New Generation of Solar Thermal Systems

WP4.4. COMBI SYSTEMS – INTEGRATED OR EXTERNAL BOILER

January 2007

CONTENTS

SUMMARY (ARIAL 12, BOLD)

Side-by-side measurements of the REBUS and the SolvisMax SX-655 solar combi systems are described. Both systems use a condensing gas boiler as auxiliary energy supply system. In one system, the gas boiler is build into the hot water storage tank. The other system uses an external gas boiler.

1. Introduction

The document will describe laboratory tests carried out at the Technical University of Denmark on two solar combisystems, one with an integrated boiler and one with an external boiler.

2. Side-by-side measurements of the REBUS and the SolvisMax SX-655 solar combi systems.

The REBUS system is described in detail in /1/. The condensing gas boiler is a Nefit Milton Smartline HR 24 from the Danish company Milton A/S. The boiler is modulating in the interval from 5.7 kW to 23 kW for space heating load and to 28.5 kW for domestic hot water preparation. Figure 1 shows the design of the compact solar combi system units consisting of a technical unit and a hot water storage tank unit and the hydraulic scheme of the system. The volume of the hot water tank is 300 l. The boiler uses the upper 70-80 l.

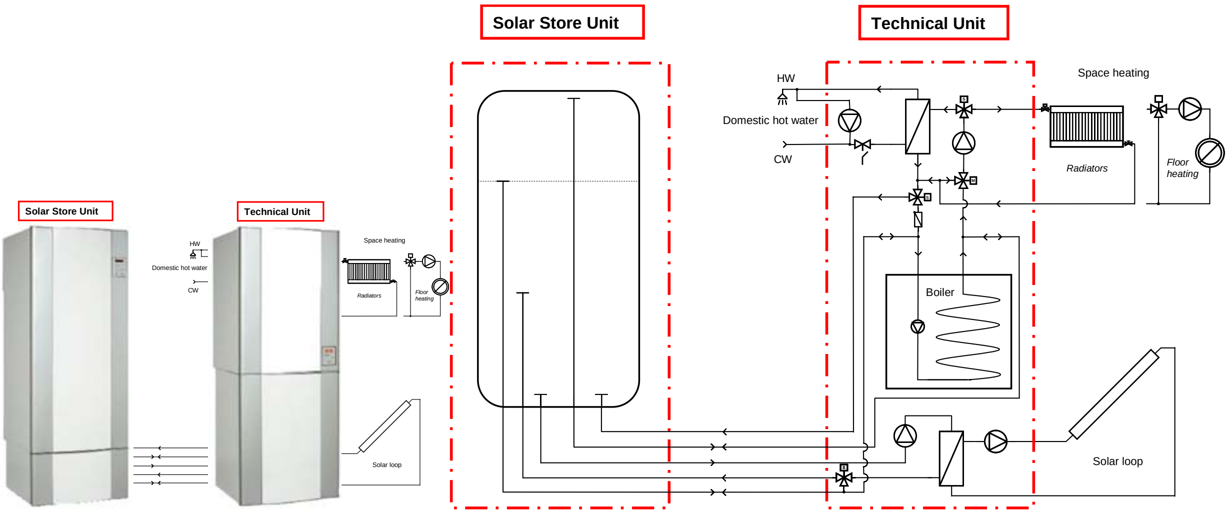

Figure 1 **Right**: Design of the compact solar combi system as two 60 x 60 cm units: On the left side a solar tank and on the right side the prefabricated technical unit with integrated condensing natural gas boiler or pellet boiler and all the other components like pumps, switching valves, mixing valves, expansion vessels, plate heat exchanger, controller, etc. **Right**: Hydraulic scheme of the REBUS solar combi system. Figures from /1/.

The SolvisMax system has an integrated gas boiler which is modulating in the interval 5 kW to 20 kW. The total tank volume is 635 l. The upper 136 l are used for heating of domestic hot water. 30 l are reserved for space heating. The remaining 469 litres are reserved for the solar collectors. Figure 2 shows schematic illustration of the heat storage tank of the SolvisMax system and the positions of the temperature sensors used for the investigations.

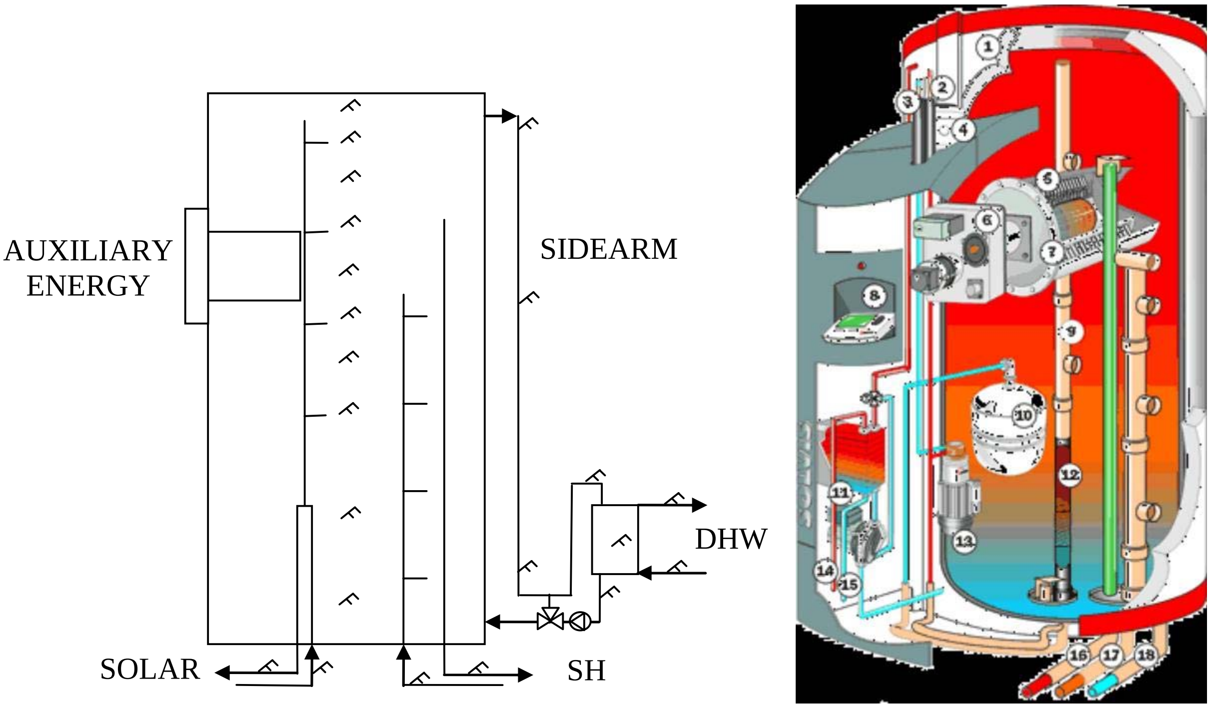

Figure 2 The heat storage tank of the SolvisMax system.

Side-by-side measurements of the two systems have been carried out in the test laboratory at the Department of Civil Engineering at the Technical University of Denmark. The SolvisMax system has an auxiliary volume for heating of domestic hot water. Hence the temperature in the top of the SolvisMax tank is kept at a constant high temperature level regardless of the temperature level in the space heating system. The REBUS system does not have an auxiliary volume for domestic hot water. Hence the temperature in the top of the REBUS tank is only a few degrees higher than the required temperature for the space heating system.

During the tests, constant space heating loads in the range from 5 kW to 10 kW were drawn from the systems. The solar collector loop and the domestic hot water draw off were not used.

Figure 3 shows a schematic illustration of the principle of the space heating system. A mixing valve determines the temperature of the water going to the space heating system (T_{flow}). The volume flow rate in the space heating system is fixed. The return temperature from the space heating system (T_{return}) results from the flow temperature to the space heating system, the volume flow rate and the size of the space heating system.

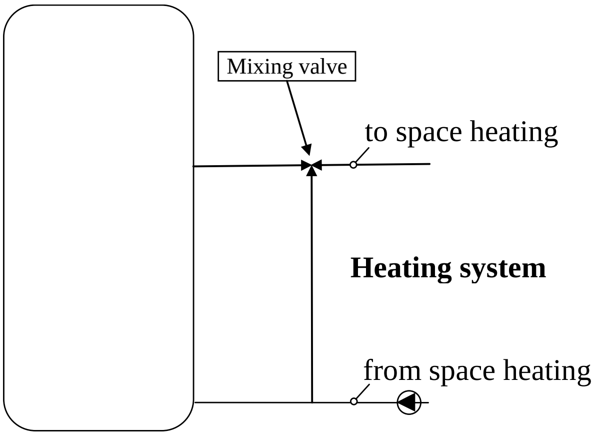

Figure 3 Schematic of the heating system.

Figure 4 and 5 show examples of the temperatures in the SolvisMax and the REBUS system during operation, respectively.
From Figure 4 it can be seen that the flow temperature is about 47ºC with a return temperature of about 25ºC. Further, it can be seen that the boiler in the SolvisMax system starts approximately two times per hour, and that the exhaust gas temperature is about 42ºC.

Figure 5 shows that the flow temperature in the REBUS system is about 46ºC when the boiler is not in operation and increases to about 52ºC when the boiler is in operation. The exhaust gas temperature is about 48ºC. The REBUS boiler starts about once every hour.

The volume reserved for space heating in the SolvisMax system is only 30 l. The space heating volume in the REBUS system is 70-80 l. This explains why the SolvisMax system has more boiler operation periods. The exhaust gas temperature is higher in the REBUS system than in the SolvisMax system because the volume flow rate going through the REBUS boiler is very high. This enables the REBUS boiler to modulate to a low power.

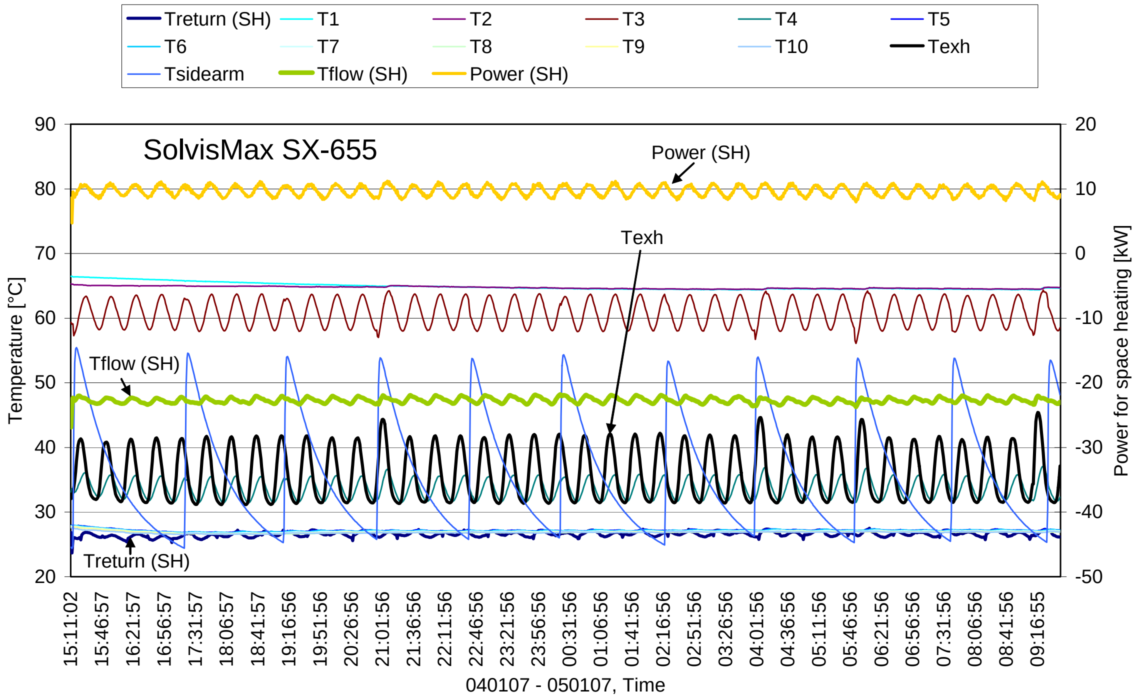

Figure 4 Temperatures in the SolvisMax system. T1-T10 show the temperatures in the storage tank from top to bottom. Tsidearm is the temperature in the side arm before the heat exchanger. The temperature in the side arm is kept hot (>25ºC) by the pump in the side arm. The explanation for this strategy is that the pump during a domestic hot water draw off is activated by a sudden temperature drop.

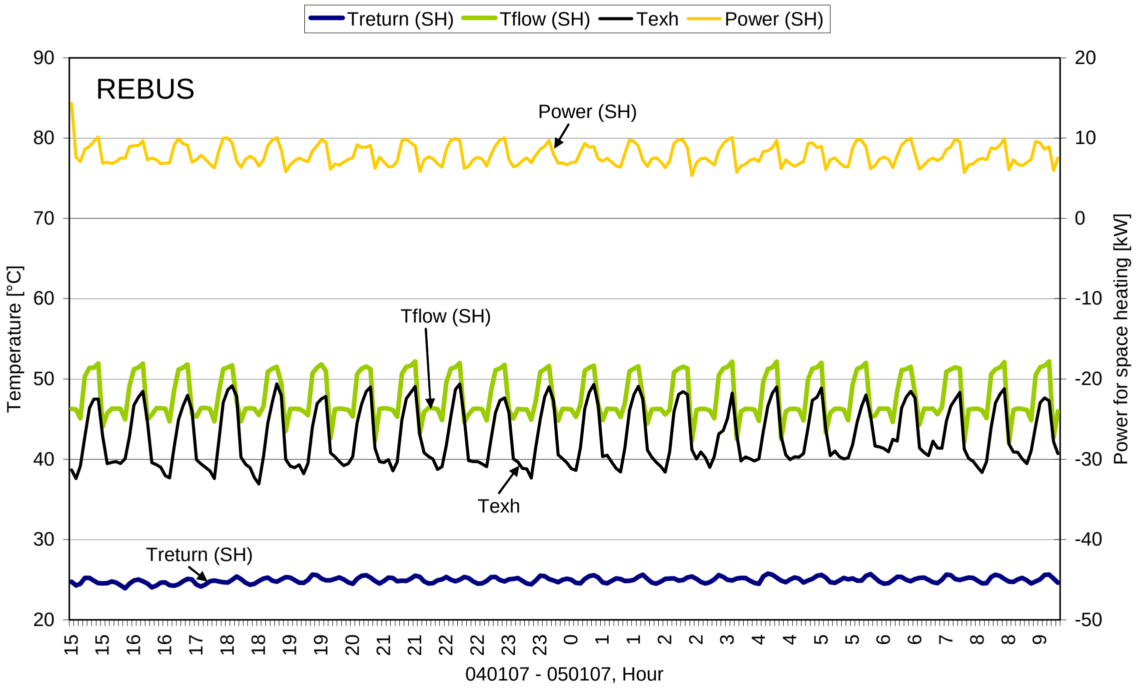

Figure 5 Temperatures in the REBUS system.

The measurements are carried for the systems operated in space heating mode with a space heating power in the interval 5-10 kW and a logarithmic mean temperature difference between the radiator and the ambient in the interval 10-25 K.
Based on the measurements, the system efficiencies are determined. The system efficiency is defined as: The energy amount supplied to the space heating system / Energy of the gas consumption.

The lower heating value of 11.02 kWh/nm^3 is used to determine the energy of the gas. The average system efficiencies are measured to 106% for the REBUS system and 105% for the SolvisMax system. The space heating power and the mean radiator temperature do not influence the system efficiency.

In /3/ the system efficiency for the SolvisMax system operated in space heating mode was measured to about106%.

In /2/ the maximum boiler efficiency of the boiler operated in space heating mode, excluding the tank, was measured to about 108%. The uncertainty of the measurements was stated to be 3%.

The measured results correspond very well to the results from the previous investigations /2,3/.

3. Conclusions

Preliminary side-by-side measurements of the REBUS and the SolvisMax XS-655 solar combi systems show that the system efficiencies for the systems operated in space heating mode is very high. The results indicate that it is possible to reach high system efficiencies with good solar combi system designs both with an integrated boiler and with an external boiler.

Further measurements should include periods with:

- Space heating load with a power in the range from 0-5 kW.
- Space heating load and domestic hot water load.
- Domestic hot water load without space heating load.

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References

/1/	Thür A., Furbo S., Fiedler F., Bales C., 2006. Development of a compact solar combisystem. European Solar Energy Congress EuroSun 2006, Glasgow, Scotland
/2/	Milton SmartLine HR24 Test Report – 726.62 – NE05, August 2004.
/3/	Solar Combisystems, Task 26. Industry Workshop, Oslo, Norway, April 8, 2002.

WP4-D2.4.b

NEW METHOD FOR CALCULATING THE PERFORMANCE OF COMBISYSEMS

Dissemination level: Public

Author: Markus Peter
Reviewer: Harald Drück
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CONTENTS

This document describes a new method for calculating the energy performance of solar domestic hot water and solar combisystems. The method is an alternative to the one that is currently used in the EN 15316-4-3 (Heating systems for buildings - Method for calculation of system energy requirements and system efficiencies - Part 2.2.3 Heat generation systems, thermal solar systems)
This standard series EN 15316 is established in the framework of the European Building Performance Directive, EPBD.

SUMMARY

The goal of the work described in this report was to develop an analytical calculation method for the system output of solar domestic hot water (DHW) systems and solar combisystems. The calculation procedure is intended to is an alternative to the one that is currently used in the EN 15316-4-3 (Heating systems for buildings - Method for calculation of system energy requirements and system efficiencies - Part 2.2.3 Heat generation systems, thermal solar systems). The standard series EN 5316 is established on the basis of the Energy Performance of Buildings Directive (EPBD, Council Directive 2002/91/EC). Beside others, the directive aims to use solar energy for domestic hot water preparation and space heating with the goal to save primary energy and hence to reduce CO_2 emissions.

In the first stage of the introduced method solar gains were determined by system simulations performed for DHW systems and combisystems for three climatic zones within Europe, using TRNSYS[1]. For Stockholm in Sweden, Würzburg in Germany and Madrid in Spain simulations based on the specific weather data, represented by the diffuse and the direct irradiance and the ambient temperature, a given heat load, a fixed volume of the storage tank and the collector area were carried out.

For the calculation procedure the information is restricted to monthly data of the solar radiation at the location considered, the heating load for domestic hot water preparation and optional for space heating and the collector area.

The validation of the method described hereafter showed, that for the considered cases the calculated system output lies within a bandwidth of ±40% compared to the results derived by TRNSYS simulations. In most cases the calculated system output is lower than the system output simulated with TRNSYS. This is particularly the case for systems with an output of less than 250 kWh/(m²a) and more than 450 kWh/(m²a).

With the introduced method an approach for a simple analytical estimation of the system output of thermal solar systems is available. For more accurate and detailed results system simulation might be used.

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[1] **Tran**sient **S**ystem **S**imulation Program

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Table of contents

1 Introduction

In the past years all over Europe the costs for primary energy increases significantly. In Germany, for instance, between February 2004 and February 2006 the price for natural gas increased by approx. 30 %.

Due to this and maybe because of apparent changes of the climate and weather conditions, people started to become more concerned about their consumption of fossil fuels. With regard to climatic change the Kyoto Protocol /Kyo06/ aims on a reduction of the CO_2 emissions of about at least 5% worldwide in 2012. This corresponds to a reduction of 8% at the average in the European Union, related to the CO_2 emission of the year 1990. National standards like the German DIN 4701 Part 10 /DIN00/ supports the use and the dimensioning of solar heating systems to provide domestic hot water and space heating with a minimum of CO_2 emissions.

The *Energy Performance of Buildings Directive* (EPBD, Council Directive 2002/91/EC) of the European Union aims on decreasing the use of primary energy for heating purpose of buildings by providing uniform boundary conditions regarding the maximum allowed primary energy consumption within buildings in the European Union; hence to reduce the CO_2 emission to meet the requirements of the Kyoto Protocol. One standard resulting from the implementation of the EPBD is the prEN 15316, former prEN 14335. In part 2.2.3 of the prEN 15316 thermal solar systems are implemented (The prefix “pr” means *projet*, the French expression for draft).

The standard includes virtually the whole heating technology for buildings: Part 1 deals with general questions, part 2.1 with space heating emission systems, part 2.2 with space heating generation systems and part 2.3 with space heating distribution systems.

Part 2.2.3 of prEN 15316 is comparable to the German standard DIN 4701 Part 10, but is extended to solar combisystems. Among others, prEN 15316 part 2.2.3 differs from DIN 4701 part 10 in so fare, that the energy gain of a solar system is calculated for each single month and that the used calculation algorithms have to be valid for all over Europe. All calculations within the standard have to be valid for the different climatic zones met in the European Union. Generally the system outputs are based on monthly values. The directive aims on the use of solar energy to heat up domestic hot water (DHW) and to support space heating to save primary energy and to reduce CO_2 emission. Obviously the utilisation of solar energy is most feasible in months with high solar irradiance. However, in transition periods between summer and winter beside domestic hot water preparation the irradiance is often high enough to support the space heating system.

The goal of the work presented in this report was to develop an analytical calculation procedure to estimate the amount of energy used for domestic hot water and space heating within residential buildings that can be substituted by utilization of solar energy. With the introduced procedure the monthly and annual solar gain can be calculated for locations all over Europe. To estimate the solar gains the weather data of the location were the system is considered, the actual load for domestic hot water preparation and optional for space heating and the total collector area are required. The calculation procedure ought to influence the European Standard prEN 15316 part 2.2.3 (developed as prEN 14335). As soon as the European Standard is adopted, it should be transferred into national right and e.g., in the case of Germany, replaces the German Standard DIN 4701 part 10.

To develop the calculation algorithms outlined in this report, Europe was divided into three climatic zones. For these three zones detailed calculations of typical solar systems for DHW and combisystems that supplementary support the space heating have been carried out using the simulation software TRNSYS. The aim was to specify the solar gain for both, domestic hot water and space heating. Based on simulated monthly values of the energy gain of DHW or combisystems respectively and with the aid of the hours of daylight and the amount of solar radiation, a calculation method deriving the typical system outputs of the various cases had been developed. The calculations archive results in the range of the simulated outputs using TRNSYS. Hence, at least for rough estimations system simulations might be substituted by the new method.

2 Thermal Solar Systems

The main components of typical thermal solar systems are the solar collector, the storage tank, controller equipment and a supplementary heat source. With regard to the presented calculation method two systems, mainly used in residential buildings are considered:

Domestic hot water systems
Domestic hot water systems (DHW systems) heat up domestic hot water to be tapped, e.g. for shower, hand washing and cleaning dishes.

Solar combisystems
Solar combisystems serves for domestic hot water preparation and support the space heating of a building.

3 Development of the Calculation Method

The calculation method is based on two different data sources:

- Weather data of the location the results should be valid for. These data are characteristic for the climate at the specific location and can either be artificially generated or recorded by a meteorological station.
- Solar energy gains based on system simulation. These data are representing the results from system simulations for the respective locations carried out with TRNSYS. The simulation data show a clear dependency on the location.

In the following the weather data and the system simulations used to define the combined basis to develop the calculation method are described. Derived from the simulations, data like the overall heat load, the simulated system output, the solar load ratio and the relative, simulated system output are determined.
To apply the calculation method the respective weather data and information about the DHW or solar combisystems respectively have to be considered.
As the result the calculation method constitute a correlation for annual and monthly system output for both, a solar domestic hot water and a solar combisystem.

3.1 Weather Data

For each location to be investigated, weather data representing the appropriate climatic zone have to be available. The locations investigated within the development of the calculation method were Stockholm, Würzburg and Madrid.
For investigation and the later determination of the method the following data are required:

- direct solar irradiance
- diffuse solar irradiance
- ambient air temperature

Typically these data are available in hourly time steps representing the average value within the time step. For simulation with TRNSYS, hourly time steps of the data are common. In so-called *Test Reference Years*, published by meteorological institutions as reference conditions, the irradiance is typically given in W/m² on a horizontal plane while the ambient temperature is given in degree centigrade. For the calculations beside the TRNSYS simulations, the data have to be integrated to monthly values. Figure 3-1 a) shows the monthly values of the direct solar radiation on a horizontal plane for the three locations investigated. Figure 3-1 b) shows the diffuse solar radiation for these locations. In Figure 3-1 e) the average monthly values of the ambient air temperature is plotted.

3.1.1 Calculation of weather data variables

For use within the calculation method three additional variables: the global radiation, the relative global radiation and the hours of daylight have to be calculated out of the weather data. With respect to the presented calculation method *daylight* is defined with the presence of diffuse irradiance. Of course, all direct irradiance is accounted to be daylight.

Global Solar Radiation G_{month}

The monthly global solar radiation G_{month} is calculated as the sum of direct solar radiation and diffuse solar radiation, see equation (3.1) and Figure 3-1 c).

$$G_{month} = G_{direct,\, month} + G_{diffuse,\, month} \qquad [kJ/(h\cdot K)] \qquad (3.1)$$

Relative Global Radiation $G_{month,\, rel}$

The relative monthly global solar radiation $G_{month,\, rel}$ is the monthly global solar radiation divided by the annual sum of the global solar radiation of the particular location, see Equation (3.2) and Figure 3-1 d).

$$G_{month,rel} = \frac{G_{month}}{G_{annual,\, tot}} \qquad [-] \qquad (3.2)$$

Hours of daylight

For every day the time of diffuse solar irradiance is longer than the time of direct solar irradiance. For this reason the diffuse solar irradiance is used to determine the hours of daylight. The monthly value of daylight is defined as the average time per day within a month, where diffuse solar irradiance occurs, see Figure 3-1 f).

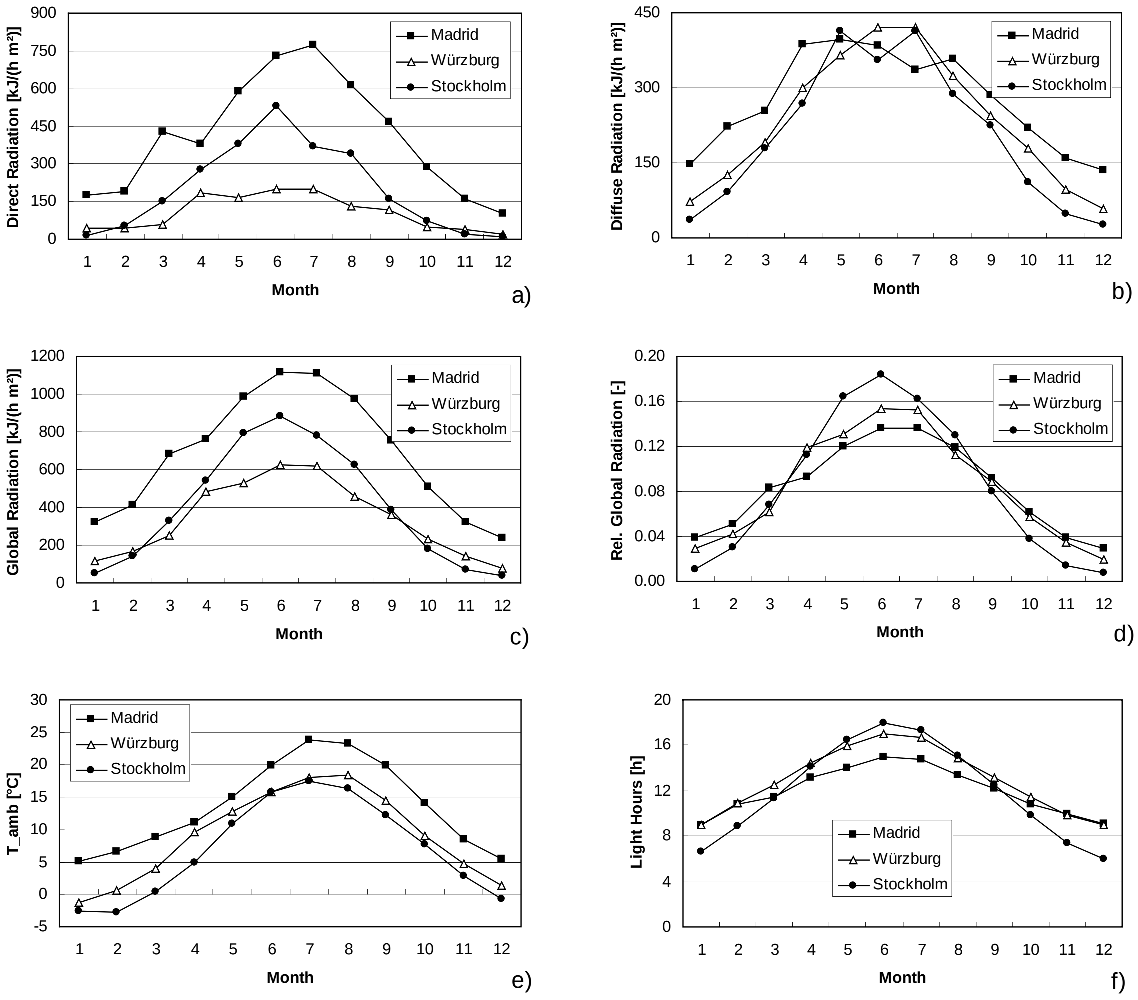

Figure 3-1: Monthly Data for three European locations: a) Direct Solar Radiation, b) Diffuse Solar Radiation, c) Global Solar Radiation, d) Relative Global Solar Radiation, e) Ambient Air Temperature, f) Mean Values of Hours of Daylight per Month.

3.2 Simulation Data

Beside the weather data simulations of solar domestic hot water systems and solar combisystems carried out with TRNSYS represent the second data basis for the development of the calculation method. The locations that are chosen represent three different climatic zones within Europe: Stockholm for the northern European climate, Würzburg for central European climate and Madrid for southern European climate.
Every single TRNSYS simulation has a specific set of inputs and parameters like the weather data for the particular location, the heat load, the collector area and other values describing the system. With these parameters the monthly gain of the thermal solar system is calculated. In total 45 simulations for the domestic hot water systems and 36 simulations for the solar combisystems have been carried out.

As an example Table 3.1 shows a selection of the outputs resulting from simulations of a DHW system located in Madrid. The total annual heat load is approximately 900 kWh, the collector area is 3 m² and the store volume amount to 102 l.

MONTH [-]	TIME [h]	Qrad [kWh/m²]	Qload [kWh]	Qcirc [kWh]	Qaux [kWh]	Qhx_sol [kWh]	Qls [kWh]	Qcol [kWh]	Qlp [kWh]	Stag_Tim [h]	Pump_Tim [h]
JAN	744.00	117.40	-75.99	-8.56	31.65	95.71	-39.49	129.20	-33.28	0.00	145.60
FEB	1416.00	111.10	-69.95	-7.73	24.87	88.27	-36.16	120.40	-31.97	0.00	141.20
MAR	2160.00	179.00	-76.32	-8.57	6.08	134.90	-53.36	189.90	-54.55	2.65	186.60
APR	2880.00	152.30	-70.47	-8.29	13.36	111.00	-45.06	157.30	-45.99	0.00	173.70
MAY	3624.00	182.10	-67.88	-8.57	3.04	129.30	-55.04	188.50	-58.66	0.00	193.90
JUN	4344.00	187.20	-60.84	-8.30	0.33	129.20	-59.65	193.50	-63.67	5.80	184.40
JUL	5088.00	197.20	-59.19	-8.57	0.13	133.90	-66.47	203.50	-69.05	22.60	175.10
AUG	5832.00	195.50	-57.83	-8.57	0.32	133.40	-65.11	204.10	-70.06	19.00	186.40
SEP	6552.00	177.80	-57.32	-8.30	0.97	125.00	-59.37	186.60	-61.07	9.63	169.70
OCT	7296.00	148.00	-62.96	-8.57	13.53	107.70	-52.45	157.40	-49.26	1.60	153.20
NOV	8016.00	105.70	-65.79	-8.29	29.98	84.90	-38.82	116.10	-31.04	0.00	129.60
DEC	8760.00	82.06	-72.91	-8.56	46.31	67.49	-34.57	91.14	-23.55	0.00	114.30
SUM	8760.00	1836.00	-797.50	-100.90	170.60	1341.00	-605.50	1938.00	-592.20	61.27	1954.00

Table 3.1: Example of simulation results of a DHW system located in Madrid, Spain

The results of the simulations of the DHW system contain:

Month:	name of the month and the annual sum [-]
Time:	time of the year of the last hour of the month (and year) [h]
Qrad:	monthly solar radiation in the collector plane [kWh/m²]
Qload:	monthly load of domestic hot water [kWh]
Qcirc:	monthly load caused by circulation of domestic hot water within the building [kWh]
Qaux:	monthly auxiliary energy delivered by the back up heater [kWh]
Qhx_sol:	monthly heat transferred by the solar loop heat exchanger [kWh]
Qls:	monthly heat loss of the domestic hot water store [kWh]
Qcol:	monthly heat delivered by the solar collector [kWh]
Qlp:	monthly heat loss of the pipework [kWh]
Stag_Tim:	time within the month the collector is in stagnation [h]
Pump_Tim:	operation time of the circulation pump of the solar loop [h]

As an example Table 3.2 shows a selection of the outputs resulting from simulations of a combisystem located in Madrid. The total annual heat load is approximately 16500 kWh, the collector area is 10 m², the domestic hot water volume of the combistore (tank-in-tank concept) is 210 l and the volume for the space heating amounts to 500 l.

MONTH [-]	TIME [h]	Qrad [kWh/m²]	QlBW [kWh]	QauxBW [kWh]	QLRH [kWh]	QaRH [kWh]	Qsl [kWh]	Qcol [kWh]	Qpl [kWh]	Stag_Tim [h]	Pump_Tim [h]
JAN	9504.00	117.60	-424.40	264.80	-960.50	911.90	-107.40	356.00	-30.35	0.00	133.80
FEB	10176.00	111.40	-388.00	235.00	-760.90	698.10	-96.84	338.30	-28.96	0.00	131.40
MAR	10920.00	179.30	-421.80	195.60	-611.60	426.30	-118.90	578.90	-43.49	0.00	190.80
APR	11640.00	152.50	-389.80	190.70	-175.90	92.96	-120.90	451.70	-41.71	0.00	170.60
MAY	12384.00	182.20	-377.50	120.20	-132.70	60.00	-148.60	541.00	-53.24	0.00	189.60
JUN	13104.00	187.20	-341.70	35.75	0.00	0.00	-171.10	548.90	-60.16	0.00	182.20
JUL	13848.00	197.10	-336.40	14.52	0.00	0.00	-193.00	586.60	-66.28	0.00	181.40
AUG	14592.00	195.30	-331.90	16.90	0.00	0.00	-190.40	585.00	-66.81	0.00	187.90
SEP	15312.00	177.50	-330.00	68.45	-114.40	24.17	-156.10	559.80	-54.79	0.00	181.80
OCT	16056.00	147.70	-361.10	184.80	-359.60	216.40	-124.90	476.90	-41.13	0.00	164.60
NOV	16776.00	105.60	-374.10	256.50	-630.70	557.20	-102.10	325.00	-27.65	0.00	127.60
DEC	17520.00	82.04	-410.40	304.40	-887.10	865.40	-98.51	242.00	-21.25	0.00	106.30
SUM	17520.00	1835.00	-4487.0	1888.00	-4633.0	3852.00	-1629.0	5590.00	-535.80	0.00	1948.00

Table 3.2: Example of simulation results of a solar combisystem located in Madrid, Spain

The results of the simulation of the solar combisystem contain:

Month: name of the month and an annual sum [-]
Time: time of the year of the last hour of the month (and year) [h]
Qrad: monthly solar radiation in the collector plane [kWh/m^2]
QlBW: monthly load of domestic hot water [kWh]
QauxBW: monthly auxiliary energy delivered for DHW preparation [kWh]
QLRH: monthly load of space heating [kWh]
QaRH: monthly auxiliary energy delivered for space heating [kWh]
Qsl: monthly heat loss of the store [kWh]
Qcol: monthly heat delivered by the solar collector [kWh]
Qpl: monthly heat loss of the pipework [kWh]
Stag_Tim: time within the month the collector is in stagnation [h]
Pump_Tim: operation time of the circulation pump of the solar loop [h]

3.2.1 Calculation of simulation data variables

In the following the variables total Qload, slr, Qsys,Sim and Qsys,rel,Sim are introduced. The total Qload is defined as the total heat load of the system, slr stands for the **s**olar **l**oad **r**atio and Qsys,Sim is the overall heat output of the system. The index "Sim" indicates values determined by simulation. Qsys,rel,Sim is the relative system output calculated out of simulation results.

Note that all definitions and equations given in chapter 3.2.1 are valid for both, monthly and annual values. Different equations are used for DHW systems and combisystems.

Total Qload

Solar DHW systems

In the case of DHW systems the total Qload is calculated as the sum of the domestic hot water heat load Qload and the heat load caused by circulation of domestic hot water, Qcirc. The energy Qload is needed to heat up the water for domestic use from the temperature of the incoming cold water to a water temperature of 45 °C. The circulation load Qcirc is the energy required to compensate the circulation heat losses in the hot water distribution loop caused by circulating the water between the store and the tap(s) for comfort reasons. Since they represent energy that is removed from the system, in the simulation summary Qload and Qcirc appear as negative values, see Table 3.1. For further use total Qload is calculated by equation (3.3).

$$\text{total Qload} = \left|\text{Qload}\right| + \left|\text{Qcirc}\right| \qquad [\text{kWh}] \qquad (3.3)$$

Solar Combisystems

For combisystems the total Qload is calculated as the sum of the load for domestic hot water preparation QlBW and the space heating load QLRH. Since the heat load for DHW and space heating is calculated separately, the required total heat load of the entire system is calculated by equation (3.4).

$$\text{total Qload} = \left|\text{QlBW}\right| + \left|\text{QLRH}\right| \qquad [\text{kWh}] \qquad (3.4)$$

Solar Load Ratio

The **s**olar **l**oad **r**atio slr is a characteristic figure for the system dimensioning. All investigated systems have different collector areas and heat loads. The solar load ratio is the ratio between the collector area and the total heat load, see equation (3.5).

$$\text{slr} = \frac{\text{collector area}}{\text{total Qload}} \qquad [\text{m}^2/\text{kWh}] \qquad (3.5)$$

Qsys,Sim

The simulated system output Qsys,Sim is the net solar energy gain per square meter of collector area. It is defined as the difference of the total heat load and the auxiliary energy Qaux divided by the collector area, see equation (3.6) and (3.7).

For DHW systems

$$Q_{\text{sys, Sim, DHW}} = \frac{\text{total Qload - Qaux}}{\text{collector area}} \qquad [\text{kWh/m}^2] \qquad (3.6)$$

For Combisystems

For combisystems the auxiliary energy Qaux is the sum of the auxiliary energy for domestic hot water QauxBW and the auxiliary energy of space heating QaRH, see equation (3.7).

$$Q_{\text{sys, Sim, com}} = \frac{\text{total Qload - (QauxBW + QaRH)}}{\text{collector area}} \qquad [\text{kWh/m}^2] \qquad (3.7)$$

Qsys,rel,Sim

In order to calculate the relative system output Qsys,rel,Sim, the value Qsys,Sim of each month is divided by the total annual value, which is the monthly values summed up over one year, see equation (3.8).

$$Q_{\text{sys, rel, Sim}} = \frac{Q_{\text{sys,Sim}}}{\text{annual sum of } Q_{\text{sys,Sim}}} \qquad [-] \qquad (3.8)$$

In the following chapter, which is describing the calculation method, the relative system output Qsys,rel,Sim calculated by equation (3.8) will be used to derive equations for the output of solar domestic hot water and solar combisystems.

3.3 Calculation Method

The calculation method is divided in two steps. The first step deals with the weather data and is therefore valid for both, DHW systems and combisystems. The second step uses specific data from the simulations. Although the procedure for the second step in principle is the same for both kinds of systems, each system is discussed separately. Finally the results lead to a general equation to predict the performance of a solar domestic hot water or a solar combisystem.

3.3.1 Calculations Based on Weather Data

Based of the respective weather data, for the calculation of the system output the relative global radiation and the hours of daylight are determined and used.

The curves for the three climate zones represented by Stockholm, Würzburg and Madrid show a similar pattern with only a view differences. The curve of Stockholm indicates a slightly higher relative global solar radiation in the summer months and less than the other two locations during the winter months, see Figure 3-1. This is because the absolute monthly difference in the global solar radiation is much larger for Stockholm than for Würzburg. On the other hand, for Madrid compared to Stockholm and Würzburg the entire level of the solar radiation is much higher, see Figure 3-1 c).

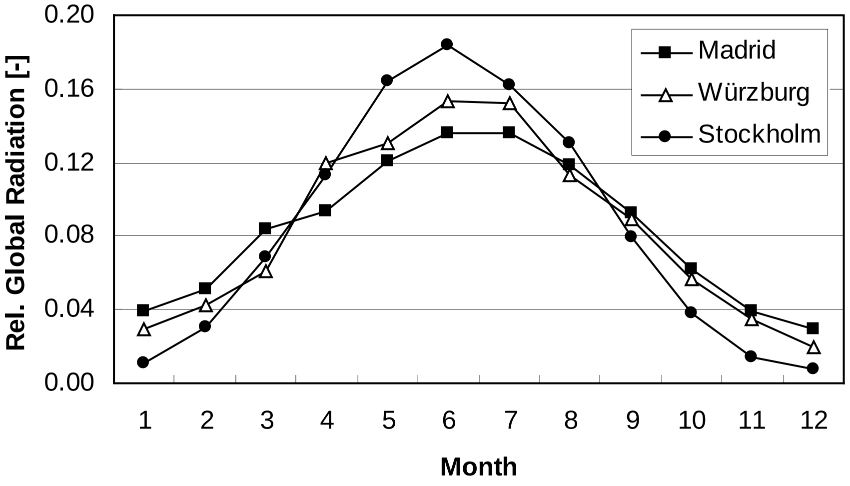

Figure 3-1: Relative Global Solar Radiation for three European locations.

Looking at the hours of daylight, there is a comparable pattern to that of the relative global solar radiation, see Figure 3-2. Northern Europe (Stockholm) has the largest differences of hours of daylight between summer and winter.

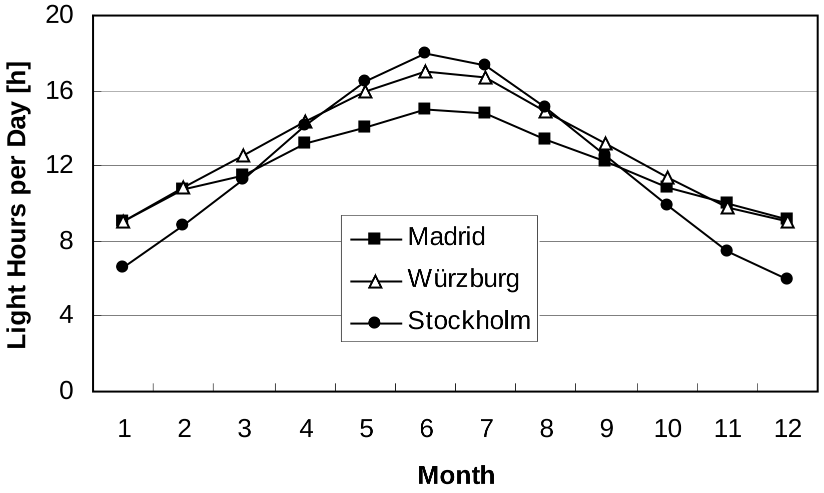

Figure 3-2: Average Hours of Daylight per day of a respective month for three European locations.

In order to compensate for the summer peak of the relative global solar radiation particularly to be observed for Stockholm, the monthly values of the relative global solar radiation are divided by the average hours of daylight, see equation (3.9).

$$\frac{G_{\text{month, rel}}}{t_{\text{daylight}}} \quad [1/h] \qquad (3.9)$$

For the three locations the quotient is shown in Figure 3-3.

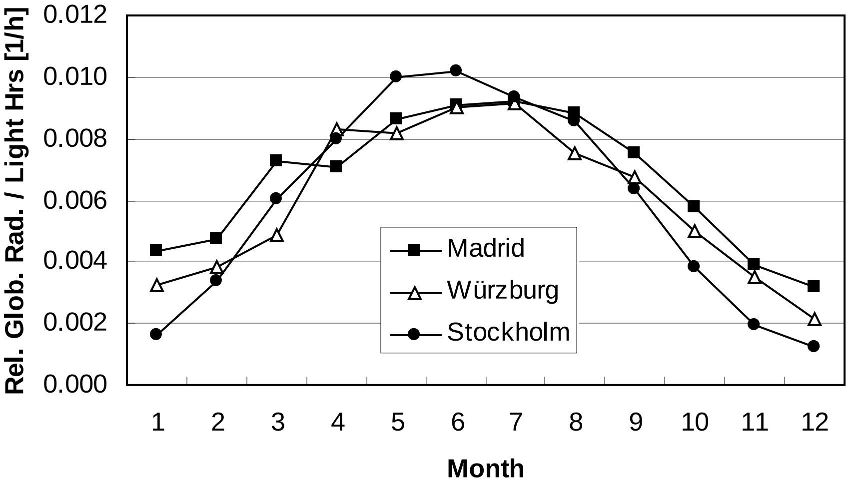

Figure 3-3: Quotient of the Relative Global Solar Radiation and the Hours of Daylight.

3.3.2 Calculations with Simulation Data for DHW systems

To elaborate an equation suitable to predict the system performance based on climatic conditions, the heat load and the collector area, the results of the simulations have to be correlated with the used weather data. To enhance the accuracy of the determined correlation a system constant, named b_{DHW} is introduced. The target is to find a constant that is valid for a defined system design all over the year and for each location. To derive this constant at first the relative global solar radiation, $slr_{avg,DHW}$, $Q_{sys,rel,Sim,DHW}$ and the hours of daylight calculated mainly from the results of 45 simulations of DHW systems are merged, see equation (3.10).

$$\frac{G_{\text{month, rel}}}{slr_{avg} \cdot Q_{\text{sys, rel, Sim, DHW}} \cdot t_{\text{daylight}}} \qquad [\text{kW/m}^2] \qquad (3.10)$$

Based on average values from these 45 simulations of DHW systems, Figure 3-1 presents the results of the quotient defined in equation (3.10).

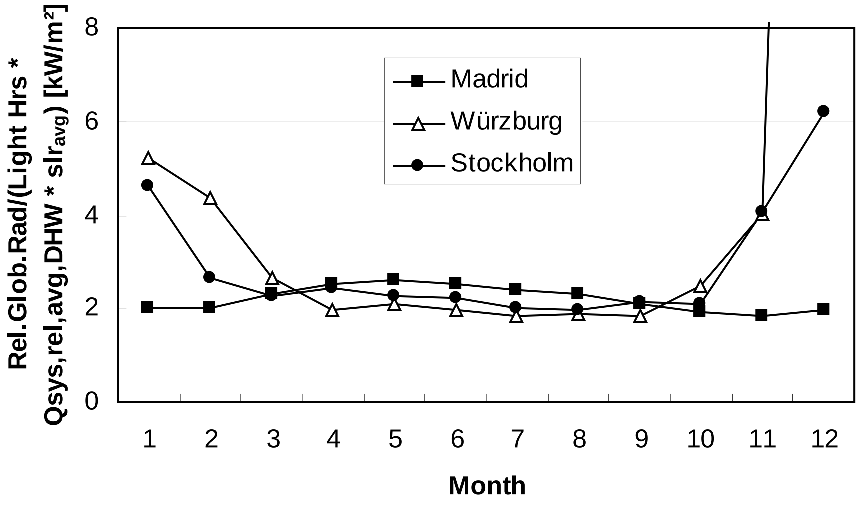

Figure 3-1: Quotient of the relative global solar radiation and the product of the average values of slr, Qsys,rel,Sim,DHW and the hours of daylight.

During summer, between month 3 (March) and month 10 (October), the curves are relatively plain and close together, see Figure 3-1. One reason, particular for DHW systems is the evenly distributed load all over the year. To account for and to smooth the differences during winter, each month has to be multiplied with a correction factor. As an example Table 3.1 shows the correction factors d_{month} for DHW systems and combisystems. The factor is dimensionless and its yearly sum for each system is equal to one.

all locations/ climates	d_{month} [-]												
	Sum	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
DHW system	1	15/247	35/494	25/247	25/247	25/247	25/247	25/247	25/247	25/247	25/247	25/494	2/247
combisystem	1	1/22	5/88	3/44	1/11	1/11	5/44	5/44	5/44	9/88	1/11	3/44	1/22

Table 3.1: Example of the Monthly Correction Factor d_{month} for DHW and combisystems

The correction factors are determined in that way, that $b_{month,location}$ of the curves in the winter months, particular for December and January, is in the region of $b_{month,location}$ for the summer months, see equation (3.11). After multiplying the data of Figure 3-1 with the correction factors, the courses of the curves changed, see Figure 3-2.

$$b_{month,location} = \frac{G_{month,rel} \cdot d_{month}}{slr_{avg} \cdot Q_{sys,rel,Sim,DHW} \cdot t_{daylight}} \qquad [kW/m^2] \qquad (3.11)$$

where

$b_{month,location}$	is the factor for each month and location [kW/m²]
$G_{month,rel}$	is the monthly average of the relative global radiation [-]
d_{month}	is a correction factor [-]
slr_{avg}	is the average solar load ratio all over the year [m²/kWh]
$Q_{sys,rel,Sim,DHW}$	is the relative system output of the DHW simulation [-]
$t_{daylight}$	is the monthly average of hours per day with daylight [h]

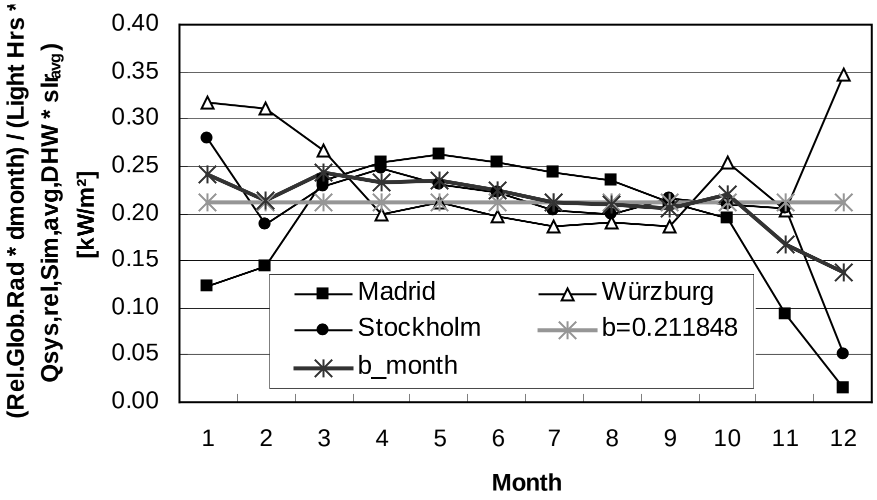

Figure 3-2: Example of the Final Correlation for the Constant b_{DHW} for DHW systems

As shown in Figure 3-2 the monthly values for $b_{month,location}$ are individual for each location. The bold black line b_{month} shows the average of the different monthly values from Figure 3-2. In the final step the mean value of this average monthly values is calculated. This mean value is represented with constant b. In the case of DHW systems the constant is b_{DHW} = 0.211848, indicated in Figure 3-2 by the bold grey line.

3.3.3 Calculations with Simulation Data for Solar Combisystems

To determine the constant b_{combi} the procedure described in Chapter 3.3.2 is repeated for combisystems. Due to the reason, that solar combisystems have a different annual distribution of Qsys,rel,Sim,combi, see Figure 3-1, the constant b_{combi} for combisystems is different from b_{DHW} for DHW systems.

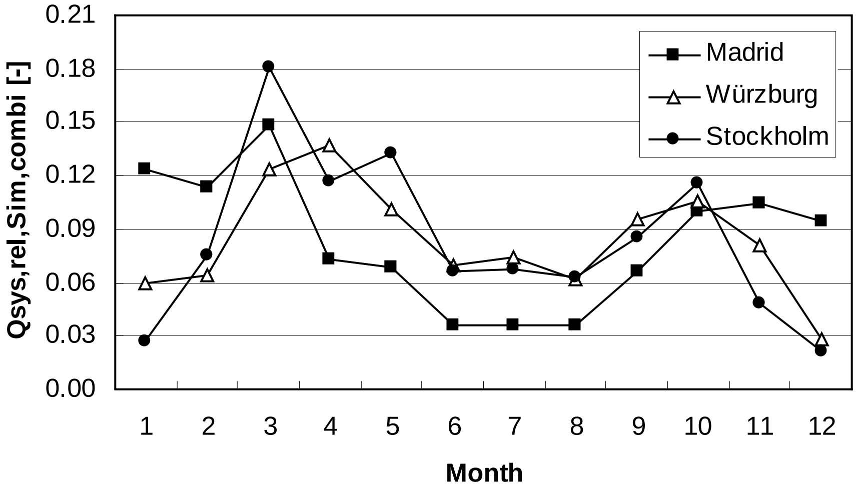

Figure 3-1: $Q_{sys,rel,Sim,combi}$ for solar combisystems at three different climate zones

Qsys,rel,Sim,combi represents the average monthly value of all 36 system simulations for combisystems for each location. Characteristically is the behaviour of the curves during summer, month 6, 7 and 8 (June, July, August), were no space heating is required.

Dividing the relative global monthly radiation by Qsys,rel,Sim,combi and the related hours of daylight, see equation (3.12), results in curves as shown in Figure 3-2

$$\frac{G_{month,\,rel}}{Q_{sys,\,rel,\,Sim,\,combi} \cdot t_{daylight}} \qquad [1/h] \qquad (3.12)$$

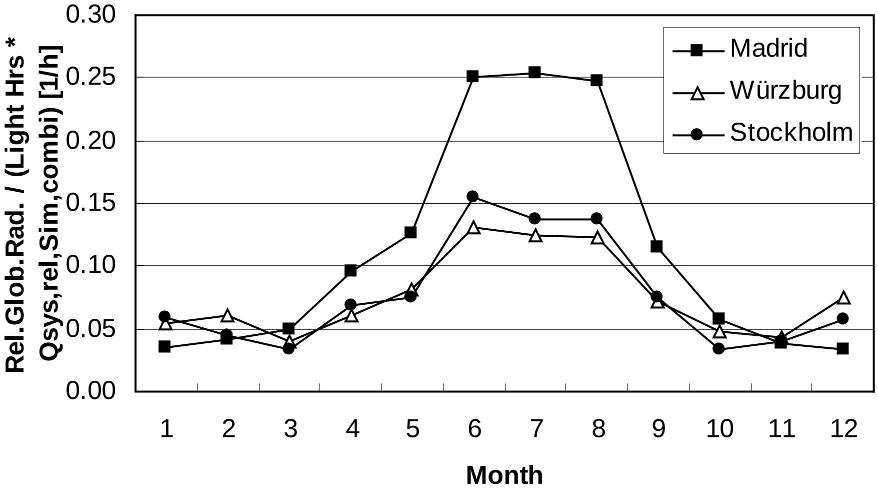

Figure 3-2: Relative Global Monthly Radiation divided by $Q_{sys,rel,Sim,combi}$ *and the hours of daylight*

During the summer months June, July, and August no space heating is required. This leads to the high plateau in this month as can be seen in Figure 3-2.

In order to eliminate the plateau in the quotient of the relative global monthly radiation and the product of Qsys,rel,Sim,combi and the hours of daylight, the quotient in addition is divided by the average slr, see equation (3.13). This operation leads to Figure 3-3.

$$\frac{G_{\text{month, rel}}}{slr_{avg} \cdot Q_{\text{sys, rel, Sim, combi}} \cdot t_{\text{daylight}}} \qquad [kW/m^2] \qquad (3.13)$$

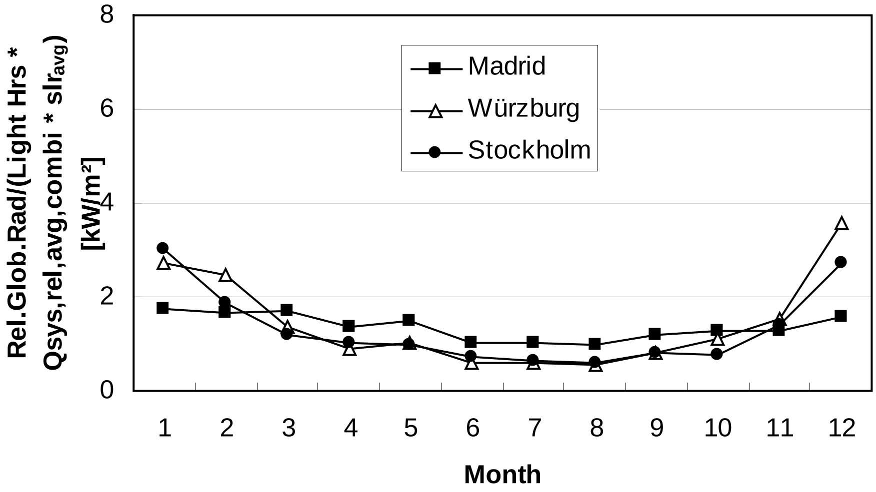

Figure 3-3: Relative Global Monthly Radiation divided by the average slr for combisystems, $Q_{sys,rel,Sim,combi}$ *and the hours of daylight.*

Equal to the DHW systems, the results are smoothed by multiplying the correction factors d_{month} given in Table 3.1. Note that the correction factor d_{month} for combisystems is different from that for DHW systems.

Again the correction factors are determined in that way, that $b_{month,location}$ of the curves for all months are approximately equal, see equation (3.14). After multiplying the data of Figure 3-3 with the correction factors, the courses of the curves changed as shown in Figure 3-4.

$$b_{month,\,location} = \frac{G_{month,\,rel} \cdot d_{month}}{slr_{avg} \cdot Q_{sys,\,rel,\,Sim,\,combi} \cdot t_{daylight}} \qquad [kW/m^2] \qquad (3.14)$$

With the exception of $Q_{sys,rel,Sim,combi}$, which is the dimensionless relative system output of the simulation of the combisystem, the symbols of equation (3.14) are defined together with equation (3.11).

Individual for the three locations the monthly values for $b_{month,location}$ are shown in Figure 3-4.

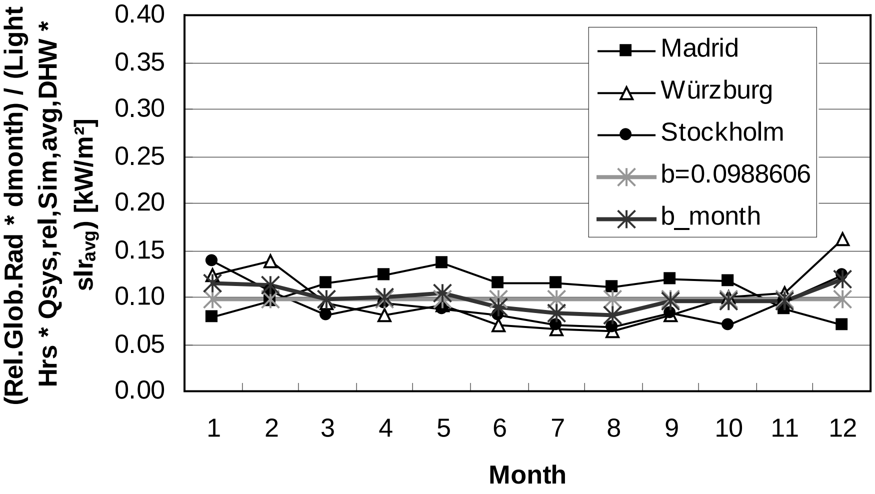

Figure 3-4: Example of the final correlation for constant b_{combi} for combisystems.

The bold black line b_{month} represents the average of the different monthly values. In the final step the mean value of this average monthly values is calculated. This mean value is represented with constant b. In the case of combisystems the constant is b_{combi} = 0.0988606, indicated in Figure 3-4 by the bold grey line.

3.3.4 Final Correlation of Constants

In Chapter 3.3.2 and Chapter 3.3.3 the values of the constants b_{DHW} and b_{combi} were derived for DHW systems and combisystems respectively. Equation (3.15) shows the final correlation for the constant b. In $Q_{sys,rel,Sim,avg}$ the abbreviation "avg" stands for both, DHW and combisystems. It has to be inserted for the case and system to be calculated.

$$b_{month,\,location} = \frac{G_{month,\,rel} \cdot d_{month}}{slr_{avg} \cdot Q_{sys,\,rel,\,Sim,\,avg} \cdot t_{daylight}} \qquad [kW/m^2] \qquad (3.15)$$

With the exception of $Q_{sys,rel,Sim,avg}$, which is the dimensionless average relative system output of the simulation, the symbols of equation (3.15) are defined together with equation (3.11).

3.3.5 Correlation for Individual Systems

So far the average values of all simulations were used to determine $Q_{sys,rel,Sim,avg}$ and slr_{avg}. In order to get a correlation for each individual system, a conversation is necessary. For each system $Q_{sys,rel,Sim,avg}$ is replaced by QX_{month}. The average slr is replaced by the individual slr of the system under investigation. This leads to Equation (3.16), variable QX_{month} is dimensionless.

$$QX_{month} = \frac{G_{month,\,rel}}{slr \cdot b_{sys} \cdot t_{daylight}} \qquad [-] \qquad (3.16)$$

where

$G_{month,rel}$	is the monthly average of the relative global solar radiation [-]
slr	is the solar load ratio, dependent on the total load and the collector area [m²/kWh]
b_{sys}	is the constant, b_{DHW} = 0.211848 for solar DHW systems and b_{combi} = 0.0988606 for solar combisystems [kW/m²]
$t_{daylight}$	is the monthly average of hours per day with daylight [h]

The variable QX_{month} is used to calculate the annual and the monthly system output.

3.4 System Output

3.4.1 Annual System Output

The procedure to calculate the annual system output is valid for DHW systems and combisystems as well. In Figure 3-1 QX_{annual} is plotted versus $Q_{sys,sim}$. QX_{annual} is the annual sum of QX_{month}, see Equation (3.17).

$$QX_{annual} = \sum_{month=1} QX_{month} \qquad [-] \qquad (3.17)$$

$Q_{sys,sim}$ is the simulated system output calculated with TRNSYS, see Chapter 3.2.1.

If QX_{annual} is plotted versus the simulated system output a kind of logarithmic correlation can be observed, see Figure 3-1.

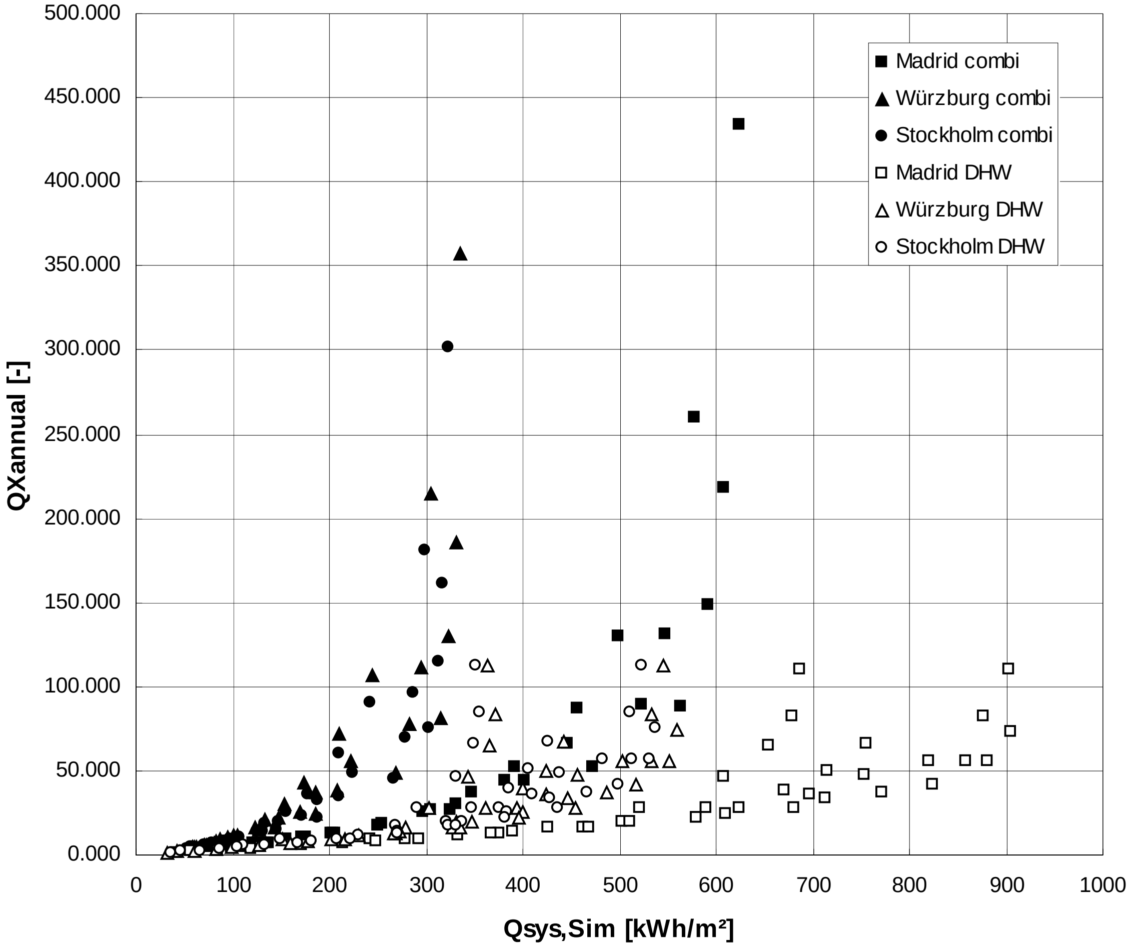

Figure 3-1: Plot of QX_{annual} versus $Q_{sys,Sim}$

In order to compensate for this “logarithmic behaviour”, the natural logarithm of QX_{annual} is used. In Figure 3-2 $Q_{sys,sim}$ is plotted on the x-axis and $\ln(QX_{annual})$ on the y-axis. Again QX_{annual} is dimensionless.

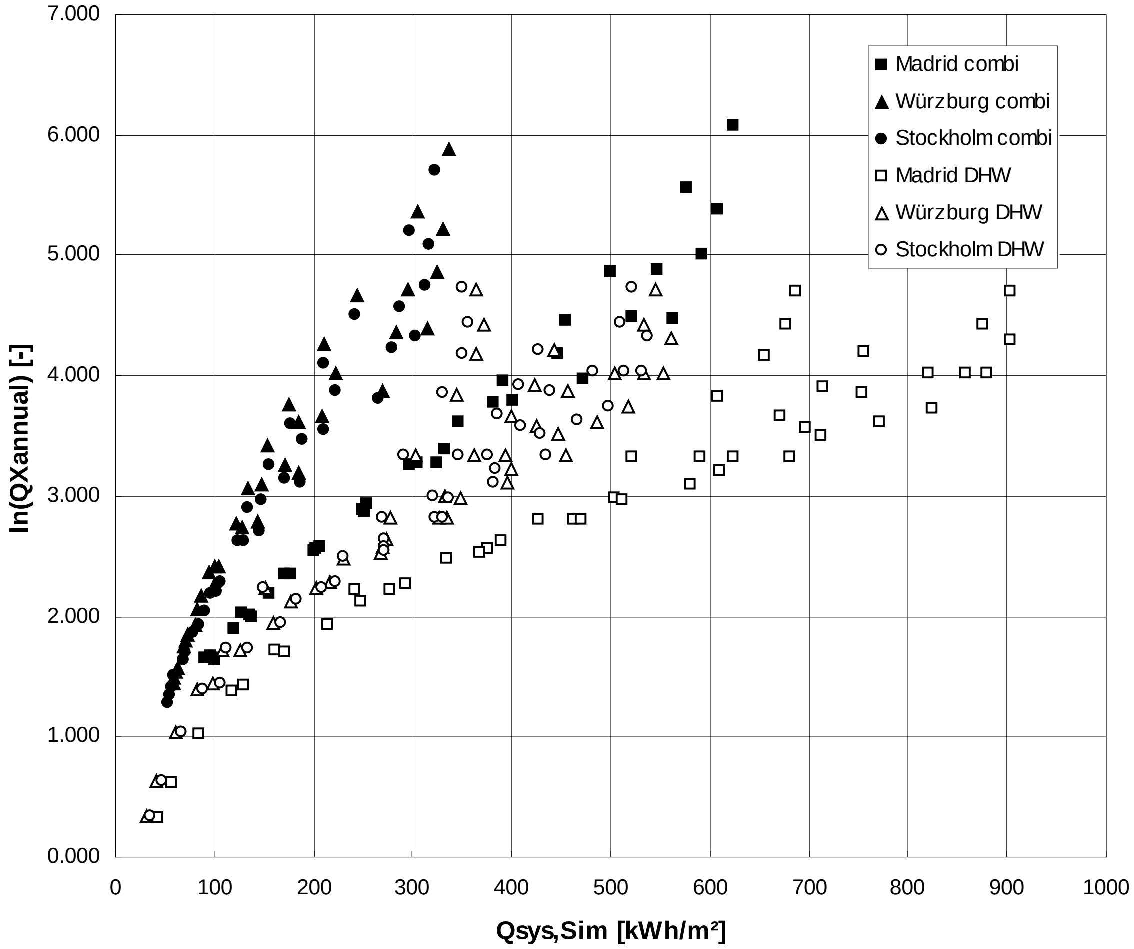

Figure 3-2: Natural Logarithm of QX_{annual} plotted versus $Q_{sys,Sim}$

In the next step the natural logarithm of QX_{annual} is multiplied by another correction factor, containing the local annual average ambient temperature and the annual sum of the global radiation. The result is the annual output as defined by Equation (3.18).

$$Q_{out,s,annual} = \ln\left(QX_{annual}\right)\cdot\left(\left(\frac{G_{annual}}{112.35°C - \vartheta_{avg}}\right)+c_{sys}\right)\cdot uc \qquad [kWh/m^2] \qquad (3.18)$$

where

QX_{annual}	is the annual sum of all QX_{month} [-]
G_{annual}	is the annual sum of the global radiation G_{month} [kJ/(h·m²)]
ϑ_{avg}	is the average annual temperature in °C.
c_{sys}	is a factor, c_{DHW}=59.08 for DHW systems and c_{combi}=3.75 for combisystems [kJ/(h·m²·°C)]
uc	is a unit correction factor [kWh·h·°C/kJ]

The values 112.35 °C and c_{sys} were evaluated by minimising the sum of the absolute differences between $Q_{out,s,annual}$ and $Q_{sys,Sim}$.
The constants c_{sys} and uc are valid for all systems and locations under investigation. The parameters G_{annual} and ϑ_{avg} are valid for all systems at one specific location. The variable QX_{annual} is specific for each single system.

In Figure 3-3 the annual system output $Q_{out,s,annual}$ calculated with Equation (3.18) is plotted versus the annual system output $Q_{sys,Sim}$, derived by means of system simulations with TRNSYS. For a more detailed discussion of Figure 3-3, see Chapter 4.1.

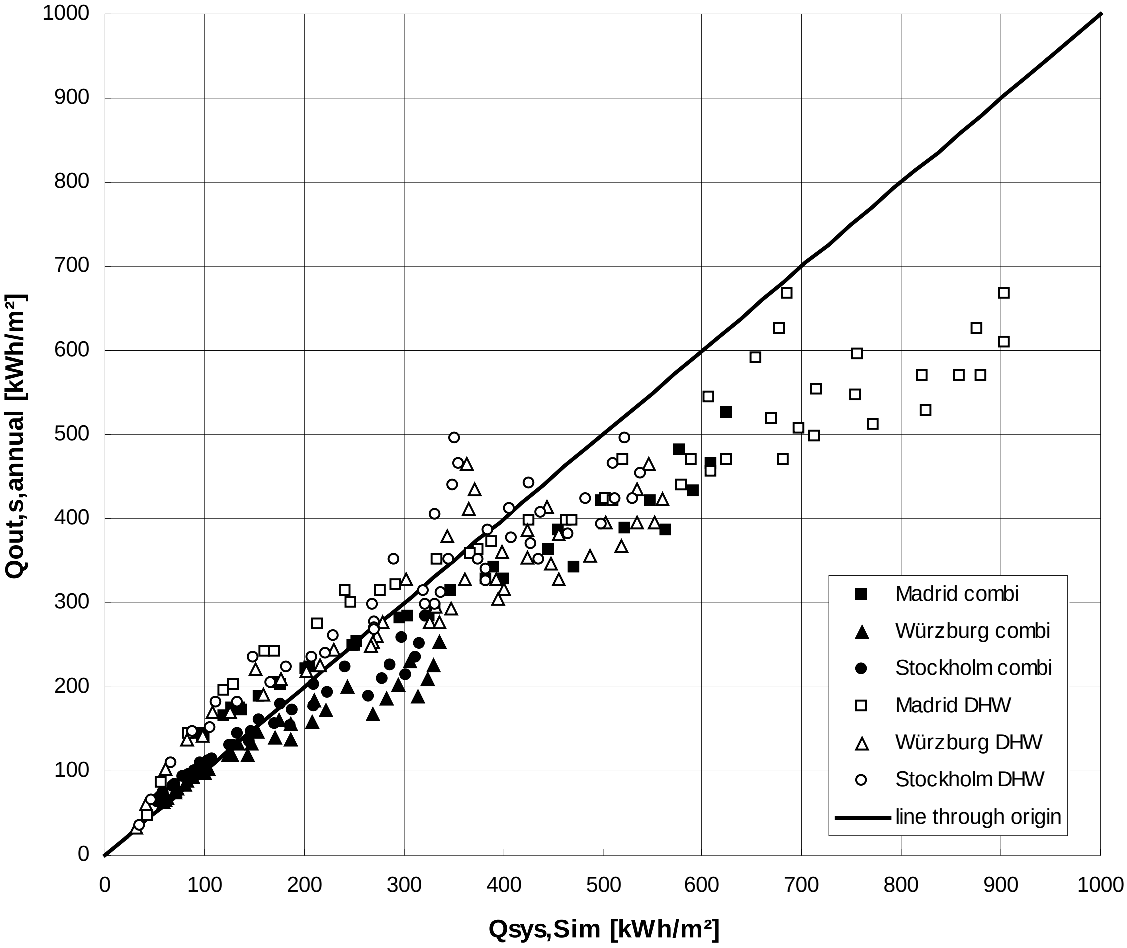

Figure 3-3: Comparison of the annual System Output ($Q_{out,s,annual}$), calculated with Equation (3.18) and the System Output ($Q_{sys,Sim}$) derived by TRNSYS simulations

3.4.2 Monthly System Output

In prEN 15316 part 2.2.3 the monthly system output is introduced as a new reference quantity. In earlier standards like DIN 4701 part 10, only the annual system output was calculated. In order to account for the interaction between a thermal solar system and other heating systems, such as heat pumps, the monthly system output is required.

The monthly values for the system output are calculated on the basis of QX_{month}, see Equation (3.16). In Equation (3.19) QX_{month} is multiplied by the correction factor d_{month} to get Q*month. In order to get Q*annual, the annual sum of all 12 monthly values is taken, see Equation (3.20).

In Equation (3.21) the relative monthly distribution is calculated by dividing Q^*_{month} through the annual value of Q^*_{annual}. To get the monthly system output $Q_{out,s,month}$, the resulting factor $Q^*_{month,rel}$ is multiplied by the annual system output $Q_{out,s,annual}$, see Equation (3.22).

$$Q^*_{month} = QX_{month} \cdot d_{month} \quad [-] \tag{3.19}$$

$$Q^*_{annual} = \sum_{month=1}^{12} Q^*_{month} \quad [-] \tag{3.20}$$

$$Q^*_{month,\,rel} = Q^*_{month} / Q^*_{annual} \quad [-] \tag{3.21}$$

$$Q^*_{out,\,s,\,month} = Q^*_{month,\,rel} \cdot Q_{out,\,s,\,annual} \quad [kWh/m^2] \tag{3.22}$$

where

Q^*_{month}	is the previously calculated OX_{month} multiplied with a correction factor d_{month} [-]
d_{month}	is a correction factor for each month [-] (d_{month} is distinguished between DHW systems and combisystems. The correction factors d_{month} are given in Table 3.1)
$Q^*_{month,rel}$	is the relative value of Q^*_{month}, referring to Q^*_{annual} [-]
Q^*_{annual}	is the annual sum of Q^*_{month} [-]
$Q_{out,s,annual}$	is the calculated annual system output [kWh/m²]
$Q_{out,s,month}$	is the calculated monthly system output [kWh/m²]

4 Validation of the Calculation Procedure

In this chapter the annual system output and the monthly system output calculated by the described procedures are compared with the simulated system output derived from TRNSYS simulations.

4.1 Validation of the Annual System Outputs

A comparison between the results derived from applying the calculation procedure presented above with results from system simulations using TRNSYS is shown in Figure 3-3. While the ordinate refers to the calculated annual system outputs, the abscissa refers to the simulated annual system outputs. An exact agreement would result in all points located on the black line plotted through the origin.

Defined as the difference between the calculated and the simulated system output divided by the simulated system output, the relative error is calculated according to Equation (4.1).

$$\text{annual relative Error} = \frac{Q_{out,\,s,\,annual} - Q_{sys,\,Sim}}{Q_{sys,\,Sim}} \cdot 100 \quad [\%] \tag{4.1}$$

The annual relative errors are shown in Figure 4-1. As is evident in Figure 3-3 particularly the data points for higher system outputs are located below the line through the origin. This indicates higher values resulting from system simulation with TRNSYS compared to the calculated outputs. This coherence is confirmed by Figure 4-1. For DHW systems above 400 kWh/m² and combisystems above 250 kWh/m² the calculated system output is lower than the simulated one. The difference can be up to 40% less system output for the calculation. On the other hand, with regard to system outputs lower than 170 kWh/m² the calculated output can be 70% higher as the simulated. Because small outputs like this are far away from ordinary system design and in practice less relevant, these extremely designed systems are only included to get information about the limitations of the introduced method.

For systems with an output higher than 170 kWh/m² the calculated results have an error smaller than ±40 % compared to the simulated system output. This is valid for both, DHW and combisystems.

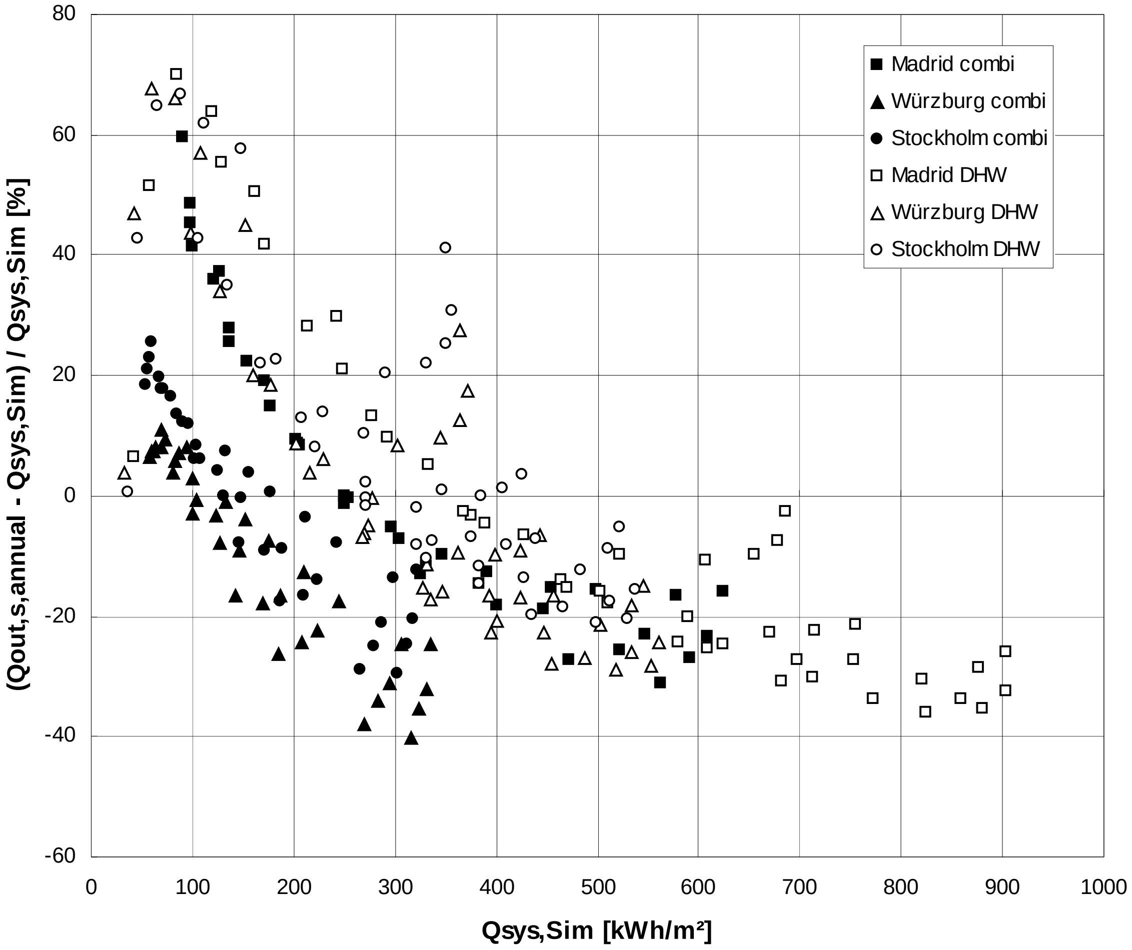

Figure 4-1: Relative Error of the Calculated Annual System Output referred to the Simulated Annual System Output calculated according to equation (4.1).

In Figure 4-2 the relative error according to equation (4.1) is plotted versus the annual slr given on the x-axis. While a simulated system output of 400 kWh/m² corresponds to an annual slr of 0.0025 m²/kWh for DHW systems, 250 kWh/m² for combisystems corresponds to an annual slr of 0.004 m²/kWh.

Annual values of slr lower than 0.0025 m²/kWh for DHW systems and 0.004 m²/kWh for combisystems respectively in most cases show lower values for the calculated system output than determined by system simulations. Annual slr higher than these values lead to higher system outputs derived by calculation compared to the simulated ones.

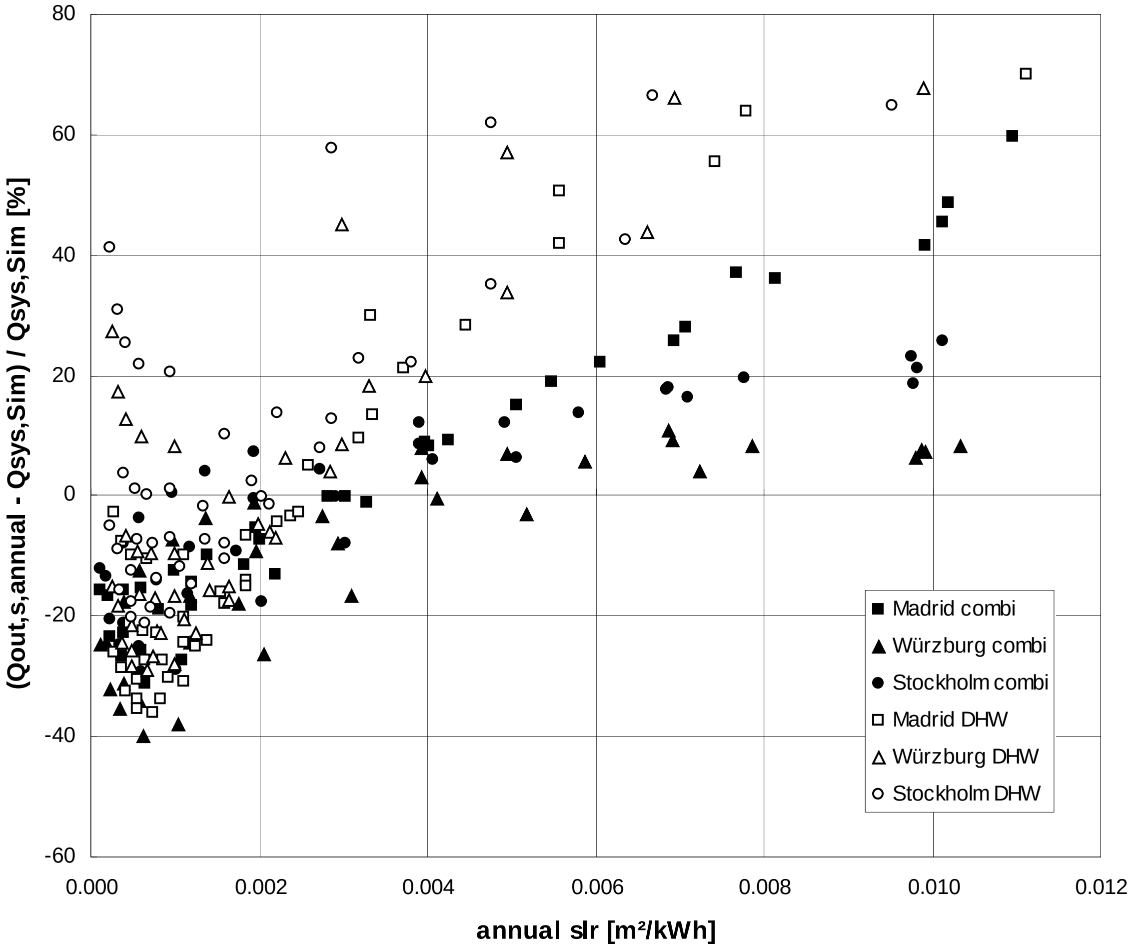

Figure 4-2: Relative Error plotted versus the annual slr

4.2 Validation of the Monthly System Output

In Chapter 3.4.2 a procedure for the determination of the monthly system output based on an analytical calculation was developed.

Figure 4-1 and Figure 4-2 shows the monthly error between the calculated and the simulated system output for several systems in percent. The values are calculated using Equation (4.2).

$$\text{monthly relative Error} = \frac{Q_{\text{out, s, month}} - Q_{\text{sys, Sim}}}{\frac{1}{12} \cdot Q_{\text{out, s, annual}}} \cdot 100 \qquad [\%] \qquad (4.2)$$

Figure 4-1 shows the smallest deviations between the calculated and simulated system outputs for all considered DHW systems at Stockholm. The highest error of about 100 % occurs for one system in June, while the average error in June is approx. 10 %. The overall, annual error for DHW systems located in Stockholm is about 2 %.

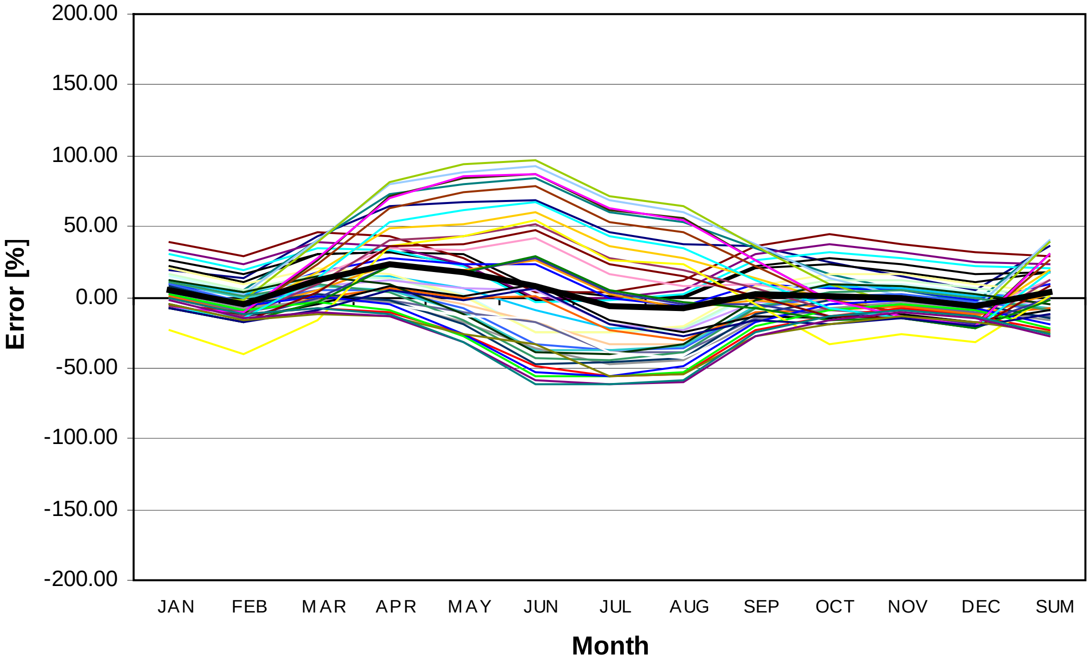

Figure 4-1: Smallest Relative Error of the monthly system output for DHW Systems at Stockholm.

Figure 4-2 shows the largest deviation (error) for combisystems for Würzburg in July. In this case the system output is calculated 200 % smaller compared to the simulated results.

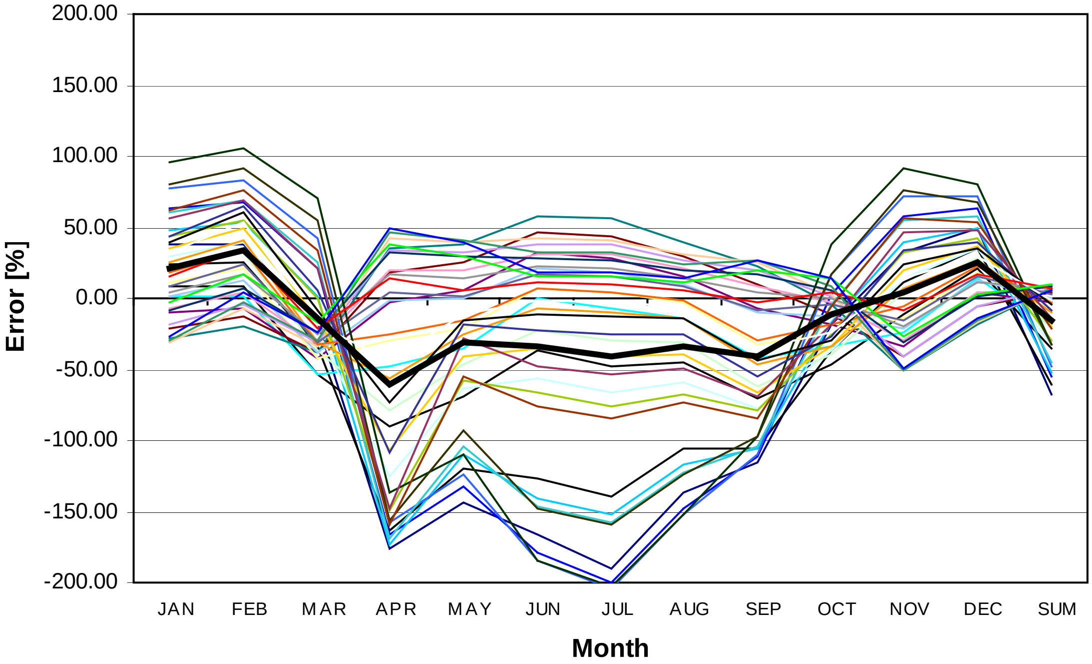

Figure 4-2: Largest Relative Error of the monthly system output for different combisystems at Würzburg.

It should be noted that most systems do not have such extreme deviations. The average error in July is approx. 40 %. The average error during the year is represented for DHW systems in *Figure 4-1* and for combisystems in *Figure 4-2* by the bold black line. For combisystems the largest average error is about –60 %. For combisystems it can be observed that mostly the average error is positive during the months November, December, January and February (winter), while in contrast it is negative during summer (April to October). A negative error means that the calculated system output is smaller than the simulated. Nevertheless, some systems behave in the opposite. Overall the annual error between calculated and simulated system output is typically in the range of ±10 %. Compared to combisystems, DHW systems in general have a smaller deviation between the calculated and simulated system output. The differences of the positive and negative errors between the summer and the winter months are much smaller. For some systems seasonal dependence even does not appear.

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WP4.D2: Direct Characterisation test procedure for solar combisystems

Dissemination level: Public

Authors: Huib Visser and Henk Oversloot (TNO)
June 2007

CONTENTS:

DIRECT CHARACTERISATION TEST METHOD FOR SOLAR COMBISYSTEMS

with main features of the test method and its implementation in the TNO test facilities.

DC TEST ON A 600 LITRES COMBISTORE

improved both test facility and test method

DC TESTING AND THE ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE

where the DC test method provides the missing link in solar combisystem characterisation.

SUMMARY

A full Direct Characterisation (DC) test has been carried out on a 600 litres solar combistore. Testing was based on the DC test procedure resulting from Task 26 of the IEA Solar Heating and Cooling Programme plus implementation work of the test procedure into the TNO test facilities.

In the nine-days test, the solar combistore was combined with a simulated collector area of 7 m^2. European climate zone II (Central European weather) was used for outdoor conditions and the annual heat demand of the house was 51.27 GJ for space heating and 10.77 GJ for hot water. The nine-days test was carried out several times in order to also characterize and tune properties of the test facilities. Test results show that the test facilities are able to reproduce conditions with respect to the loads very good. Annual performance prediction differs due to difference in input from the collector. Reasons are interaction between collector control and test facility behavior, variability in store ambient temperature and a non-optimized controller and solar combisystem. Adaptation of the test facility provided more unambiguous test results.

In principle, DC testing can be used as part of the infrastructure for assessment of solar combisystems in terms of the Energy Performance of Buildings Directive (EPBD). The methodology for incorporation of the DC test result into an update of the new European standard EN 15316-4-3 has been outlined.

NEGST – NEW GENERATION OF SOLAR THERMAL SYSTEMS
is a project financed by the European Commission DGTREN within FP6

TABLE OF CONTENTS

1. DIRECT CHARACTIRISATION TEST METHOD FOR SOLAR COMBISYSTEMS

The Direct Characterisation (DC) test method for solar combisystems started its development in Task 26 of the IEA Solar Heating and Cooling Programme. At the end of the work in Task 26, verification of the method was still insufficient for incorporation in CEN TC312 standardisation. The method needed verification through implementation in a test facility as well as actually testing solar combisystems. After that, introduction of a new work item in CEN TC312 was foreseen as well as incorporation of the DC test method in the Energy Performance of Buildings (EPBD) infrastructure. Aim of the work on solar combisystems in Work Package 4 was to provide the verification of the DC test method.

1.1 Main features of the DC test method

Scope of the DC test method is that it covers the majority of solar combisystems on the market. Restriction is that there is a clear separation between solar combisystem and dwelling. The method suits systems with heat stores up to 1500 litres and up to 15 kW heating power from the solar collector. The solar combisystem is tested including auxiliary heating.

The basic performance figure from the DC test is the annual final energy use of the solar combisystem, such as gas, oil, wood or electricity (to be seen as primary system input). Presentation of this figure prevents discussion on the reference combisystem, i.e. without solar thermal. It also prevents discussion on the efficiency of the auxiliary heating. For presentation of savings on final energy, one does have to define a (conventional) reference system with corresponding functionality for comparison.

DC testing features a simple method where test results are simply processed into an annual system performance. No calculation model is needed for the data processing. In principle, there is a choice out of three European climates, i.e. South, Central and North, and three reference single family houses, i.e. SFH30, SFH60 and SFH100 having a space heating load of about 30 kWh, 60 kWh respectively 100 kWh per m^2 floor area for the Central European climate. Space heating demand has been elaborated for climate zone II (Central European weather) in combination with the SFH60 and SFH100 dwelling. In all cases, hot water demand is 10.77 GJ/year. Choice out of nine fixed combinations of climate and heat demand brings on straightforwardness. However, drawback is that extrapolation into other climates and/or heat demands gets more difficult and inaccurate.

The DC test involves ‘black box’ in laboratory testing with the following elements: (a) initial conditioning, (b) check on whether or not requirements with respect to climate and heat demand are met, (c) simulation of all seasons in six days (‘core phase’), (d) final conditioning and (e) processing of the test data. Full description of the DC test procedure, i.e. the 5th draft and corrections of this draft can be found in [1].

1.2 Implementation of the DC test method in the TNO test facilities

The DC test method was implemented in the test facilities at TNO. Main characteristics of these test facilities are:

- Collector circuit:
  - The solar collector is simulated by a modulating electrical element (up to 12 kW) which is controlled by the collector efficiency curve and data from the climate file.
  - Flow rate in the collector circuit is determined by the supplier’s usual collector pump.
- Space heating circuit:
  - Space heating is simulated by a cooling unit (up to 20 kW) controlled by data from the space heating demand file.

- Hot water draw-off:
  - Hot water draw-off is controlled by data from hot water demand file.
  - There is 600 litres available at 9.7°C.
  - The flow rate is 10 litres/min.
- Outdoor conditions (for the outdoor sensor):
  - The outdoor temperature is simulated in an insulated box controlled by data from the climate file.

Figure 1 shows the DC test facility at TNO testing the 600 litres solar combistore in the NEGST project.

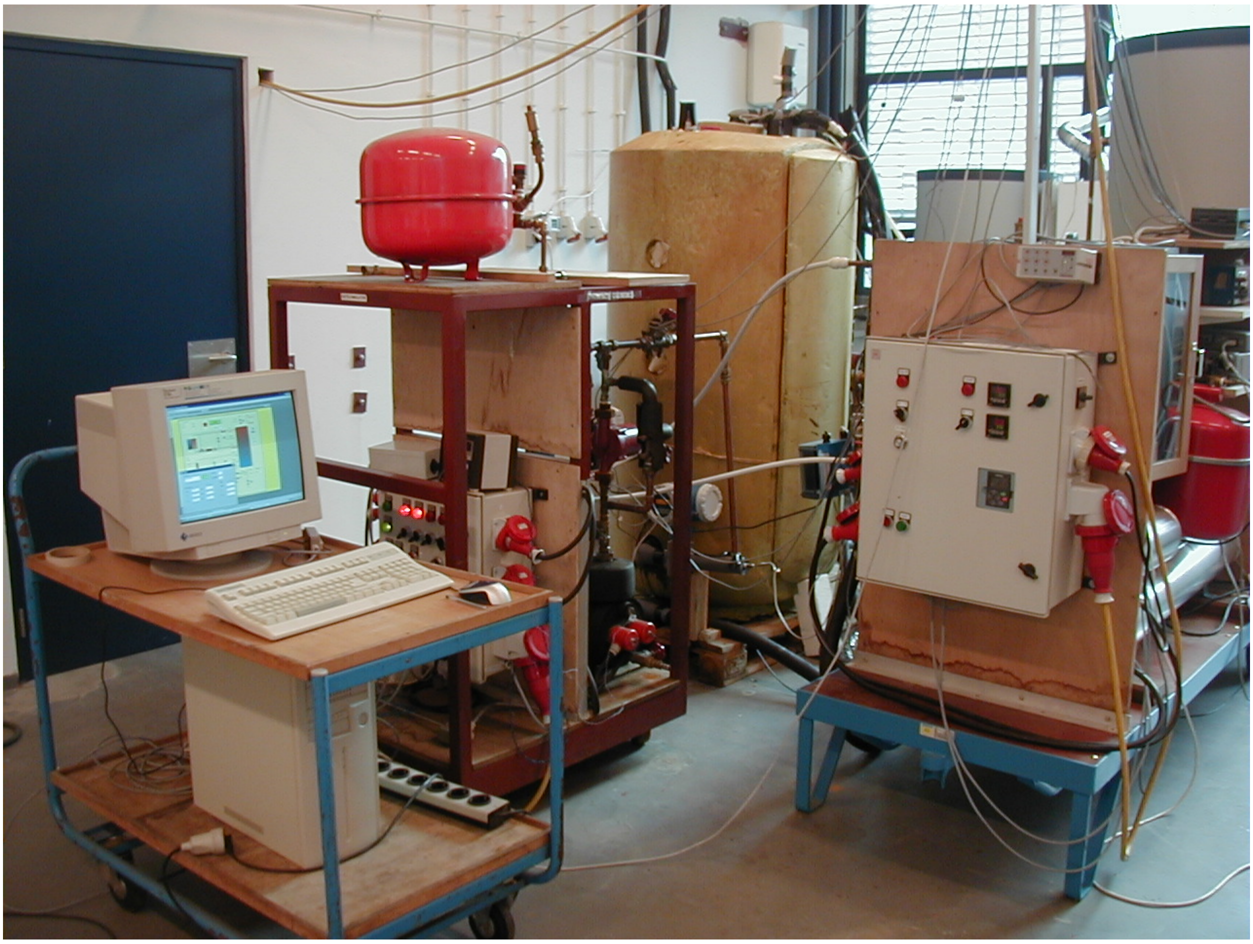

Figure 1: *The 600 litres solar combistore in the Direct Characterisation test facility at TNO.*

Operation of the test facility was verified by tests on the following solar thermal systems:

- ‘Zonnegascombi’ of supplier Atag with 4.25 m^2 collector area and 200 litres heat store.
- ‘MultiSolar’ of supplier Daalderop with 4.23 m^2 collector area and 180 litres heat store.
- A new solar combisystem concept of Gasunie.
- A solar combisystem with 7 m^2 collector area and 600 litres heat store, especially measured for the NEGST project.

The first two tests led to corrections in processing of the data ([1]). Results of the latter test have been presented in the next section.

It turned out that the DC test method appeared to be quite attractive to industry and developers, mainly because of its simplicity. That is why the method was also used to characterise the combination of solar domestic hot water system and gas-fired auxiliary heater as put together by suppliers Alpha Boilers and Itho Images. The method was even used as basis for characterising a conventional combisystem with gas saving device (Alpha Boilers) and a micro-system for cogeneration of heat and electricity (Gasunie).

2. DC TEST ON THE 600 LITRES COMBISTORE

A full Direct Characterisation test has been carried out at TNO on a 600 litres solar combistore in combination with a common combi gas heater; see Figure 1. In the nine-days test, the solar combistore was combined with a simulated collector area of 7 m^2. European climate zone II (Central European weather) was used for outdoor conditions and heat demand of the house was according to SFH100 with annual space heat demand of 51.27 GJ and hot water demand of 10.77 GJ. The nine-days test was carried out several times in order to also characterize and tune properties of the test facilities. The table below presents the results for two of the tests carried out.

Table 1: *DC test results and annual gas use as result of data processing for two the tests on the 600 litres solar combistore.*

Test	$Q_{L,SH,test}$ [GJ]	$Q_{L,dhw, test}$ [GJ]	$V_{gas,test}$ [m^3]	$m_{water,test}$ [kg]	$Q_{col,test}$ [GJ]	$V_{gas,y}$ [m^3]
I	0.8896	0.1886	34.52	8.500	0.1185	2014
II	0.8897	0.1901	33.90	10.845	0.1682	1976

$Q_{L,SH,test}$: Heat delivered to space heating during the 6 days core phase of the test.
$Q_{L,dhw, test}$: Heat delivered to hot water during the 6 days core phase of the test.
$V_{gas,test}$: Gas used during the 6 days core phase of the test.
$m_{water,test}$: Water mass from the combustion gas during the 6 days core phase of the test.
$Q_{col,test}$: Collector output during the 6 days core phase of the test.
$V_{gas,y}$: Annual gas use.

Conclusions from the test results in the table are:

- The test facilities are able to reproduce conditions with respect to the loads very good: within 1%.
- Gas use in the test differs due to difference in input from the collector. Of course this difference can also be seen in the annual performance prediction.

Further research on the difference in collector input revealed a complex combination of grounds, i.e.:

- Interaction between collector control and test facility behavior.
- Sensitivity of collector control on ambient temperature as the store was not put up in a conditioned room.
- A non-optimized controller and solar combisystem.

Result was very frequent collector pump switching. Adaptation of the device of the test facility providing the heat from the collector led to less frequent collector switching and more unambiguous test results.

3. DC TESTING AND THE ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE

Recently, a new European standard, EN 15316-4-3 ([2]), on the thermal performance of solar domestic hot water (DHW) systems and solar combisystems was published. The new standard provides the link between European product standards and the Energy Performance of Buildings Directive (EPBD); see Figure 2. Product standards involve EN 12976-2 for solar DHW systems, EN 12975-2 for solar collectors and EN 12977-3/4/5 for heat stores and controllers. EN 15316-4-3 supports two methods, i.e. the system approach and the component approach. For the component approach default values for collectors, heat stores and other components can be used to determine the thermal performance of the solar thermal system, or (better) values from component testing. Currently, the system approach has been elaborated for solar DHW systems only and uses the Dynamic System Test procedure as indicated in EN 12976-2. The DC test method provides a potential system approach for solar combisystems to be added in EN 15316-4-3 in future.

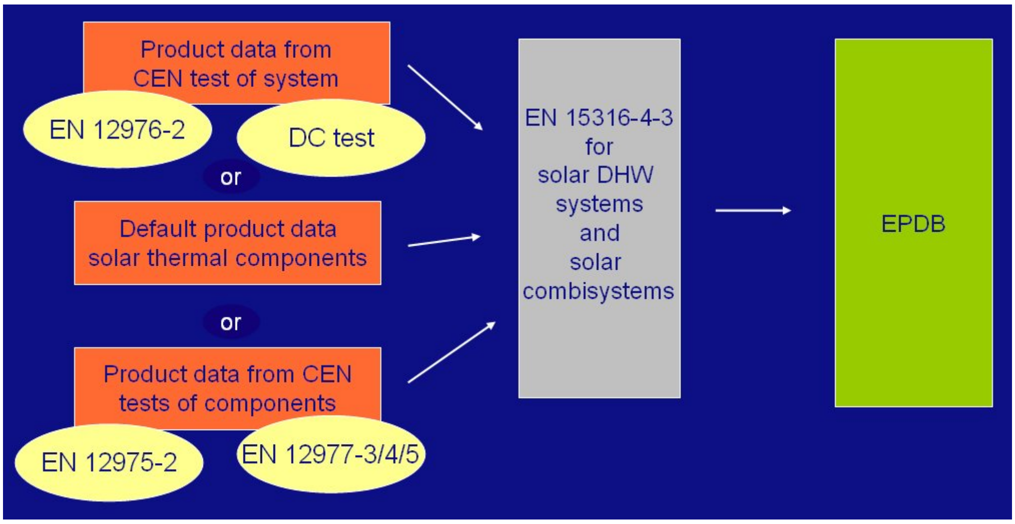

Figure 2: *New European standard EN 15316-4-3 providing the link between product standards, the DC test and the EPBD.*

New standard EN 15316-4-3 estimates reduction of heat load for any climate, space heating and hot water load (see Figure 3), whereas DC testing yields final energy use (and savings) of solar thermal for one climate, one space heating and one hot water load. That means that using the DC test result requires translation into EPBD terms. The so-called FSC method ([3]), result of the work in IEA Solar Heating and Cooling Task 26 may be used for this translation.

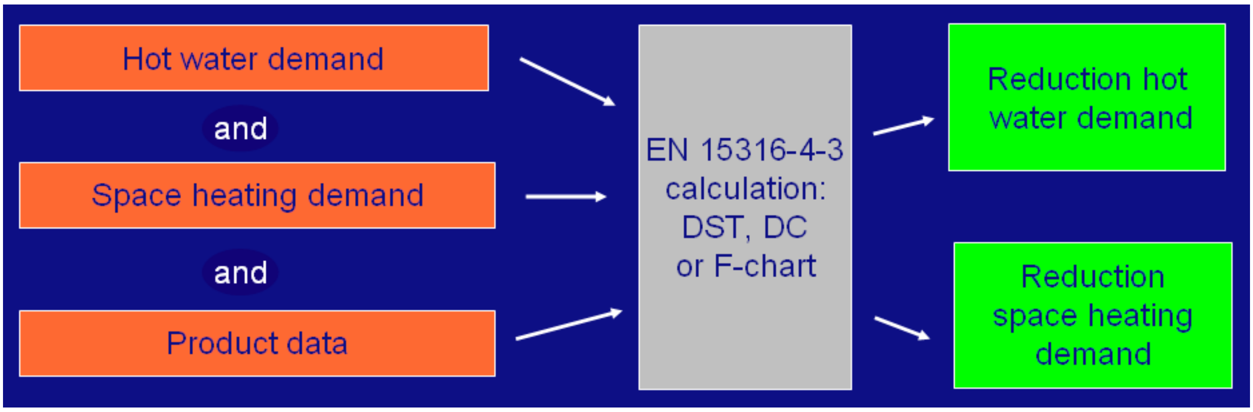

Figure 3: *Input and output of European standard EN 15316-4-3.*

The FSC method presents the fractional energy savings F_{sav} as function of FSC. Fractional energy savings are obtained through dividing the savings by the final energy use of the reference system and the Fractional Solar Contribution presents the annual maximum contribution of solar energy to the final energy use of the reference system. This way of presentation enables characterisation of a solar combisystem in a single curve. Generally, every solar combisystems has its own curve; see Figure 4.

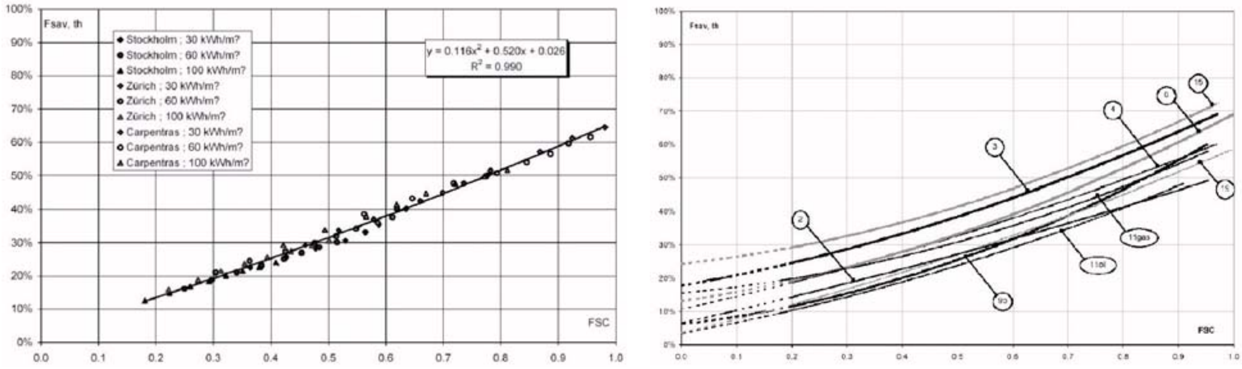

Figure 4: *Exale of a calculated solar combisystem in various climates and houses presented in energy savings as function of fractional solar contribution FSC (left) as well as a whole collection of solar combisystems presented in this way.*

The slope of the curve in the FSC figure is rather constant for all solar combisystems. This provides the basis for extrapolation of the ‘one point’ DC result into thermal performance for a whole range of climates and heat demands; see Figure 5.

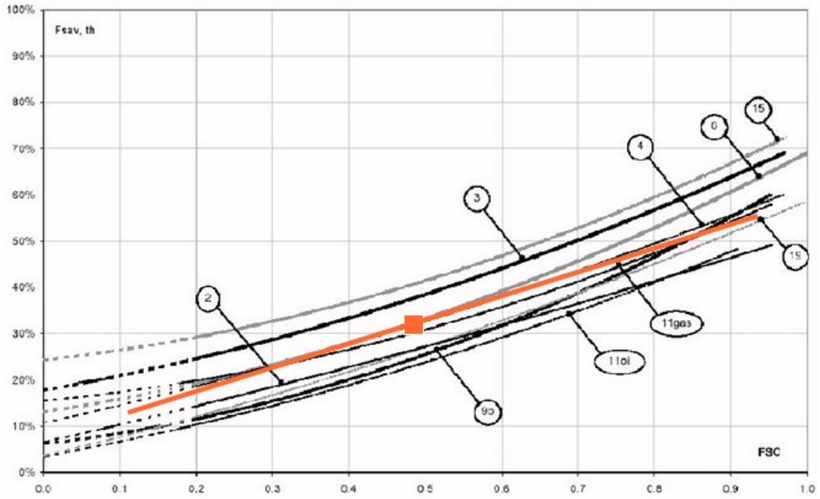

Figure 5: *Example of extrapolation of the DC test result into thermal performance for a whole range of climates and heat demands.*

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[1] Visser, H. Solar combisystems – infrastructure for thermal performance characterisation and possibilities for further knowledge development. Report no. 2004-DEG-R014, TNO, Delft, The Netherlands, 2004.

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[3] T. Letz. Validation and background information on the FSC procedure. Technical report Task 26 – Subtask A. IEA Solar Heating and Cooling Programme.