Validation and background information on the FSC procedure

A Report of IEA SHC - Task 26

Solar Combisystems

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Validation and background information on the FSC procedure

by

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A technical report of Subtask A

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Nomenclature

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

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

1 Introduction

Characterisation of solar combisystems with proper evaluation of performance is difficult. For example, is a solar combisystem with a 10 m² solar collector providing fractional energy savings of 50% for a well insulated house in Carpentras (France) 'better' than another with a 20 m² solar collector that ‘only’ provides fractional energy savings of 20% for in a badly insulated house in Stockholm? What if the first system has a lifetime of 15 years and costs 30 % less than the second one that has a lifetime of 25 years?

A number of questions arise:

- Are some solar combisystems better adapted to particular climates?
- Are some solar combisystems better adapted to particular loads?
- What is the influence of the collector size?
- How can one compare a solar combisystem with a collector range between 5 and 12 m², with a solar combisystem with a collector range between 10 and 30 m²?
- Is it possible to develop a method which removes all external parameters (climate, load, collector size) and makes it possible to characterise a solar combisystem in an intrinsic way?

In the framework of Task 26, a new method has been developed to characterise solar combisystems in a simple way. This method makes it possible to compare systems built in different locations, with different collector areas and delivering heat to different space heating and domestic hot water loads. The basic concept is to compare the actual fractional energy savings of the system with the maximum theoretical fractional energy savings. The method is appropriate for the representation of the two main target functions:

- the fractional thermal energy savings ($f_{sav,therm}$)
- the extended fractional energy savings ($f_{sav,ext}$)
- the fractional solar indicator (f_{si})

2 Target Functions

The target function for the optimisation is based on fractional energy savings f_{sav}. According to CEN/TC 312, ISO/TC 180, f_{sav} is related to the purchased auxiliary energy. Three different indicators are used.

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

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

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

with:

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

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

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

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

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

with:

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

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

η_{el} = 40% for all systems

2.3 Fractional savings indicator (f_{si})

This last definition includes also the penalty function of the solar combisystem in the fractional energy savings.

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

3 Fractional Solar Consumption definition

The monthly final energy demand for heating ($E_{ref,month}$) in an example house is shown in the first line of Table 1. The data include store and boiler losses as well as boiler efficiency, giving the so-called **'reference consumption'**. This monthly reference consumption without a solar combisystem $\mathbf{E_{ref,month}}$ [kWh] is calculated with the following equation:

Equ. 4: $$E_{ref,month} = \frac{(Q_{SH} + Q_{DHW} + Q_{loss,ref})}{\eta_{boiler,ref}}$$

where: Q_{SH} is the monthly space heating load

Q_{DHW} is the monthly domestic hot water load

$Q_{loss,ref}$ are the monthly storage tank losses

$\eta_{boiler,ref}$ is the reference boiler efficiency

For the reference system, no heat-store for space heating is assumed. The monthly heat loss of the DHW-storage of the reference system $Q_{l,ref}$, is given by [1]:

equ.5: $$Q_{loss,ref} = (UA)_{S,ref} \cdot (T_S - T_{amb}) \cdot \Delta t_m$$ [kWh]

where: $(UA)_{S,ref}$ is the heat loss rate of the store [W/K]
T_S is the reference storage temperature [52.5 °C]
T_{amb} is the reference room temperature [15 °C]
Δt_m is the number or hours in the month

The size of the store, $V_{S,ref}$, is defined as 0.75 times the daily DHW-discharge volume (in litres), with the heat loss rate: $(UA)_{S,ref} = 0.16\sqrt{V_{S,ref}}$ in W/K (prENV 12977-1:2000).

With a reference daily DHW-discharge volume of 200 litres, the size of the reference tank is 150 litres.

Table 1: Example calculation of FSC value

[kWh]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Reference consumption	2659	2131	1477	989	412	320	237	226	359	1230	1905	2494	14415
Solar irradiation available	716	991	1477	1740	1989	2017	2335	2183	1769	1230	663	558	17668
Usable solar energy	716	991	1477	989	412	320	237	226	359	1230	663	558	7943
												FSC	0.57

The solar irradiation on the collector area is calculated by multiplying the solar collector area **A** [m²] by the monthly global irradiation in the collector plane **H** [kWh/m²]. The monthly reference consumption and the solar irradiation are shown on Fig. 1 where they define three zones:

① : Final energy consumption of the building, which exceeds the solar potential.
② : Final energy consumption of the building that could be saved by solar energy. This is called 'usable solar energy' ($\mathbf{Q_{solar,usable}}$).
③ : Solar energy in excess.

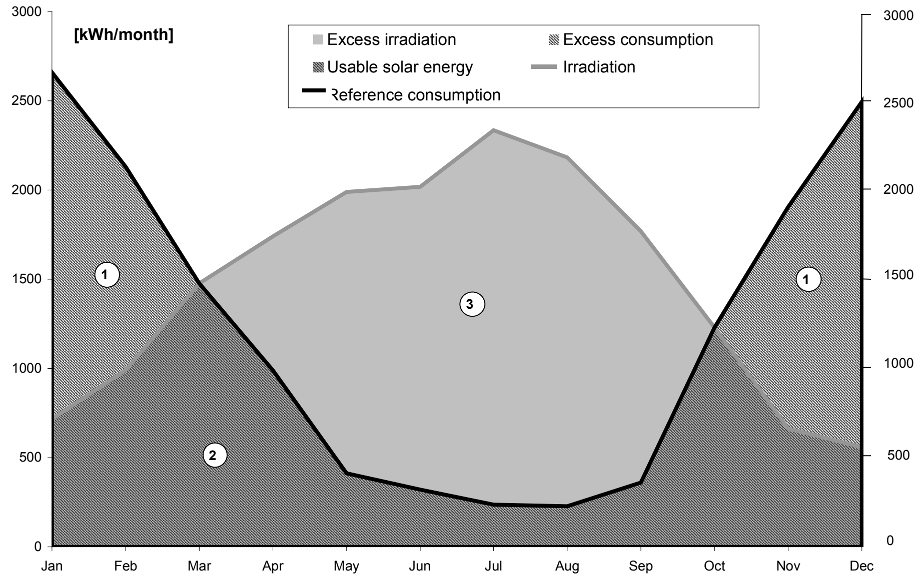


Fig. 1: Monthly plot of final energy consumption for a reference system and solar radiation on a specific collector area, azimuth and slope

$Q_{solar,usable}$ is calculated on a monthly basis in a simple way, using the solar collector area **A** [m²], the monthly solar irradiation in the collector plane **H** [kWh/m²] and the monthly reference consumption $\mathbf{E_{ref,month}}$ [kWh]. The minimum of this reference consumption and the available irradiation is taken for each month and then summed over the year:

equ. 5: $$Q_{solar,\,usable} = \sum_{1}^{12} \min(E_{ref,\,month}\ , A \cdot H)$$

The yearly <u>reference consumption</u> E_{ref} is the sum of the monthly reference consumptions $E_{ref,month}$:

equ. 6: $$E_{ref} = \sum_{1}^{12} E_{ref,month}$$

Dividing the usable solar energy $Q_{solar,usable}$ (②) by the reference consumption of the house $\mathbf{E_{ref}}$ (① + ②), a new parameter, called **Fractional Solar Consumption (FSC)** is defined. FSC can be considered as the <u>maximum theoretical fractional energy savings</u>, which could be reached if the solar combisystem had no losses.

equ. 7: $$FSC = \frac{Q_{solar,usable}}{E_{ref}}$$

FSC is a dimensionless quantity, which takes simultaneously into account the climate, the building (space heating and domestic hot water loads), the size of the collector area, and its orientation and tilt angle, but which <u>does not depend on the choice of any particular solar combisystem</u>.

Table 1 above shows an example of the calculation procedure, resulting in a FSC of 0.57.

Comparing the real fractional energy savings to FSC gives a good indication of the ‘effectiveness’ of a solar combisystem; the closer f_{sav} is to FSC, the better the solar combisystem converts the usable solar energy into real auxiliary energy savings.

4 Relation between target functions and fractional solar consumption

Analysis of simulations made in the framework of Task 26 has shown that plotting the target functions, real fractional energy savings (thermal or extended), against FSC gives a cloud of points with a parabolic shape. Thus the target functions can be expressed by a very simple parabolic equation in FSC, and the coefficients for it can be identified with a very good regression coefficient (close to 1).

equ. 8: $f_{sav} = a \cdot FSC^2 + b \cdot FSC + c$

a, **b** and **c** are 3 characteristic coefficients of the solar combisystem.

The fractional thermal energy savings and the extended fractional energy savings are calculated according to the equations given in chapter 2.

Fig. 2 is an example of the relation between $f_{sav,\,therm}$ and FSC. Points have been calculated for the 3 reference climates and the 3 reference houses defined by Task 26 and for several collector sizes. For this diagram, a French design tool for System #3a, called PSD-MI [2], has been used. The reference values (domestic hot water tank losses and boiler efficiency) are not exactly the same as those defined in Task 26, but this does not matter: what is important to consider is the distribution of points. It can be seen that the points are close to the mean parabola (regression factor very close to 1).

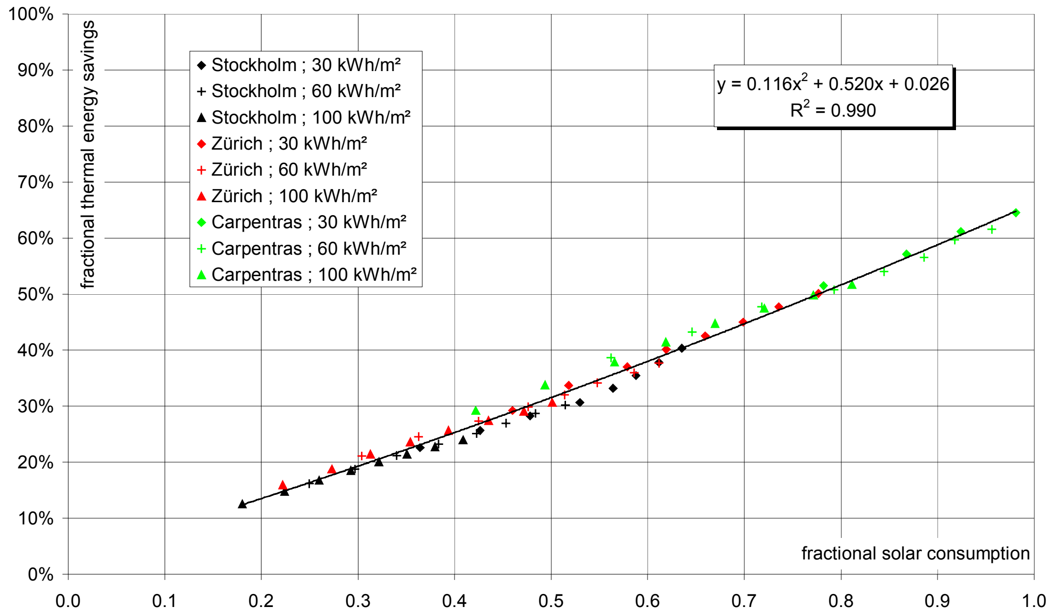


Fig. 2: Fractional thermal energy savings versus fractional solar consumption for System #3a, calculated with PSD-MI [2]

Figure 3 gives the results for the fractional thermal energy savings, for all systems simulated in Task 26. Many simulations were carried out using different system sizes. Some of these were done to do a sensitivity analysis of that particular parameter but didn't match systems that are actually sold by the manufacturer, for example a very small storage tank with a very large collector area. These points were eliminated from the curves. In the same way, only points where the comfort criteria are achieved have been kept.

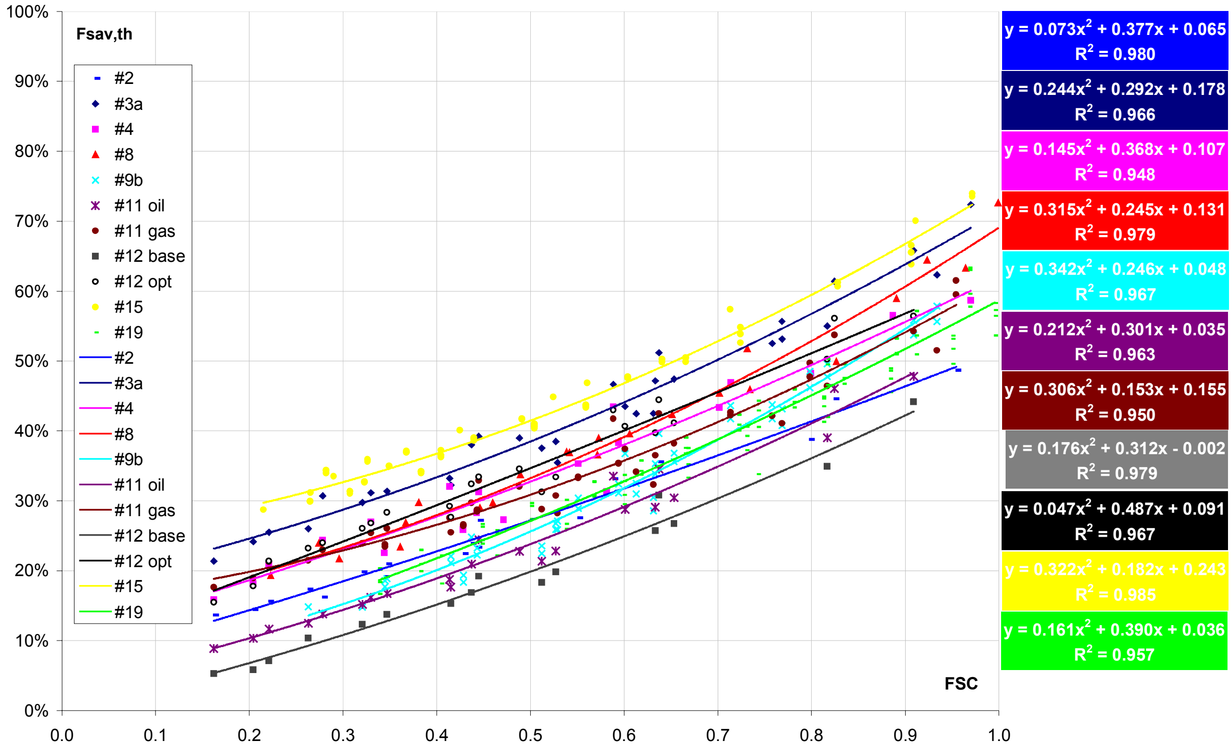


Fig. 3: Fractional thermal energy savings versus fractional solar consumption for systems simulated in task 26

Similar figures have been drawn for the extended fractional energy savings and for the fractional solar indicator (figures 4 and 5): similar shapes of curves can be noticed.

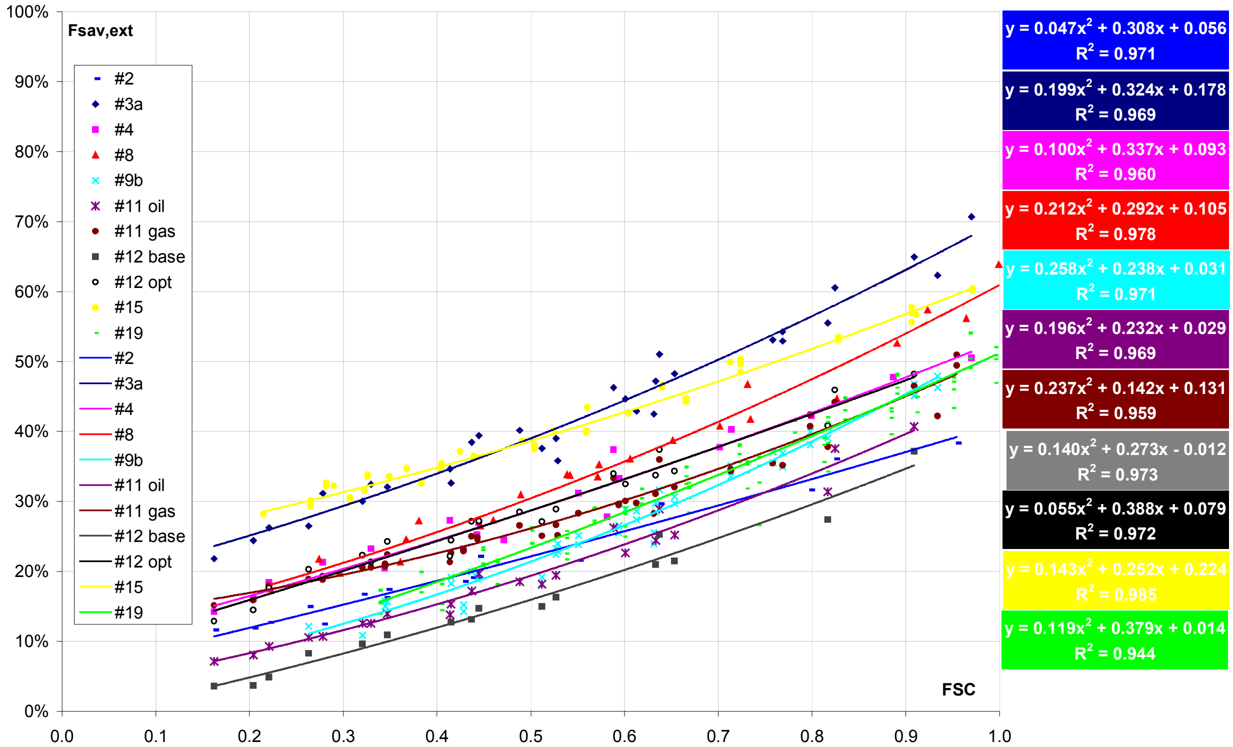


Fig. 4: Extended fractional energy savings versus fractional solar consumption for systems simulated in task 26

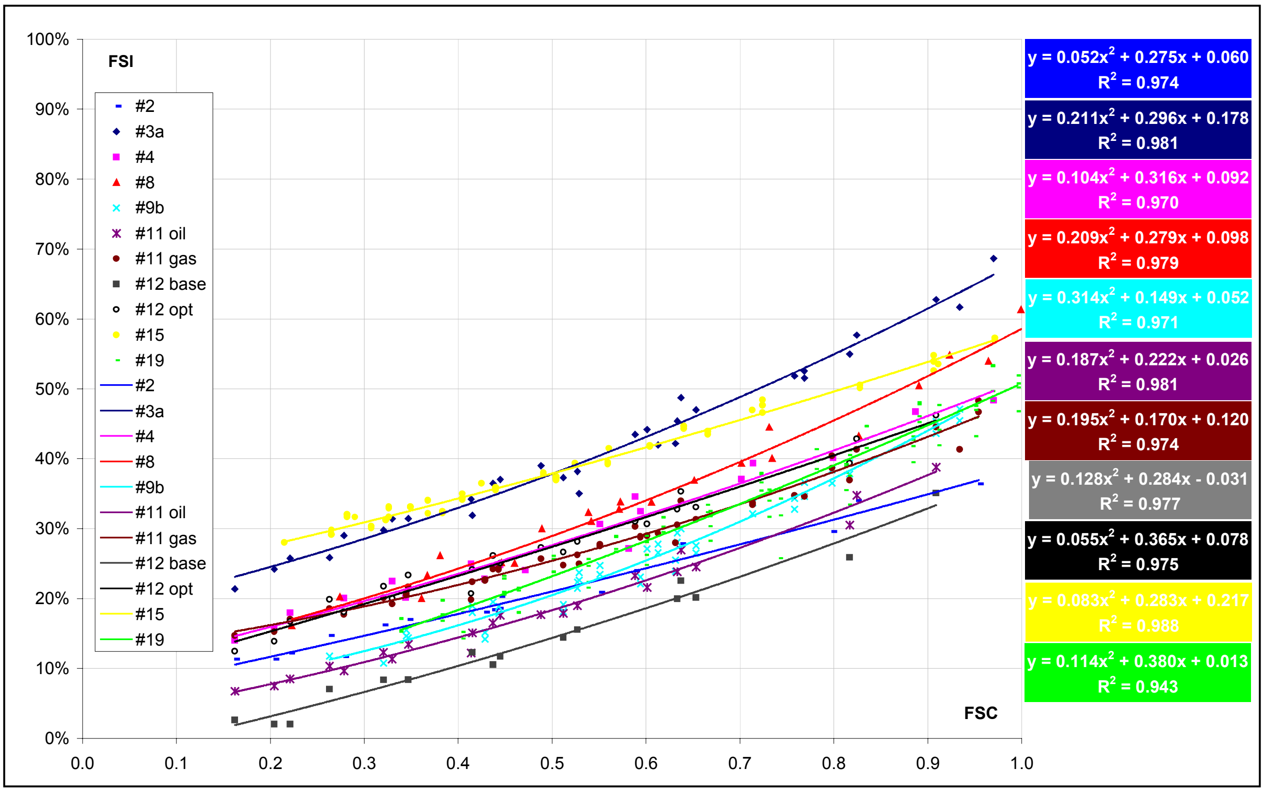


Fig. 5: Fractional solar indicator versus fractional solar consumption for systems simulated in task 26

It must be pointed out that there is a limit to this presentation, and that points where FSC = 1 obviously have to be eliminated. But the method can be used for the three target functions.

5 Improvement of the method: Definition of a storage capacity correction factor

A scattering of points around the parabolic curve can be noticed. In order to investigate this, points have been sorted according to the storage size / collector area ratio. The following figure shows some $f_{sav,therm}$ curves from Fig. 2, with points for three different ratios. Obviously, scattering of points is reduced. Results classified according to this ratio show better regression factors. For a small ratio the heat storage capacity is too low leading to a poorer collector efficiency and consequently a lower $f_{sav.}$

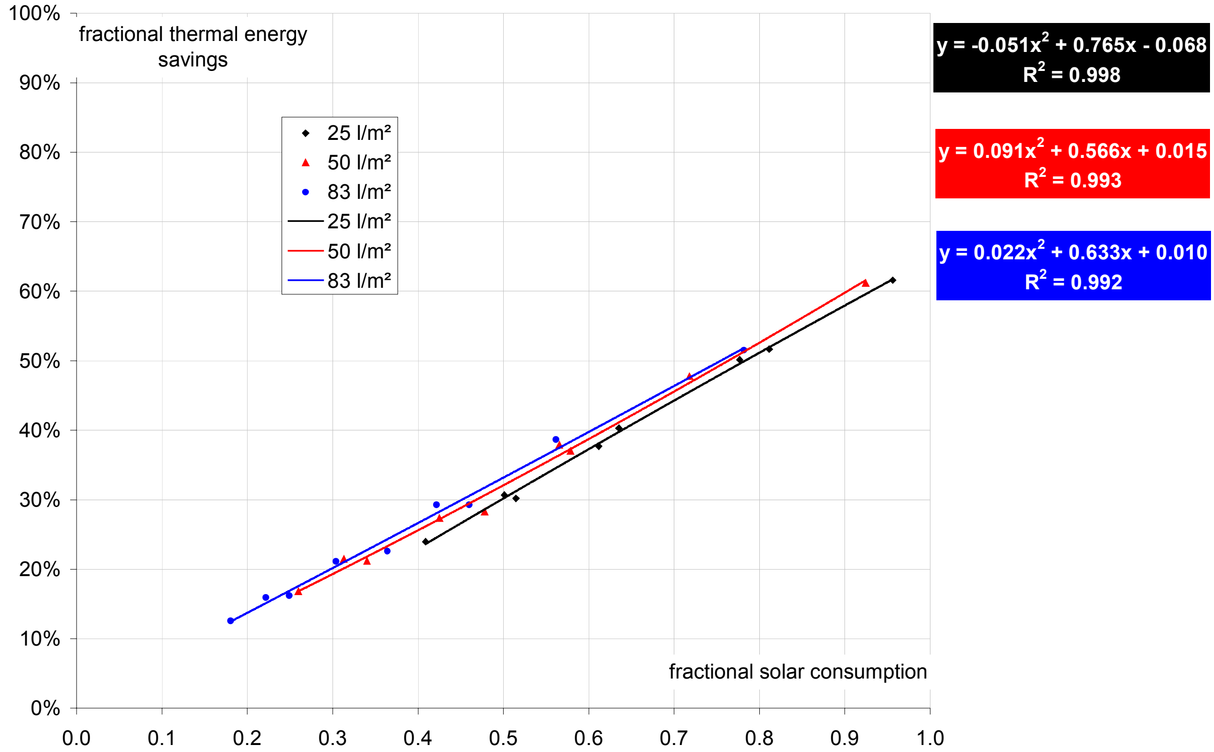


Fig. 6: Fractional thermal energy savings versus fractional solar consumption for System #3a, sorted according to the ratio storage size / collector area

Therefore, a **storage capacity correction factor SC** has to be introduced, in the same way as it is done in the f-chart method [4]. Equation 8 has to be slightly modified and becomes equation 9 with characteristic coefficients **a'**, **b'** and **c'** instead of **a**, **b** and **c**.

equu.9: $$f_{sav,therm} = SC\,(a' \,.\, FSC^2 + b' \,.\, FSC + c'\,)$$

An equation for SC has been derived so that SC has a maximum value of 1 for a specific storage size / collector area ratio.

equ.10:
$$SC = \left(\frac{V}{\alpha \,.\, A} + \beta\right)^{\gamma} - \gamma\,(1+\beta)^{(\gamma-1)}\left(\frac{V}{\alpha \,.\, A} + \beta\right) + 1 - (1-\gamma)(1+\beta)^{\gamma}$$

where: V is the storage volume [l]
A is the collector area [m²]

α, β and γ have been calculated in order to get the highest regression factor for the parabolic curve representing $f_{sav,th}$ /SC versus FSC. The following values have been obtained:

α = 160 l/m² β = 0.1 γ = 0.25

With these numerical values equation 10 becomes:

equ.11:
$$SC = \left(\frac{V}{160\ A} + 0.1\right)^{0.25} - 0.001455\,\frac{V}{A} + 0.20864$$

Using this more accurate method the regression factors of the parabolic curve are improved for most systems and just kept identical for some others, as shown in figure 7. System #4 has a constant storage size / collector area ratio, so that there is no influence of introducing the storage size correction factor.

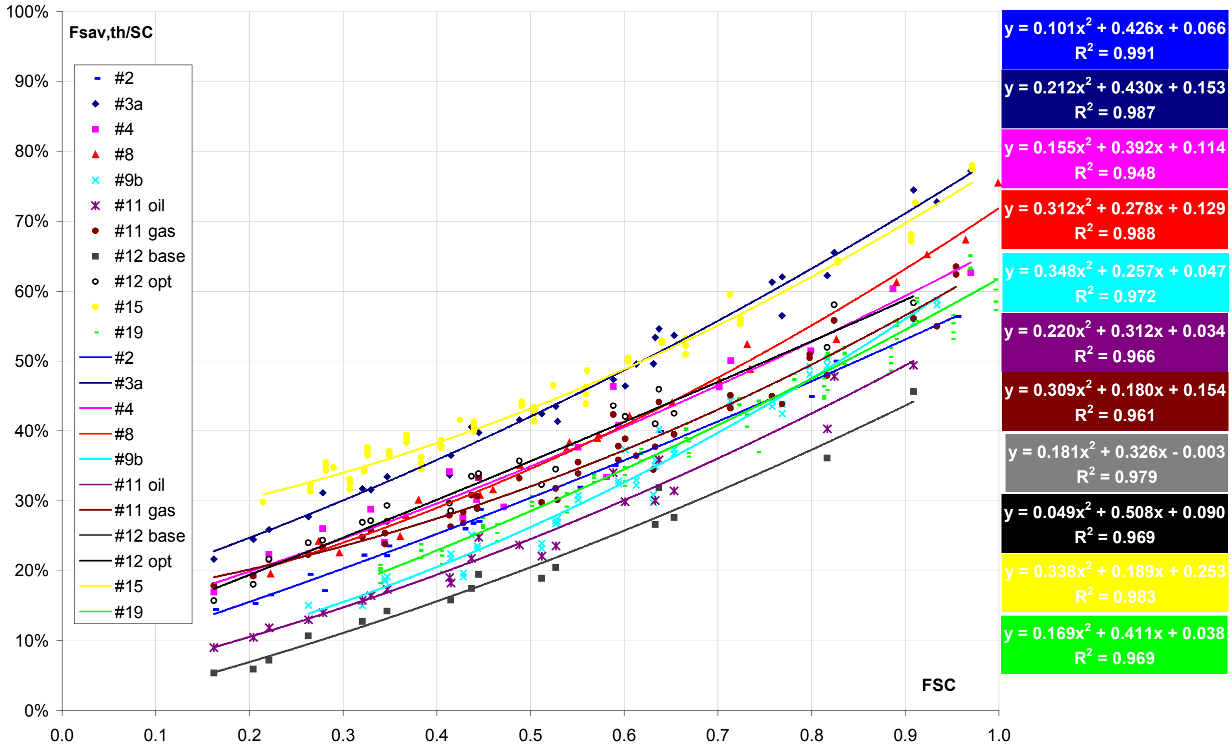


Fig. 7: Fractional thermal energy savings with storage size correction factor, according to fractional solar consumption for systems simulated in task 26

In Figure 8 the storage size correction factor has been plotted against the storage size / collector area ratio.

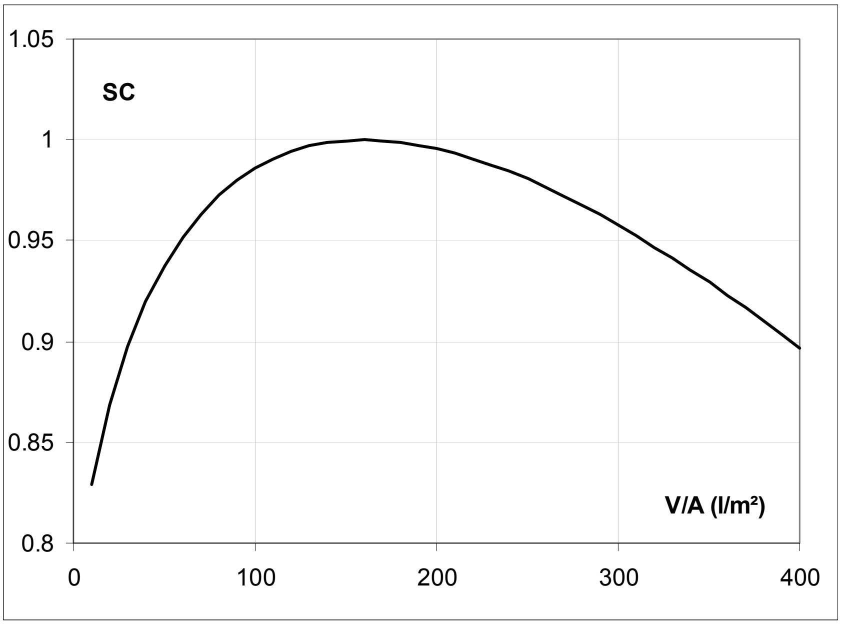


Fig. 8: Storage size correction factor

Similar figures have been drawn for the extended fractional energy savings and for the fractional solar indicator (figures 9 and 10): similar shapes of curves can be noticed.

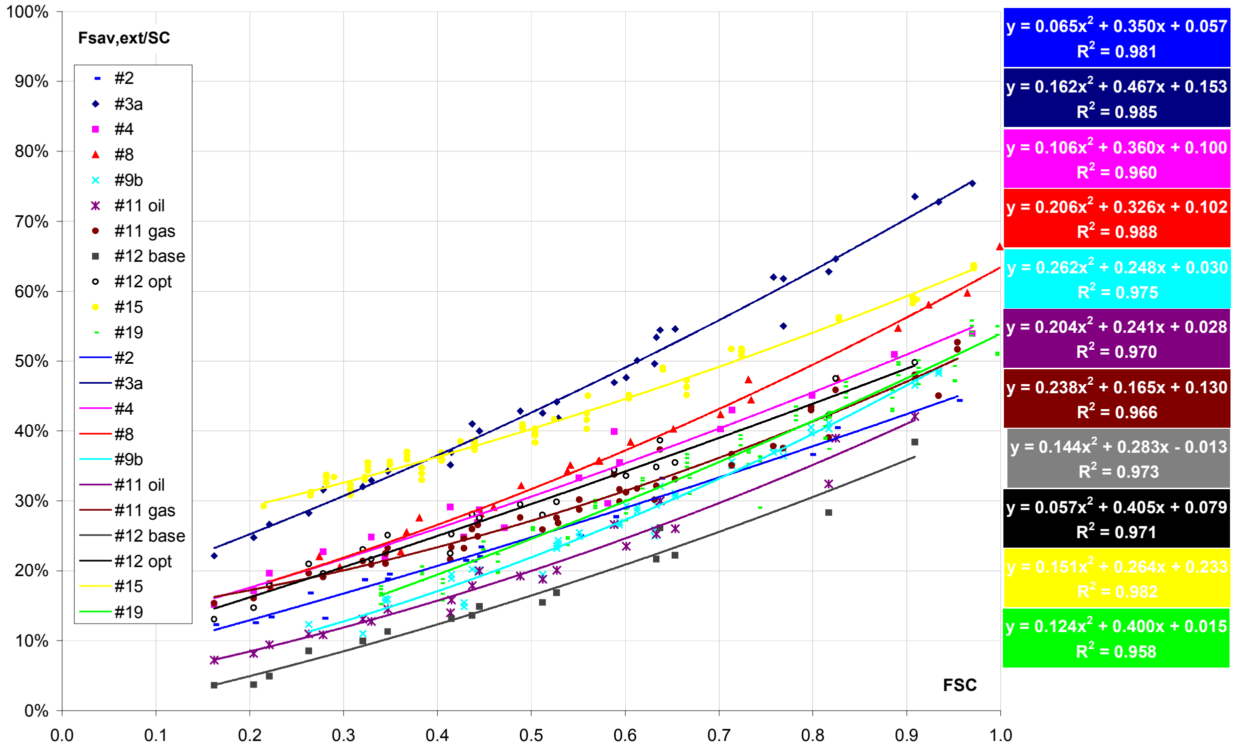


Fig. 9: Extended fractional energy savings with storage size correction factor, according to fractional solar consumption for systems simulated in task 26

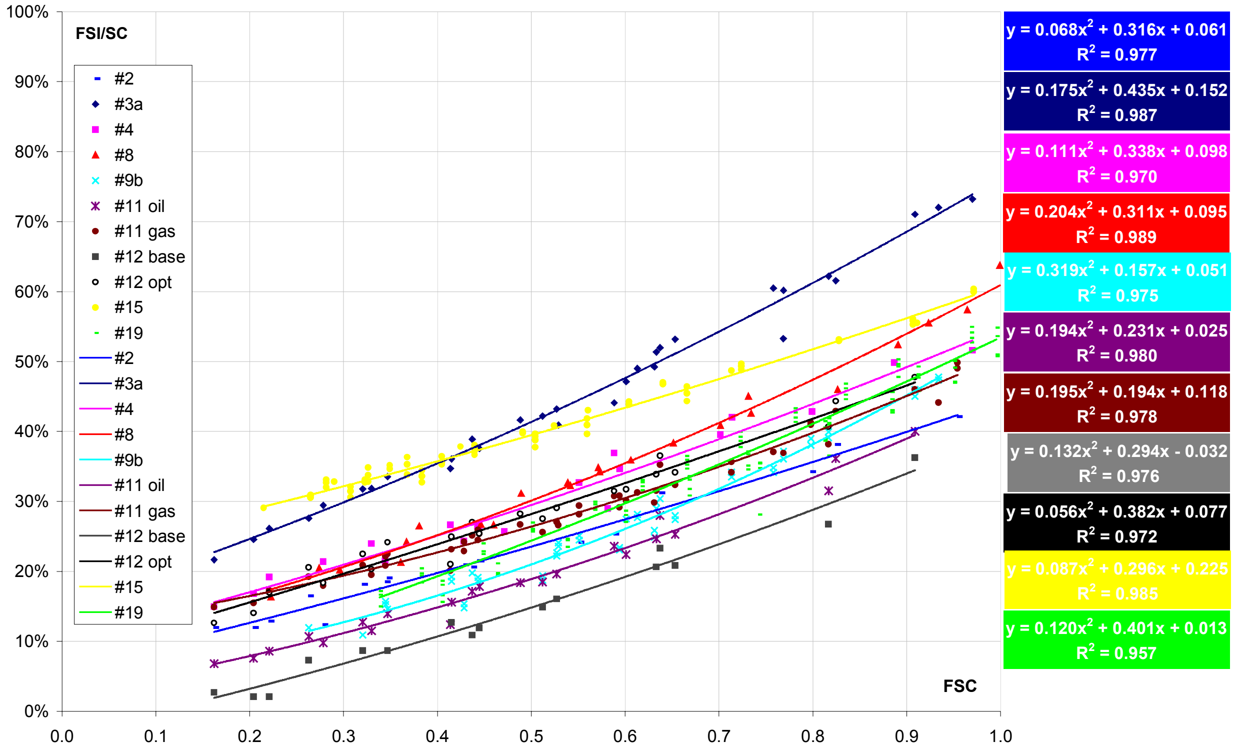


Fig. 10: Fractional solar indicator with storage size correction factor, according to fractional solar consumption for systems simulated in task 26

6 Effect of storage size

In results presented until here, curves have been drawn for systems only differing by their hydraulic diagram. But it is not obvious that combisystems with identical hydraulic diagrams, but having different storage sizes, can be represented by a single curve.

Some systems exist or have been simulated with a single storage size: it is the case for Systems #2, #3a, #8. It can be noticed that curves for these systems show the highest regression factors.

Other combisystems can be installed with different storage sizes, so that they can behave more or less differently according to this parameter, and according to other linked parameters such as the heat loss coefficient of the storage tank, the size of the heat exchanger(s),...

Figure 11 show curves sorted according to storage sizes for 2 different systems.

For System #9b, curves for different storage sizes are close each other. The regression factor for all storage sizes (0.972) is not far from those for each storage size (0.958, 0.968, 0.973 and 0.986). In that case, the behaviour of the system can be described by a unique data set a, b and c.

Curves for System #11 gas differ more. The regression factor for all storage sizes together (0.961) is much smaller than the one for each storage size (0.980 and 0.991). In that case, the behaviour of the system cannot be described by a unique data set a, b and c.

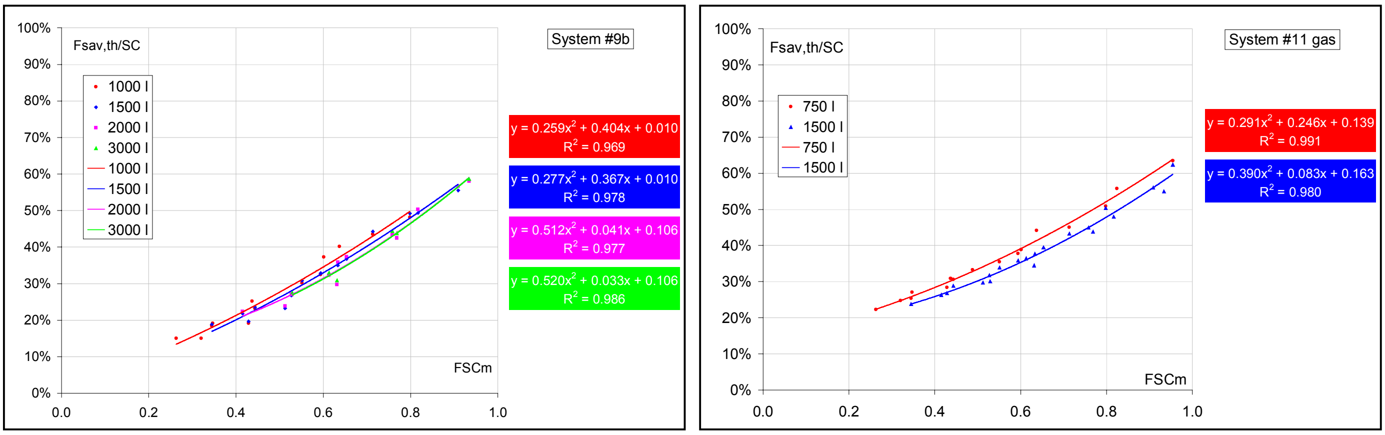


Fig. 11: Fractional thermal energy savings with storage size correction factor, according to fractional solar consumption, sorted out according to storage sizes

7 Calculation of FSC on a daily basis

One can wonder whether it is better to calculate the fractional solar consumption on a monthly basis or on a daily basis, using a method similar to the one presented in chapter 3, and if it would lead to a more accurate correlation.

For a daily approach, equations 4, 5, 6 and 7 have to be adapted and become:

equ.12: $$E_{ref,day} = \frac{Q_{SH,d} + Q_{DHW,d} + Q_{loss,ref,d}}{\eta_{boiler,ref}}$$

where: $Q_{SH,d}$ is the daily space heating load

$Q_{DHW,d}$ is the daily domestic hot water load

$Q_{loss,ref,d}$ are the daily storage tank losses

$\eta_{boiler,ref}$ is the reference boiler efficiency

equ.13: $$Q_{loss,ref,d} = (UA)_{S,ref} \cdot (T_S - T_{amb}) \cdot \Delta t_d \qquad \text{(kWh)}$$

where: Δt_d is the number or hours in a day

equ.14: $$Q_{solar,usable} = \sum_{1}^{12} \min(Cons_{ref,d}, A.H_d)$$

where: H_d is the daily irradiation in the collector plane (kWh/m²)

equ.15: $$E_{ref} = \sum_{1}^{365} E_{ref,day}$$

Figures 12, 13 and 14 show how the curves of figures 7,9 and 10 are modified using this daily approach.

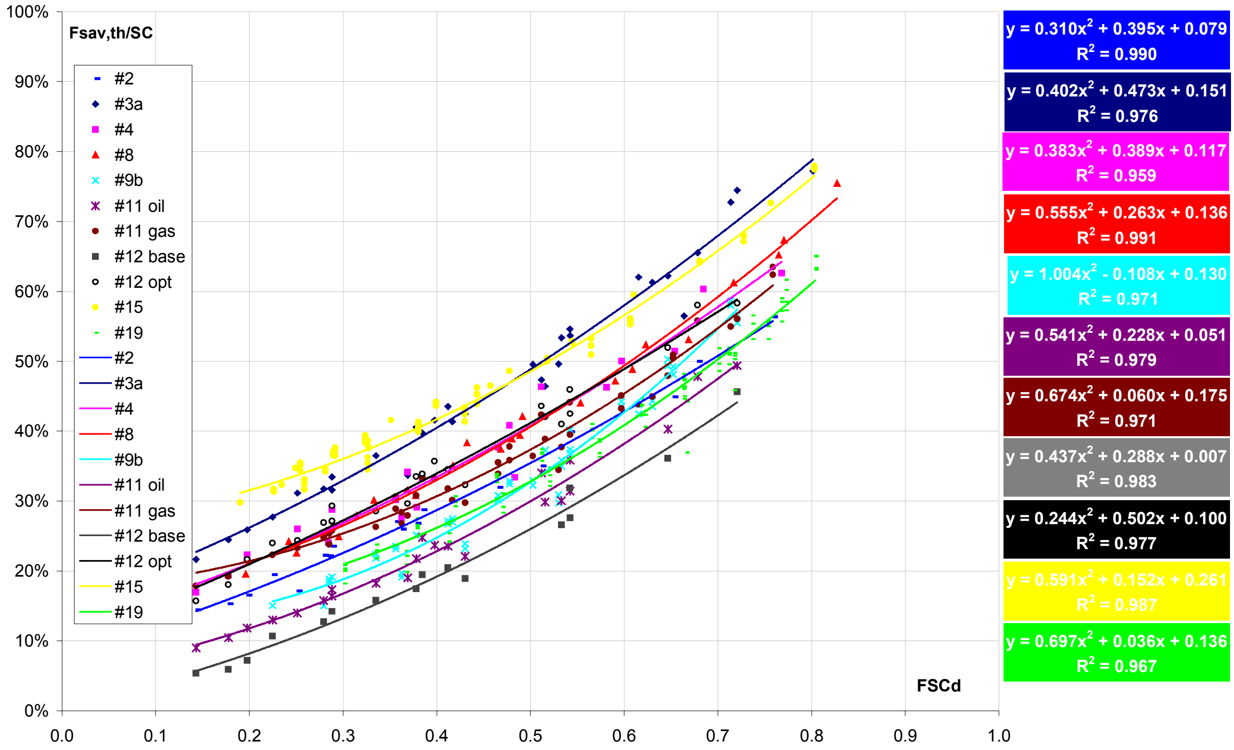


Fig. 12: Fractional thermal energy savings with storage size correction factor, versus fractional solar consumption calculated on a daily basis, for systems simulated in task 26

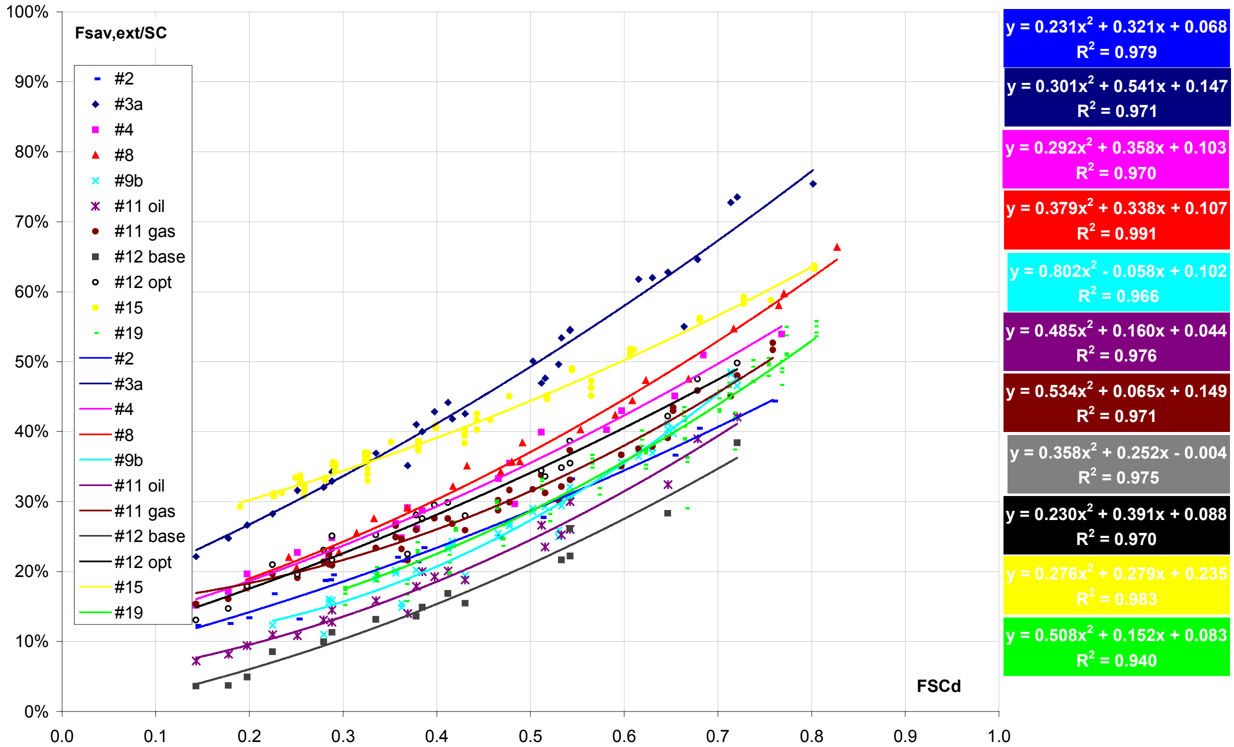


Fig. 13: Extended fractional energy savings with storage size correction factor, versus fractional solar consumption calculated on a daily basis, for systems simulated in task 26

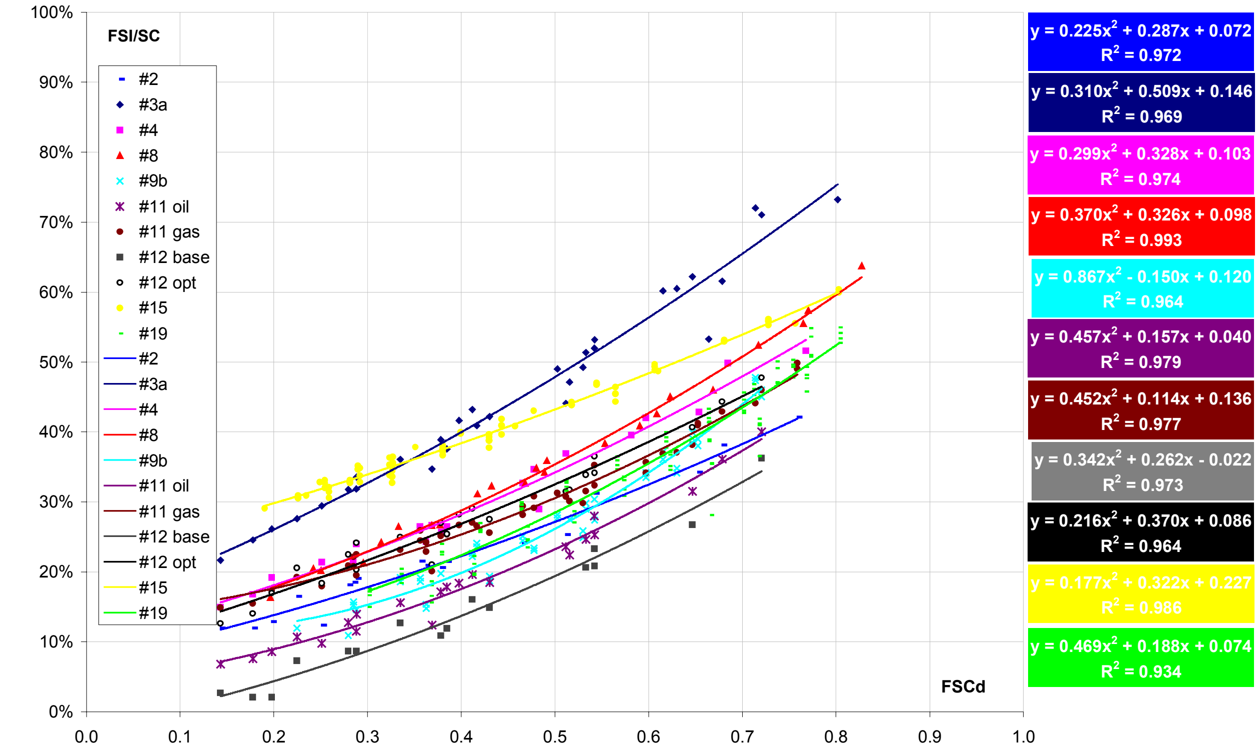
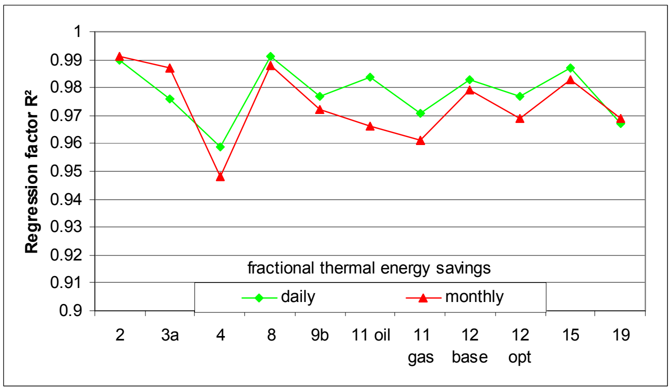
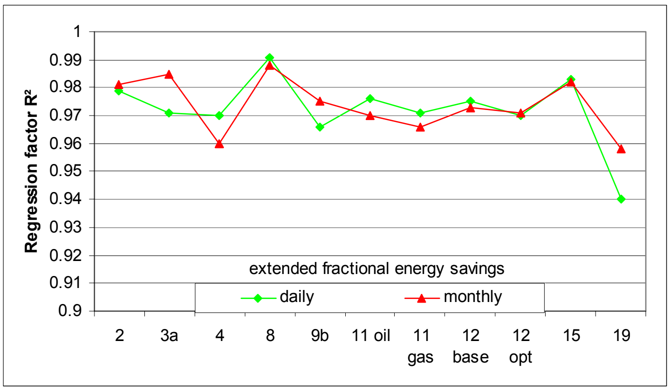


Fig. 14: Fractional solar indicator with storage size correction factor, according to fractional solar consumption calculated on a daily basis, for systems simulated in task 26

Comparing the regression factors R^2 (figure 15) , it can be seen that for some systems, the daily approach improves the accuracy of the curves, but in some cases, it is the opposite.





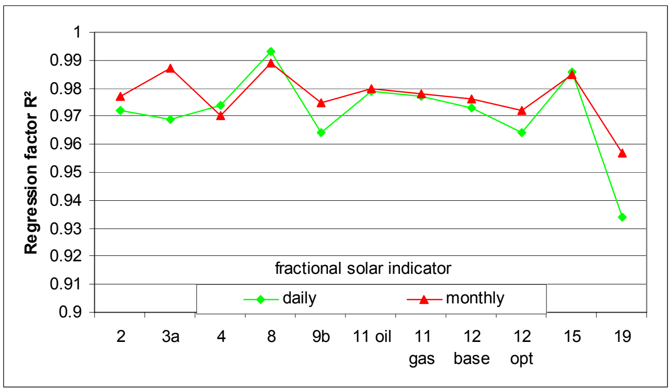


Fig. 15: Comparison between monthly and daily approach for the fractional solar consumption

Figure 15 gives an overview of the results: the daily approach seems to be a little more accurate for the fractional thermal energy savings, but not as good for the fractional solar indicator. For the extended fractional energy savings, both methods lead to equivalent results. No superiority of a method on the other is evident. So it can be concluded that both method are globally equivalent. Due to the fact that a monthly calculation is much easier and faster than a daily one, and also to the fact that the monthly approach is better adapted to the presentation of monitoring results, <u>it can be concluded that the monthly approach can be fruitfully adopted.</u>

8 Validation of the FSC method

For results presented until here, all simulations have been made with a south-oriented solar collector, a tilt angle of 45 °, and with a DHW consumption of 200 l/day. In order to test the validity of the FSC method, additional simulations have been performed with other parameters. It is a first attempt to extend the range of parameters.

Below, two examples with other values are presented:

8.1 System #11 oil (simulations by Chris Bales)

- specific storage volume: 93 l/m²
- collector azimuth angle between 0 and 67.5 °
- collector tilt angle between 22.5 and 90 °

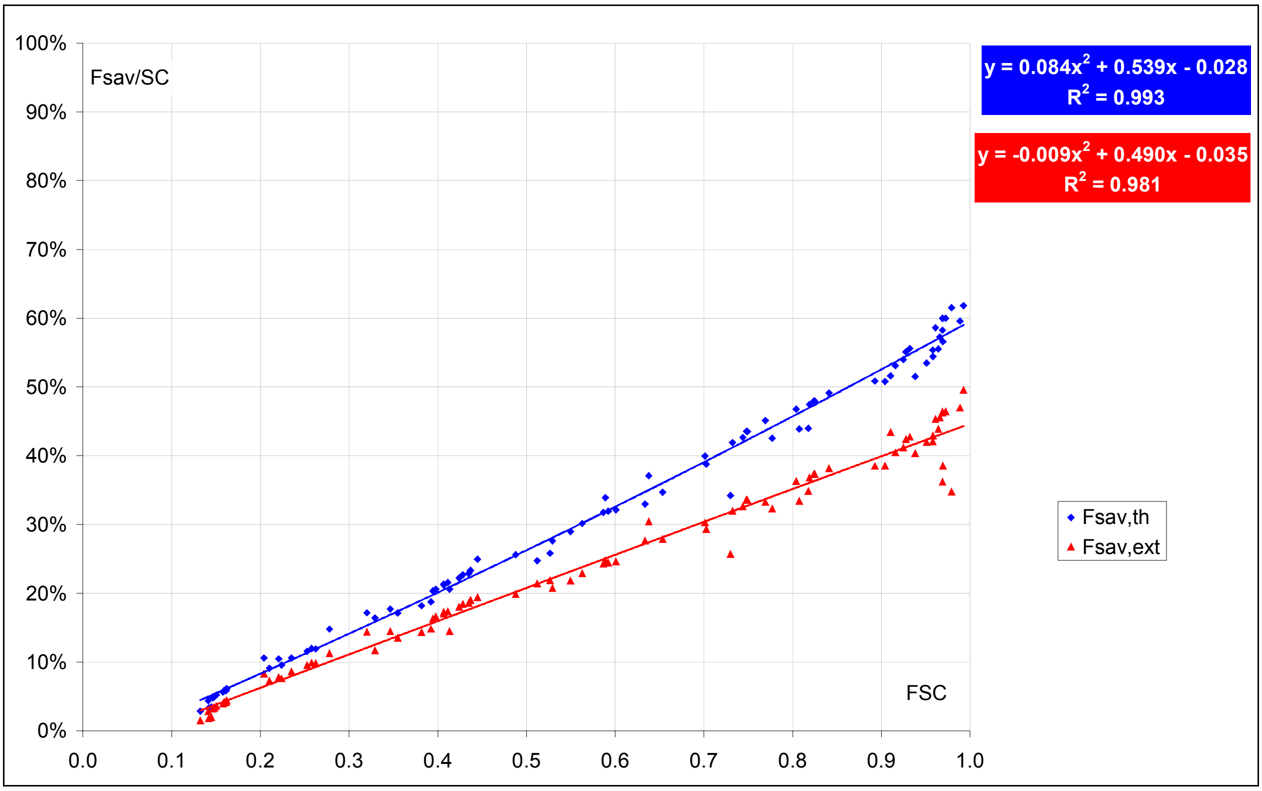


Fig. 17: Fractional energy savings with storage size correction factor, according to fractional solar consumption for System #11 oil (calculations by Chris Bales)

8.2 System #3, 500 l storage (simulations by Thomas Letz)

- for this study, calculations have been performed with System #3 described in the coloured booklet [3], leading thus for $f_{sav,therm}$ to absolute values that differ from those shown in previous figures.
- collector azimuth angle between 0 and 67.5 °
- collector tilt angle between 22.5 and 90 °
- DHW consumption: 100 l/d, 200 l/d, 300 l/d

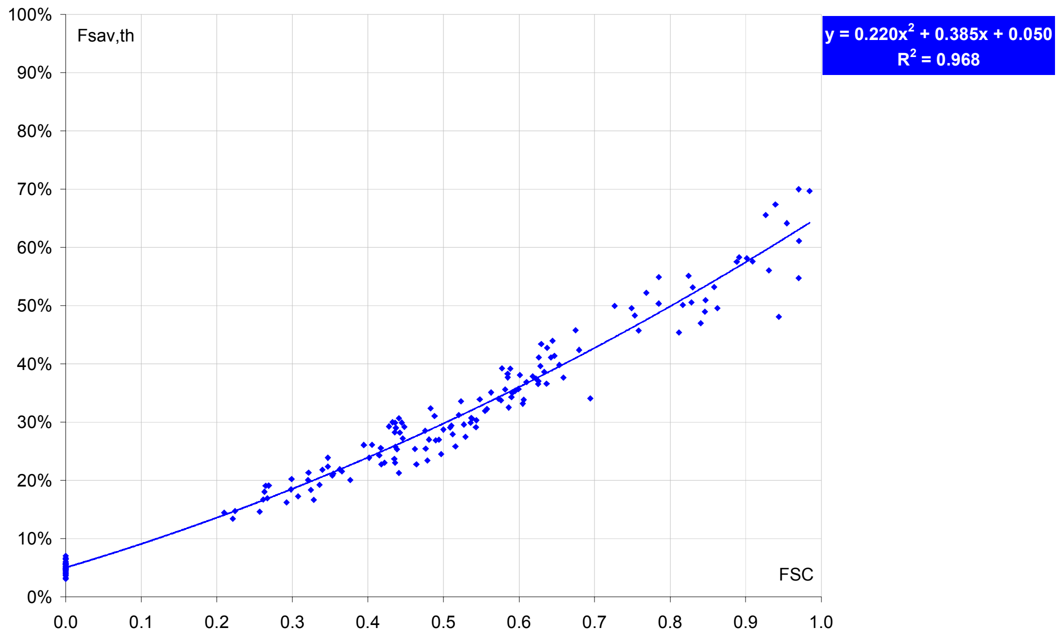


Fig. 18: Fractional energy savings without storage size correction factor, according to fractional solar consumption for System #3a (calculations by Thomas Letz)

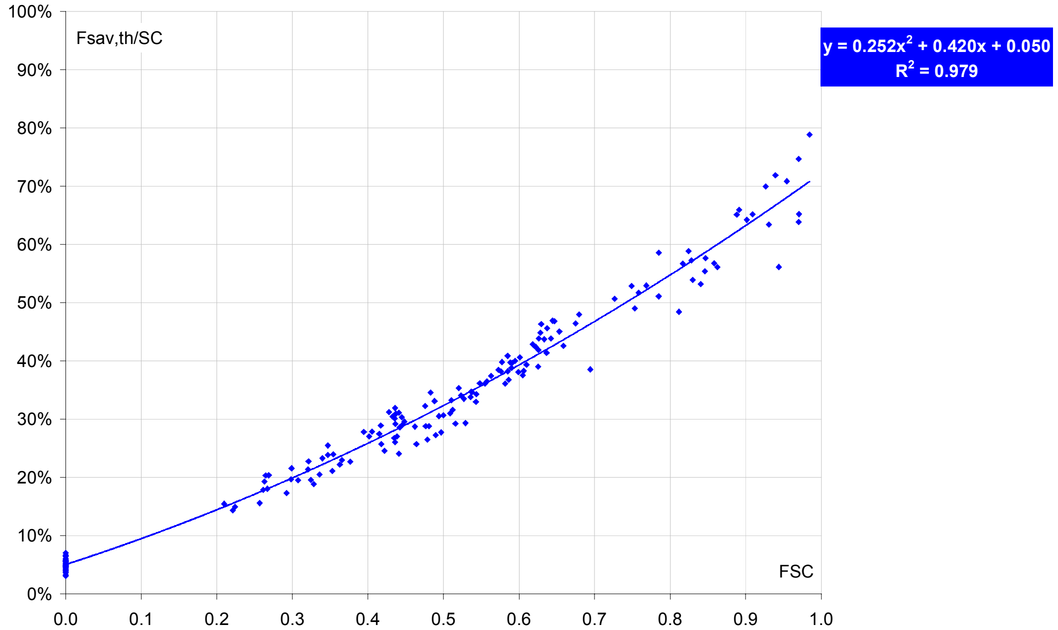


Fig. 19: Fractional energy savings with storage size correction factor, according to fractional solar consumption for System #3a (calculations by Thomas Letz)

For both examples, equation 11 with the storage capacity correction factor of equation 13 gives good results, showing that the FSC method can be used for a wide range of system parameters. However, it would be useful to have a deeper look at that point.

9 Use of the FSC procedure to calculate auxiliary energy

The FSC procedure can be used to calculated very easily an estimate of the auxiliary energy used by a combisystem $\hat{E}_{aux}$. The first step is to calculate an estimate of the fractional thermal energy savings $\hat{f}_{sav,\,therm}$:

equ.16: $\hat{f}_{sav,\,therm} = a\,.\,FSC^2 + b\,.\,FSC + c$ (simplified method)

or $\hat{f}_{sav,\,therm} = SC\,(\,a'\,.\,FSC^2 + b'\,.\,FSC + c'\,)$ (detailed method)

equ.17: $\hat{E}_{aux} = E_{ref}\,(\,1 - \hat{F}_{sav,\,therm})$

Comparing the auxiliary energy calculated by simulations $E_{aux,sim}$ with the simplified estimate $\hat{E}_{aux}$ allows to evaluate the accuracy of the FSC method for development of simplified design tools. Figure 20 shows the result of the comparison of estimations using the simplified method, without storage size correction factor, for simulations of the 11 studied combisystems.

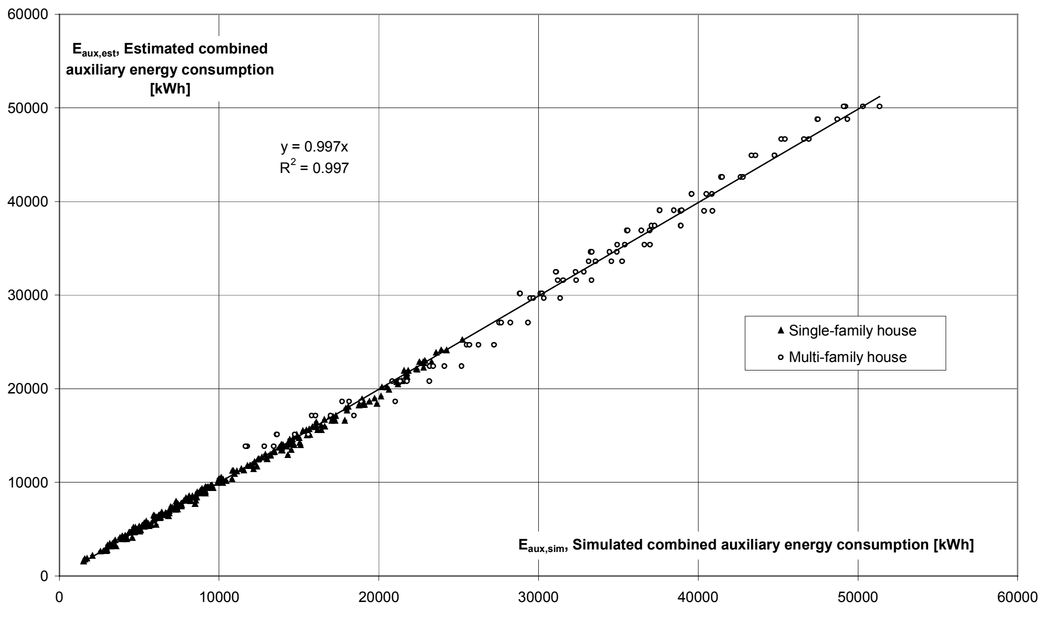


Fig. 20: Comparison between estimated and simulated auxiliary energy

Estimated values of auxiliary energy are very close to simulated values, since the regression factor (0.997) is very close to 1. Using the storage size correction factor improves a little more the accuracy of the method, since the regression factor reaches 0.998.

10 Conclusion and recommendations

The FSC procedure provides an easy way to characterise and compare combisystems. Different accuracy levels can be adopted, with or without storage size correction factor, depending on the required accuracy level.

The method works equally well for the three target functions defined by task 26.

10.1 Combisystems characterisation

A generic combisystem can be described by:

- A hydraulic diagram, related to a specific concept
- A control strategy
- Main dimensioning parameters:
  - collector area range
  - storage volume range

  Storage size and collector area must be chosen in a given range, with realistic values (figure 21).
- Secondary dimensioning parameters, usually dependent on the storage size:
  - heat exchangers size
  - insulation level (UA-value for the store)
  - volume heated by the auxiliary ….
  - …

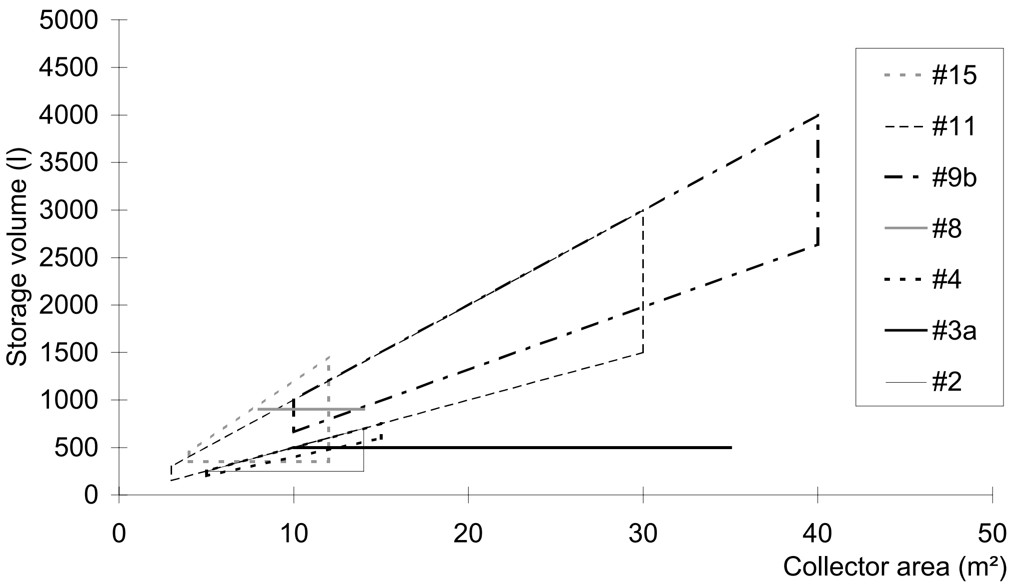


Fig. 21: Example of size diagram of combisystems (numbers refer to the generic systems)

With regard to the characteristic coefficients suitable for the FSC procedure, three different situations can be met:

- system installed with a unique storage size (for example #3a or #8): the system is described by a single data set **a**, **b** and **c** (or **a'**, **b'** and **c'**).

- system installed with several storage sizes, that cannot be summarised in a single equation (for example #11 gas): one data set for each storage size. For rough evaluation, a single data set could be used.
- System installed with several storage sizes, that can be summarised in a single equation (for example #9): a single data set.

10.2 Combisystems comparison

Equation 11 gives a practical analytic expression, that can be used for simplified design tools for example. But a disadvantage is that the figure f_{sav}/SC = f (FSC) cannot be used for visual comparison of different combisystems, because of the different values for the storage capacity correction factor: systems with low storage capacity correction factors will show a higher f_{sav}/SC value.

On the other hand, equation 9 allows to draw simple comparison diagrams.

11 References

[1] IEA SHC – TASK 26 : SOLAR COMBISYSTEMS; Subtask C milestone report C 3.1 ; optimisation procedure; May 03 ; 2002 ; 27 p.

[2] CSTB; PSD-MI: Monthly method for evaluating the thermal performances of Direct Solar Floors ; 1998.

[3] SUTER J.-M., LETZ T., WEISS W., INÄBNIT J.; SOLAR COMBISYSTEMS in Austria, Denmark, Finland, France, Germany, Sweden, Switzerland, the Netherlands and the USA, Overview 2000 ; IEA SHC – TASK 26 ; Bern ; 2000 ; 42 p.

[4] DUFFIE J. A., BECKMAN W. A.; Solar Engineering of Thermal processes, John Wiley & Sons, New-York ; 1991 ; 919 p.