.2	1.71	0	21.9	25	0
139	S;H	0	17.4	0	0	22.7	24.9	0
140	S;H	0	16.7	8.74	0	23.1	24.8	0
141	S;H	0	16	6.82	0	23.5	24.8	0
142	S;H	0	15.8	0	0	23.8	24.7	0
143	S;H	0	15.1	0	0	23.8	24.6	0
144	S/A;H	0	10.8	0	108	36.3	24.6	5.28
145	S/A;H	0	9.8	0	112	37	25	5.60
146	S/A;H	0	9.8	0	115	37.2	25.3	5.73
147	S/A;H	0	9.5	0	122	37.6	25.6	6.14
148	S/A;H	0	9.1	0	126	38.1	25.9	6.43
149	S/A;H	0	8.8	0	130	38.1	26.2	6.45
150	S/A;H	2	9.1	0	133	38.1	26.4	6.51
151	S/A;H	85	8.8	13.43	104	37.9	26.1	5.15
152	S/A;H	201	9.3	1.49	72	37.5	25	3.76
153	S/A;H	97	9.5	0	101	37.4	24.6	5.39
154	S/A;H	331	9.5	2.13	74	37	23.8	2.38
155	S/A;H	359	10	0	0	36.2	22.2	1.69
156	S/A;H	131	10.7	2.98	72	36	22.2	4.15
157	S/A;H	22	10.4	0	104	36.4	23.3	5.72
158	S/A;H	140	10.1	0	68	36.2	23.6	3.60
159	S/A;H	133	10.7	1.07	68	36	23.2	3.66
160	S/A;H	162	10.4	0	61	36.2	22.9	3.40

161	S/A;H	51	10.4	0	68	36.2	22.8	3.83
162	S/A;H	0	10.4	1.71	101	36.8	23.6	5.56
163	S/A;H	0	9.5	0	108	37.8	24.5	6.00
164	S/A;H	0	8.8	8.74	112	38.8	25.2	6.34
165	S/A;H	0	8	6.82	115	39.6	25.7	6.69
166	S/A;H	0	7.5	0	119	40.1	26.1	6.95
167	S/A;H	0	7.2	0	122	40.6	26.5	7.21
168	W;H	0	-9.5	0	205	60.2	37.2	19.73
169	W;H	0	-8.5	0	212	58.9	37.3	19.18
170	W;H	0	-7.9	0	223	58.1	37.5	19.22
171	W;H	0	-7.7	0	230	57.6	37.7	19.17
172	W;H	0	-7.1	0	238	57.2	38	19.07
173	W;H	0	-7	0	248	56.8	38.2	19.31
174	W;H	0	-6.5	0	256	56.5	38.5	19.23
175	W;H	7	-5.2	13.43	263	55.5	38.6	18.56
176	W;H	70	-3.8	1.49	263	54	38.2	17.36
177	W;H	103	-3.2	0	266	52.9	37.8	16.81
178	W;H	152	-1.9	2.13	259	51.9	37.3	15.82
179	W;H	172	-0.3	0	263	50.2	36.6	14.94
180	W;H	232	1.3	2.98	256	48.4	35.8	13.46
181	W;H	330	2.3	0	248	46.9	34.9	12.46
182	W;H	196	3.1	0	274	45.8	34.5	12.92
183	W;H	121	4.6	1.07	302	44.4	34.6	12.39
184	W;H	70	5.4	0	342	43	34.6	12.01
185	W;H	4	6.4	0	389	41.9	34.7	11.70
186	W;H	0	6.6	1.71	421	41.2	34.7	11.44
187	W;H	0	7.2	0	450	40.7	34.7	11.29
188	W;H	0	7.6	8.74	482	40.1	34.6	11.09
189	W;H	0	7.5	6.82	511	39.9	34.6	11.33
190	W;H	0	7.9	0	533	39.7	34.7	11.14
191	W;H	0	8.3	0	562	39.2	34.6	10.80

Remarks and further test conditions as addition to Tables A3 and A4:

- Start time indicates the start of the prescribed test conditions. Irradiance, ambient temperature and surrounding air velocity continue for the whole time interval between two start times. The same applies to the test conditions for space heating. Test conditions for domestic hot water draw-off are valid for the time needed to fulfil the requirements with respect to the discharged energies.
- Type of day refers to winter (W), spring/autumn (S/A) and summer (S) days.
- Type of domestic hot water draw-off refers to low daily quantity (L = 140 litres of (45-9.7)°C per day) or high daily quantity (H= 260 litres of (45-9.7)°C per day).
- Surrounding ambient air velocity is 1.0 m/s.
- Mains temperature is 9.7°C. This temperature has been derived from mains water temperature data available for climate zone II. Course of mains temperature has a sinus shape around yearly average values of 9.7°C; amplitude is 6.3 K. For the simplicity of the test procedure the mains temperature has been set to the yearly average: 9.7°C.
- Domestic hot water volume flow rate is 600 l/h.
- Discharged energy to domestic hot water has been calculated as follows: mass of domestic hot water x specific heat x 35.3 where the latter value has been specified as 35.3 = 45 – 9.7 with 9.7°C the yearly average value of mains temperature in climate zone II. Discharged energy shall be delivered at a temperature of at least 45°C.