The extended FSC procedure for larger storage sizes

A Report of IEA Solar Heating and Cooling programme - Task 32

Advanced storage concepts for solar and low energy buildings

Report A1 of Subtask A

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Edited by:
Thomas Letz

Contributions from:
Richard Heimrath
Robert Haberl
Herbert Zondag

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by
Thomas Letz (editor)*

Contributions from:

Richard Heimrath, IWT, Graz, Austria

Robert Haberl, SPF, Rapperswil, Switzerland,

herbert Zondag, ECN, Petten, Netherlands

A technical report of Subtask A

INSTITUT NATIONAL
DE L'ENERGIE SOLAIRE
EDUCATION

*** INES - Education**
Parc Technologique de Savoie Technolac
50 avenue du Léman BP 258
F - 73 375 LE BOURGET DU LAC Cedex

Executive Summary

In task 26 "Solar Combisystems", a new characterization method had been proposed, allowing to summarize the behaviour of a whole combisystem with a simple parabolic equation giving the thermal or extended fractional energy savings according to a new parameter called Fraction Solar Consumption (FSC).

This method presents many advantages, since it allows to visualize on a simple diagram either simulation, test or monitoring results, or to develop very simple dimensioning methods.

An extension of this method for solar combisystems using larger energy storages is presented in this report. A new definition for the Fraction Solar Consumption FSC' is given, which allows to keep a simple correlation between the main indicators (Thermal and extended fractional energy savings) and FSC'. Moreover, for small energy storage sizes, the new parameter is similar to the previous one.

To test the new proposal, results of simulation made by different participants have been used, for solar combisystems equipped either with water storages or chemical storages.

Contents

1) Definition of an extended Fractional Solar Consumption (FSC')

When the solar irradiation on the collector, calculated by multiplying the solar collector area A [m²] by the monthly global irradiation in the collector plane H [kWh/m²], is shown on the same diagram as the consumption of a house, three zones are defined:

① : energy consumption of the building, that exceeds the solar potential
② : energy consumption of the building, which could be saved by solar energy with use of a short term energy storage. It is called 'usable solar energy' ($\mathbf{Q}_{solar,usable}$)
③ : solar energy in excess in summer time

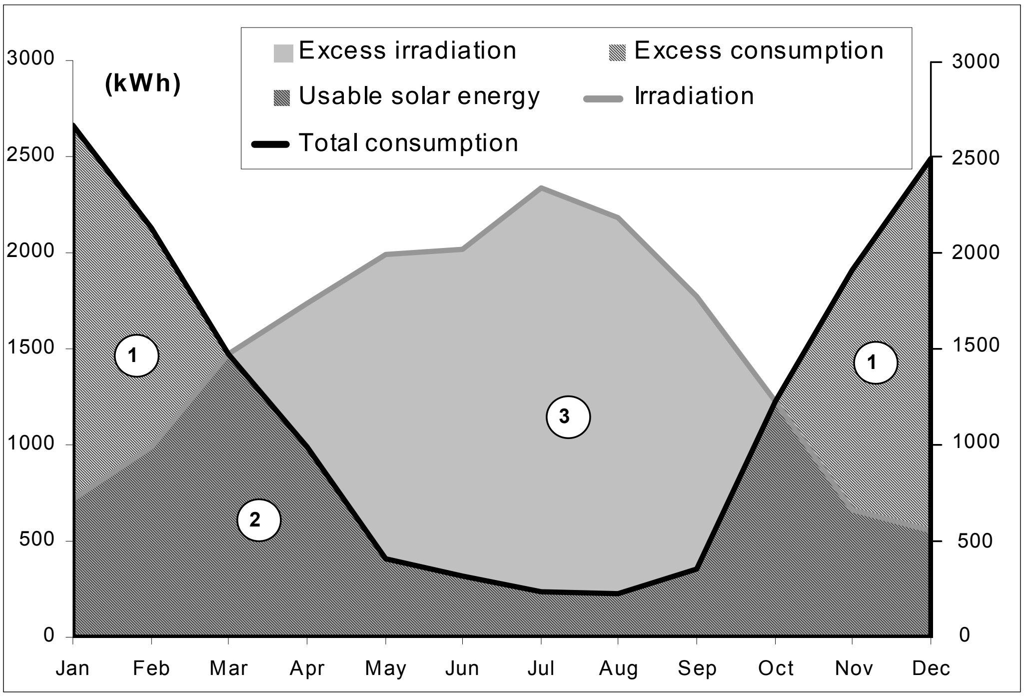


Fig. 1: Monthly plot of final energy consumption for a reference system and solar radiation on a specific collector area, azimuth and slope

An indicator usually used to evaluate the possibilities of a solar combisystems (SCS) is the ratio between the available irradiation and the load: $\frac{[(2)+(3)]}{[(1)+(2)]}$. This ratio is more or less the same as the Y dimensionless group defined in the f-chart method (Duffie and Beckman, 1991). In the f-chart method, the Y dimensionless group includes some characteristic parameters of the solar collector (the collector-heat exchanger efficiency factor F'_R, and the monthly average transmittance-absorptance product $(\overline{\tau\alpha})$ We chose not to include this two characteristic parameters in our new proposal in order to have an indicator that is independent of the studied SCS.

The ratio can be split in two parts:

equ.1: $\mathrm{FSC} = \frac{[(2)]}{[(1)+(2)]}$ which has already been defined in task 26 (Letz, 2003)

equ.2: $$\frac{\left[\sum_{1}^{12} Q_{solar,excess}\right]}{\left[\sum_{1}^{12} E_{ref,\,month}\right]} = \frac{[(3)]}{[(1)+(2)]}$$ which is the ratio between the part of excess irradiation non used in summer time and the load. A part of this energy can be used in winter time, according to the heat storage capacity $Q_{store,cap}$, or more precisely the ratio between the storage capacity and the load. This ratio is the inverse of the Equivalent Number of Cycles (ENC) defined by:

equ.3: $$\mathrm{ENC} = \frac{\left[\sum_{1}^{12} E_{ref,\,month}\right]}{Q_{store,\,cap}}$$

To take into account the limitation created by the storage, a correction factor is introduced with an α exponent, in order to define a modified Fractional Solar Consumption FSC':

equ.4: $$\mathrm{FSC'} = \mathrm{FSC} + \frac{1}{\mathrm{ENC}^{\alpha}} \frac{\left[\sum_{1}^{12} Q_{solar,excess}\right]}{\left[\sum_{1}^{12} E_{ref,\,month}\right]}$$

In the next paragraphs, it will be studied if this new parameter is useful to obtain a simple correlation between FSC' and the two indicators:

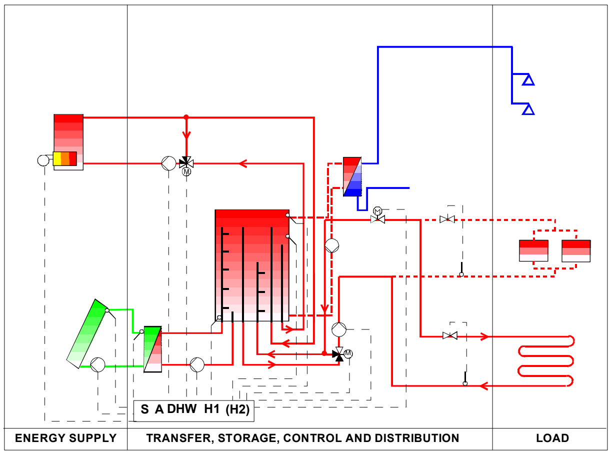
- Thermal fractional energy savings $F_{sav,th}$ (paragraphs 2 to 4)
- Extended fractional energy savings $F_{sav,ext}$, which takes also into account the parasitic electricity used by a SCS (paragraph 5)

2) Analysis with Richard Heimrath's Template Solar System (simulations made par Thomas Letz):

Different values of α have been tried, in order to get a good shape of the interpolation curve obtained when plotting the fractional energy savings $F_{sav,th}$ against FSC'.

In a first step, 80 simulations have been performed with Richard Heimrath's Template Solar System.

- 4 climates (ST, ZÜ, BA and MA)
- 5 buildings (SFH 15, SFH 30, SFH 60, SFH 100, SFH 100 SHD)
- 1 ratio storage size / collector area = 50 l / m²
- 4 systems sizes (10 m² / 500 l ; 15 m² / 750 l ; 20 m² / 1000 l ; 25 m² / 1250 l)



2.1. Current FSC method

The following diagram (Figure 2) shows that the FSC method does not work anymore for large storage sizes and collector areas: for these parameters, FSC is equal to 1 and it is impossible to visualize differences between various sizes of the installations.

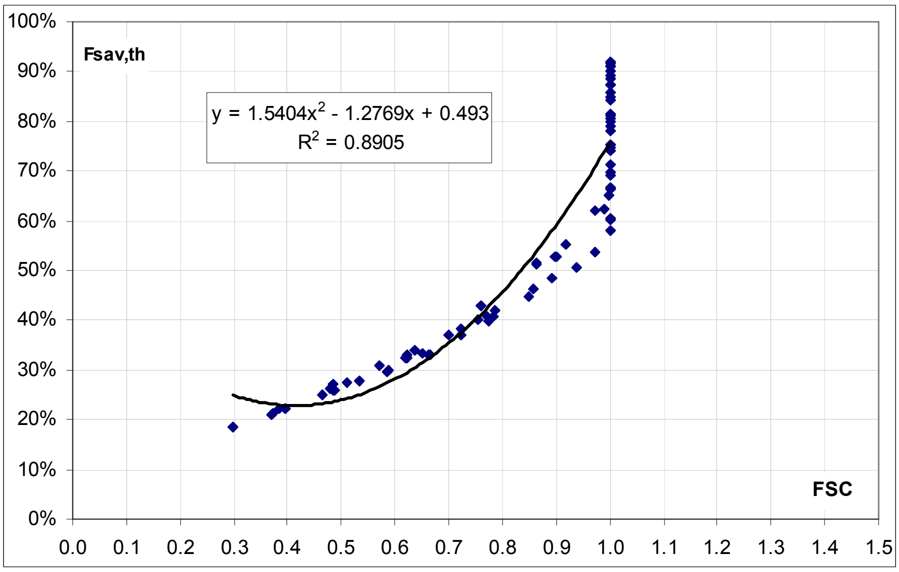


Fig. 2: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

2.2. New FSC' proposal

Hereunder is the diagram with this new definition of FSC', with α = 2/3:

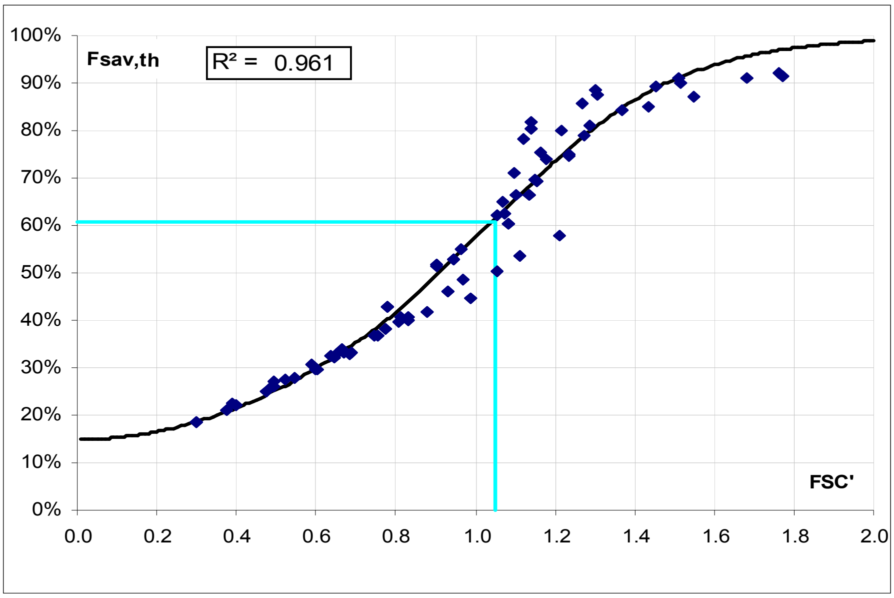


Fig. 3: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 2/3)

<u>Comments</u>

1. The interpolation curve is made with two parts :

For FSC' < X, a parabolic part, as it has been done in task 26 :

equ.5: $\quad$ $Fsav,th = a\, FSC'^2 + b\, FSC' + C$

For FSC' > X, a sigmoid part, in order that Fsav,th remains under 1 even for high FSC' values :

equ.6: $$Fsav,th = f - \frac{1-f}{1+\exp(-d(FSC'-X))}$$

The three coefficients d, f and X are calculated in order that the two functions are continuous and their derived functions also. Moreover, the inflexion point of the sigmoid curve is obtained when FSC' = X.

This leads to the following values for d and f :

equ.7: $$d = \frac{4(2aX+b)}{(1-f)}$$

equ.8: $$f = 2(aX^2+bX+c)-1$$

In order to find the best interpolation curve, 4 parameters have to be fitted: a, b, c and X. In the previous FSC method, only 3 parameters had to be fitted.

2. Different values for α have been tested :

With α = 0.5, the following diagram is obtained:

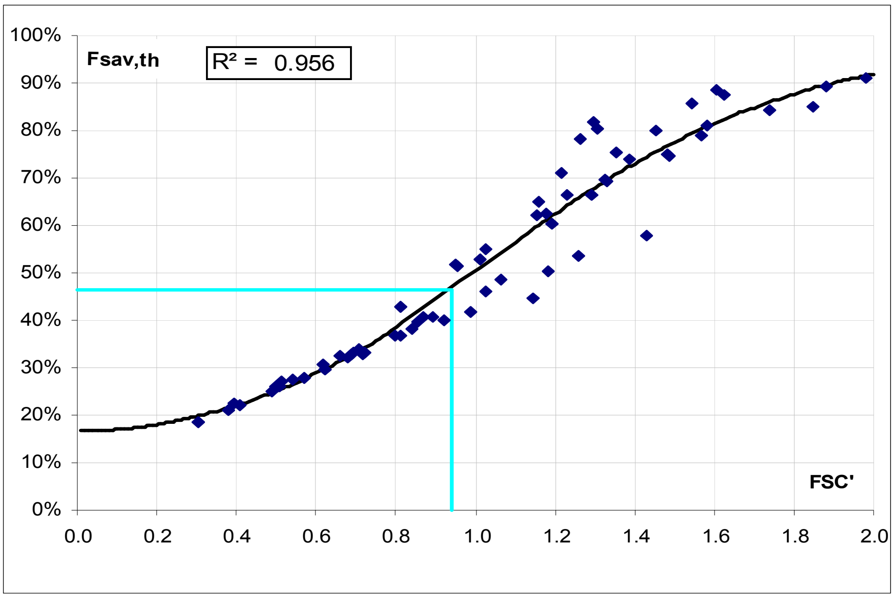


Fig. 4: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 1/2)

With $\alpha = 1$, the following diagram is obtained:

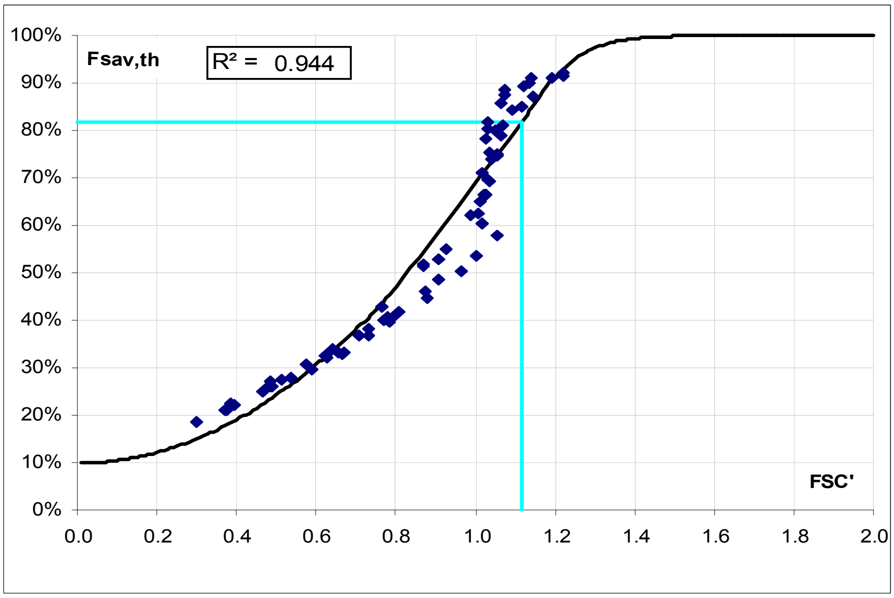


Fig. 5: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 1)

There is no clear reason to justify the choice of $\alpha = 2/3$, except the fact that the shape of the curve seems to be adequate, and the correlation has a good regression coefficient. Further investigation is still needed to clarify this point.

3. The new definition for FSC' and the new expression for the interpolation curve is consistent with what has been proposed in task 26: for FSC < 1, the new formulation is very close to the older one.

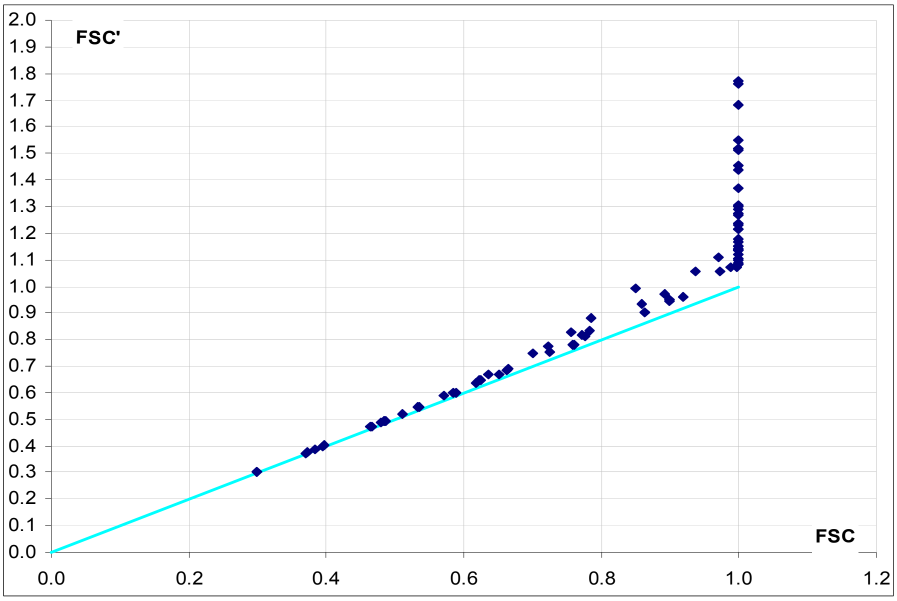


Fig. 6: Comparison between FSC and FSC'

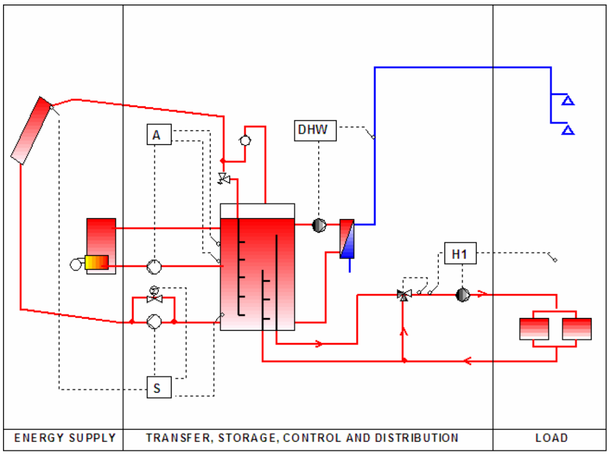
3) Analysis with Robert Haberl's results (SCS with a water storage tank):

3.1. Constant ratio for storage size / collector area

First analysis is made with a constant ratio for storage size / collector area. Simulations have been made with a 70 l/m² value.

In a first step, 112 simulations have been performed by Robert Haberl:

- 4 climates (ST, ZÜ, BA and MA)
- 4 buildings (SFH 15, SFH 30, SFH 60, SFH 100)
- 1 ratio storage size / collector area = 70 l / m²
- 7 systems sizes (8 m² / 560 l ; 10 m² / 700 l ; 12 m² / 840 l ; 14 m² / 980 l ; 16 m² / 1120 l ; 18 m² / 1260 l ; 20 m² / 1400 l)



3.1.1. Current FSC method

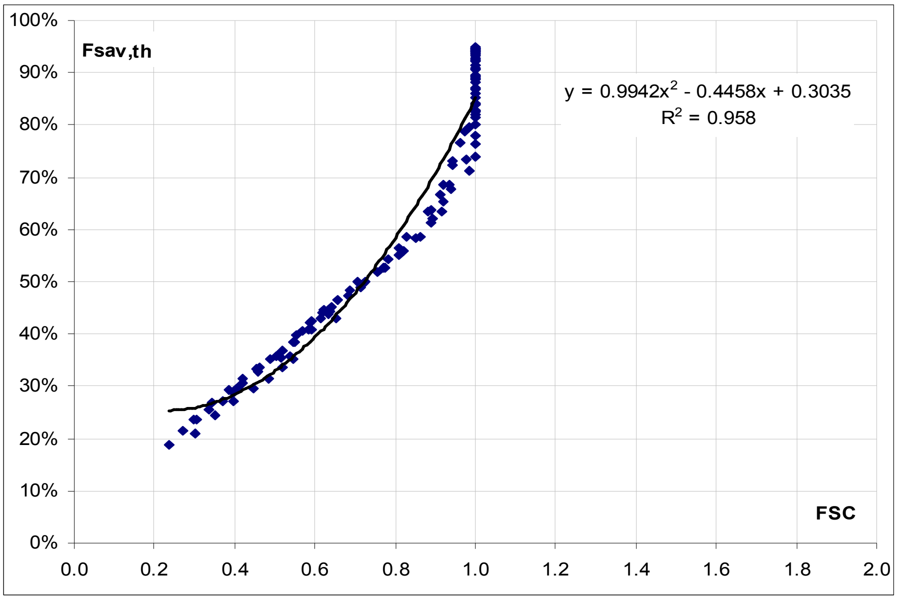


Fig. 7: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

3.1.2. New FSC' proposal

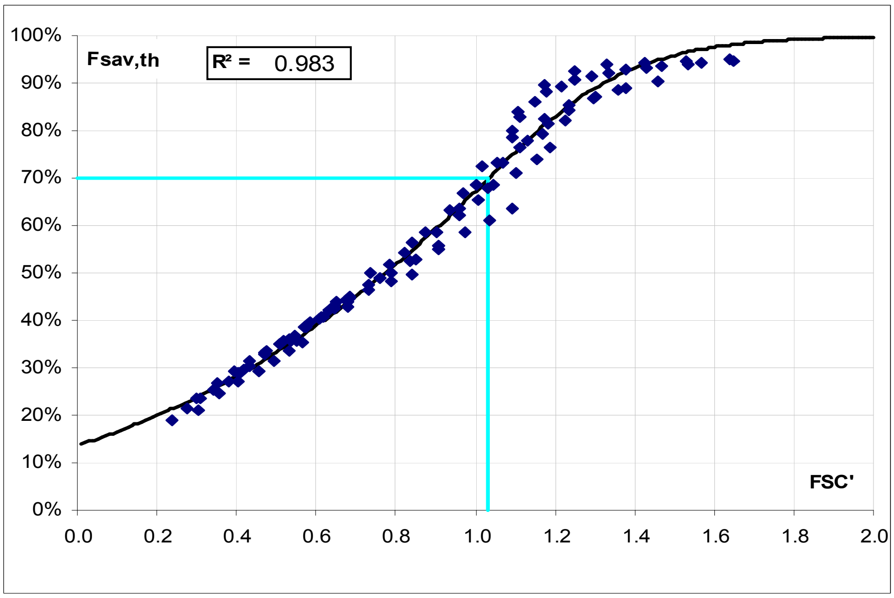


Fig. 8: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC'

<u>Comments :</u>

1. The correlation is excellent: the regression coefficient is very close to 1.

3.2. Constant storage size (800 l)

Second analysis is made with a constant storage size (800 l)

In this second step, 112 simulations have been performed by Robert Haberl:

- 4 climates (ST, ZÜ, BA and MA)
- 4 buildings (SFH 15, SFH 30, SFH 60, SFH 100)
- 1 storage size 800 l
- 7 systems sizes (8 m² ; 12 m² ; 16 m² ; 20 m² ; 24 m² ; 28 m² ; 32 m²)

3.2.1. Current FSC method

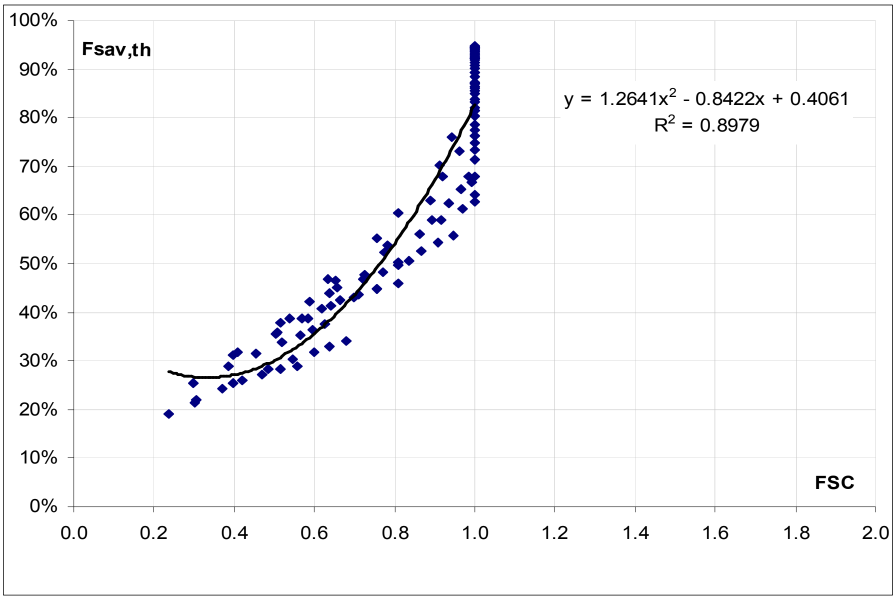


Fig. 9: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

3.2.2. New FSC' proposal

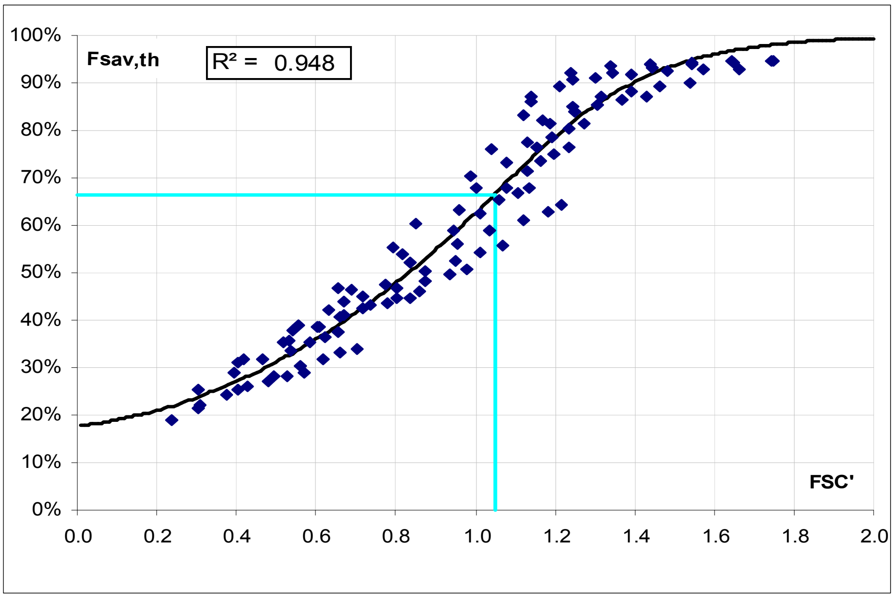


Fig. 10: Thermal fractional energy savings $F_{sav,th}$ as a function oft FSC'

<u>Comments :</u>

1. The correlation is good, but not excellent: the regression coefficient is close to 0.95.

2. It has been investigated if a storage size correction factor, as defined in task 26, could improve the correlation :

3.2.3. New proposal with storage size correction factor

A storage size correction factor SC has been introduced in a slightly different way it had been done in task 26: in task 26 (Letz, 2003), the proposed equation was:

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

Here the proposed equations 5 and 6 are modified just by replacing FSC' by SC.FSC', where

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)

With α = 160 l/m², β = -0.06 and γ = 0.5, the correlation is excellent.

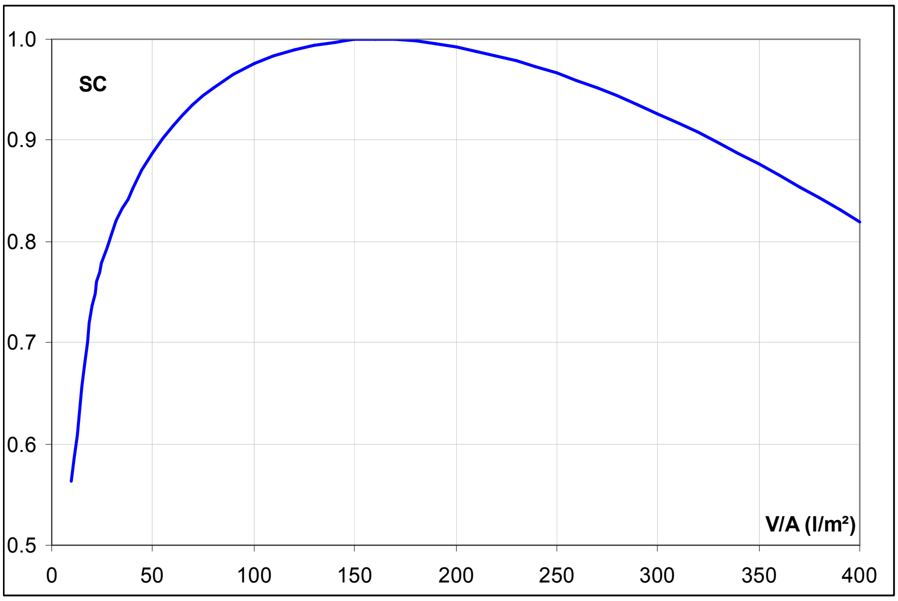


Fig. 11: Storage size correction factor

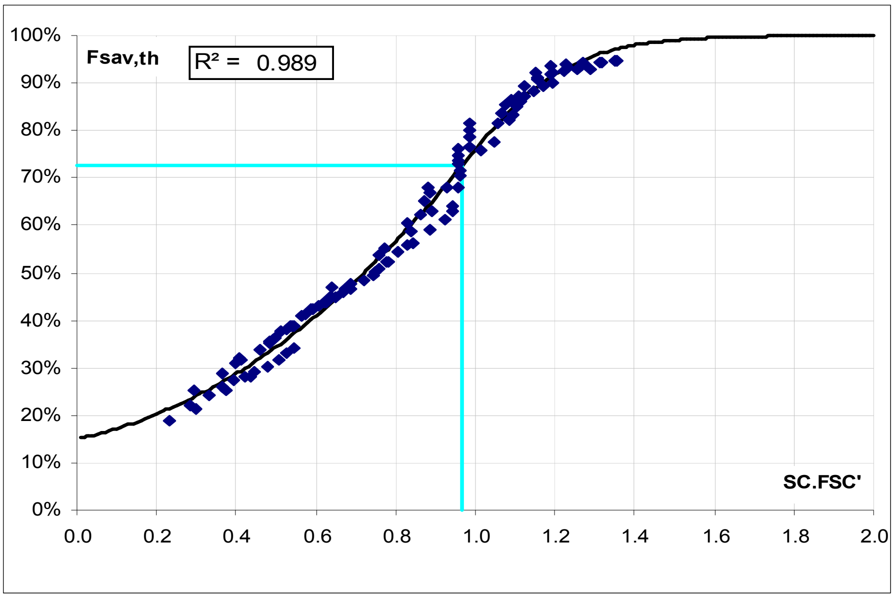


Fig. 12: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC'

Comments:

1. The three values for α, β and γ have been determined for one particular system. But it is not obvious that these values are suitable for all systems using a water storage. More simulations results with other systems are needed to clarify this point.
2. For systems using different storage ratio for storage size / collector area, it is therefore proposed to sort out results by constant or nearly constant ratio for storage size / collector area. Figure 13 shows that this method gives much better regression coefficients. It allows also to visualise the effect of increasing the storage ratio, for a defined collector size.

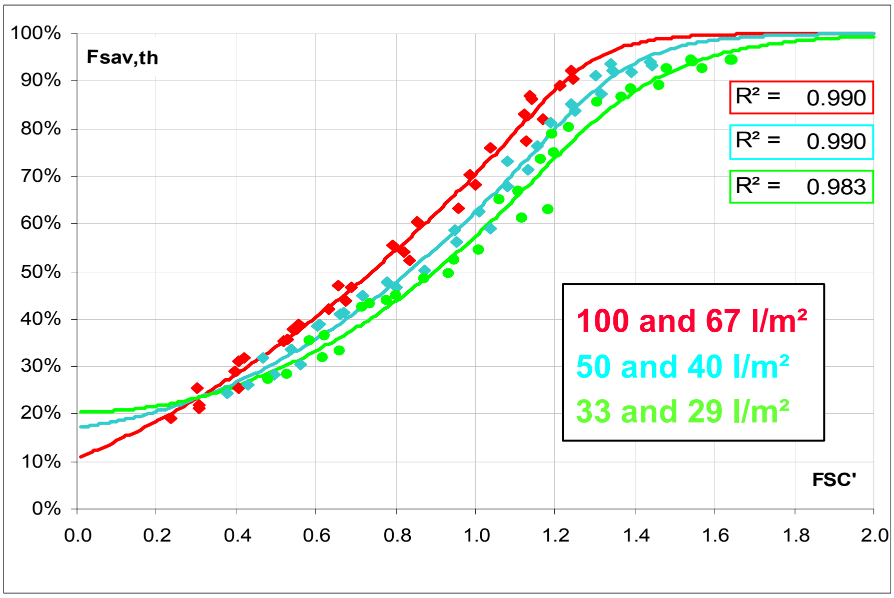


Fig. 13: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC', simulation results sorted by ratio storage size / collector area

4) Analysis with Herbert Zondag's results (SCS with a chemical storage tank):

Short description of the system:

- based on reversible reaction A+2H2O <-> Ax2H2O + heat, in which hydratation of material A has DH = 61 kJ/mol and DS = 150 J/mol/K
- assuming almost ideal case: assuming unload temperature of 50 C and DH = 61 kJ/mol (load temperature a little above 50 C)
- effects of heat transfer and moisture transfer have been ignored.
- limited storage energy losses only due to lost sensible heat of dehydration products
- fixed borehole temperature of 10 °C

36 simulations have been performed by Herbert Zondag:

- 3 climates (ST, ZÜ and MA)
- 3 buildings (SFH 15, SFH 60, SFH 100)
- 1 storage size : $Q_{store,cap}$ = 4 GJ = 1111 kWh
- 4 systems sizes (5 m², 10 m², 20 m², 40 m²)

4.1. Current FSC method

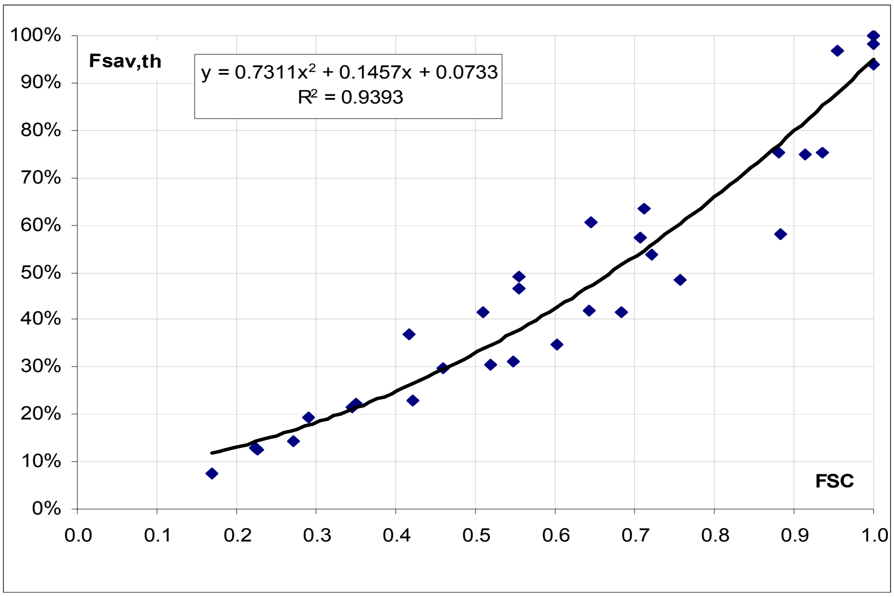


Fig. 14: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

The previous FSC method is limited to FSC = 1

4.2. New FSC' proposal

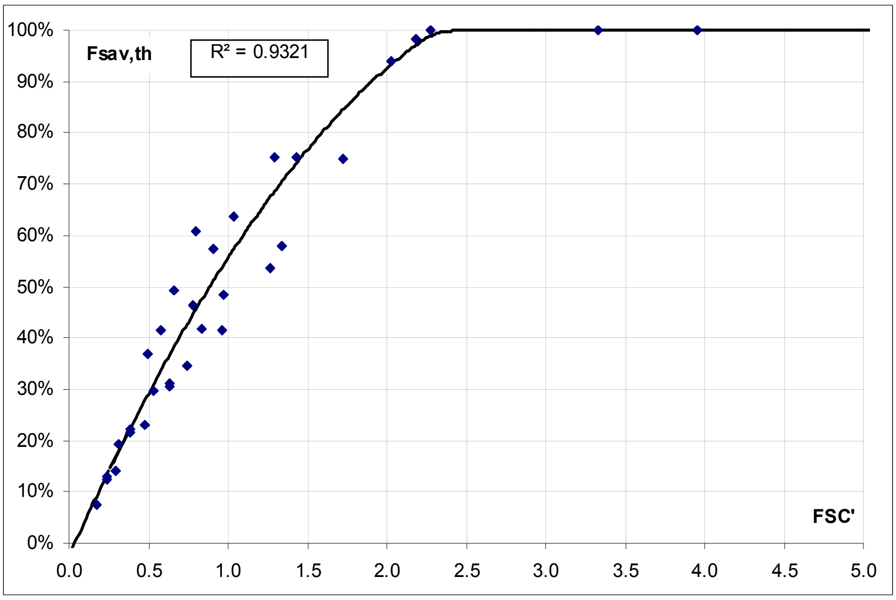


Fig. 15: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC'

<u>Comments :</u>

1) The new proposal gives a similar fitting of points than the older one, but allows to get FSC' greater than 1
2) The shape of the curve is quite different from the one for the Template Solar System. It is likely due to the larger storage capacity (1111 kWh) compared with the water storage capacities in the Template Solar System (up to 102 kWh). FSC' values can be far greater than the ones for water storages.
3) The simulations have been done with a constant storage size, but different collector areas. Therefore the ratio storage size / collector size is not constant. Sorting the results according to ratio storage size / collector size, the correlation can be improved :

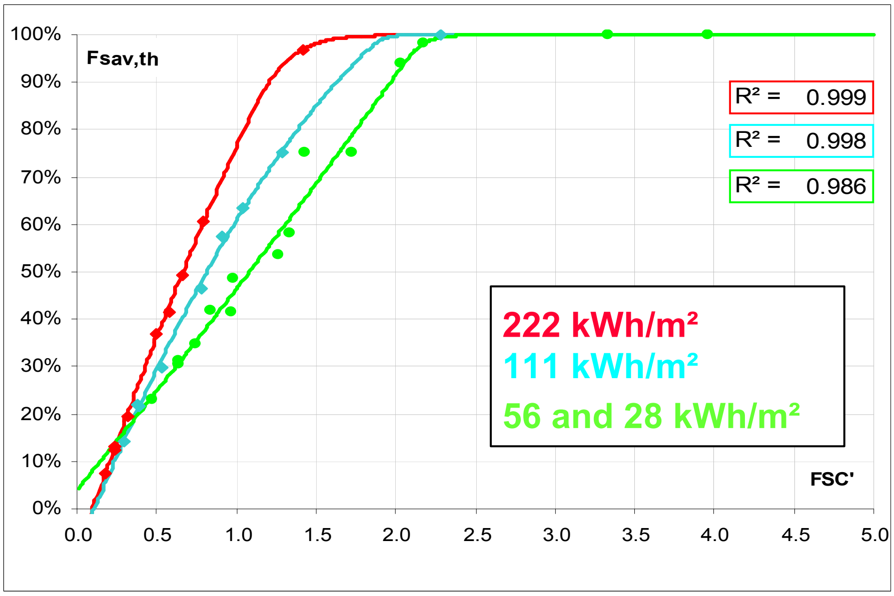


Fig. 16: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC', simulation results sorted by ratio storage size / collector area

5) Extended FSC' procedure for extended fractional energy savings :

In task 26 (Letz, 2003), it has been shown that the FSC procedure was also valid for the extended fractional energy savings. Figure 17 shows the correlation obtained with this indicator plotted according to the extended FSC' parameter, for the same simulation results as in paragraph 2 (Richard Heimrath's Template Solar System).

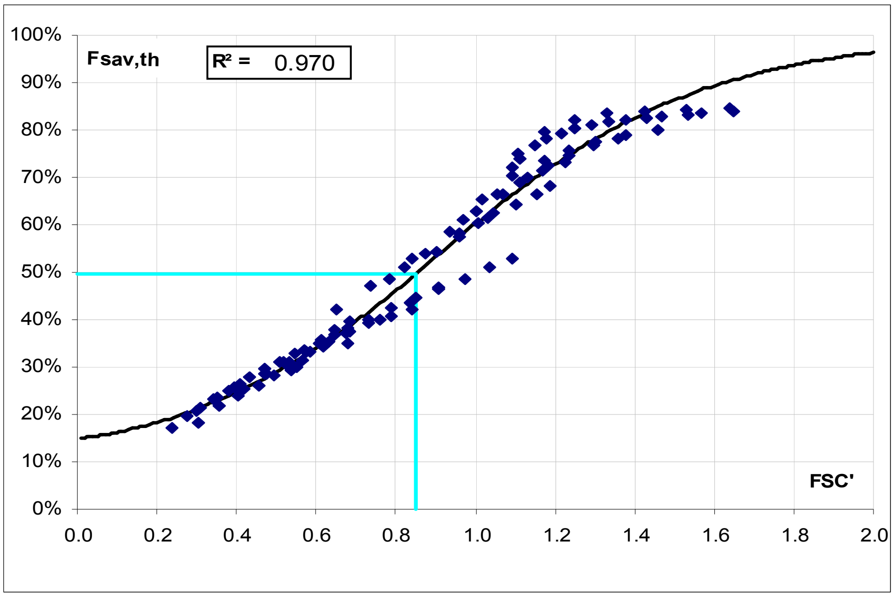


Fig. 17: Extended fractional energy savings $F_{sav,ext}$ as a function of FSC' (α = 2/3)

For Robert Haberl's simulation results (paragraph 3), the diagram for the extended fractional energy savings is given in Figure 18.

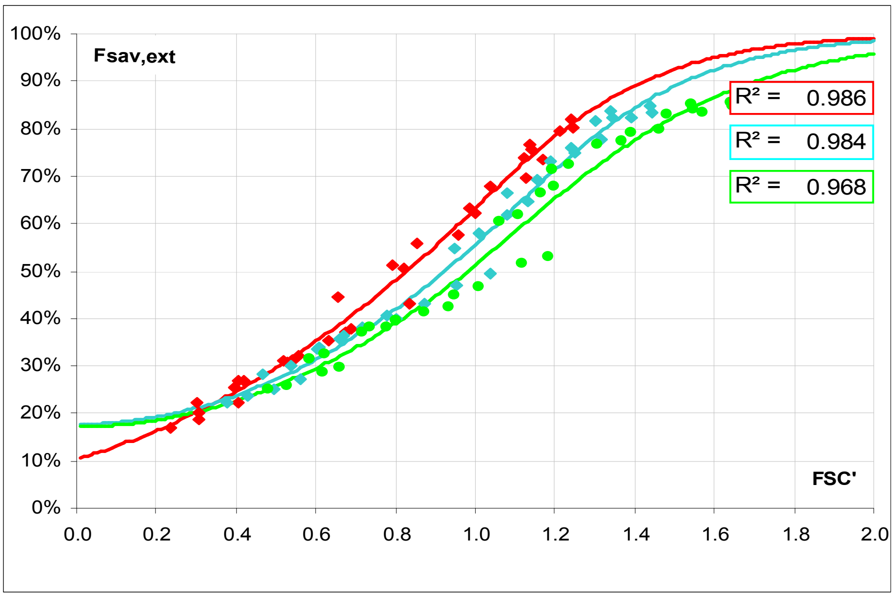


Fig. 18: Extended fractional energy savings $F_{sav,ext}$ as a function of FSC'

For Herbert Zondag's simulation results (paragraph 4), the diagram for the extended fractional energy savings is given in Figure 19.

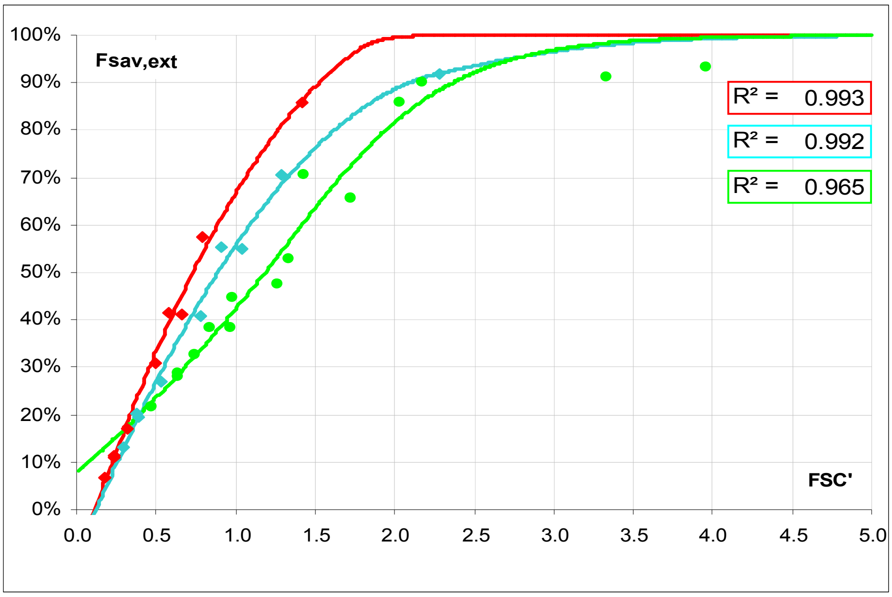


Fig. 19: Extended fractional energy savings $F_{sav,ext}$ as a function of FSC'

For the three sets of simulation, the correlation for $F_{sav,ext}$ looks like the one obtained for $F_{sav,th}$, showing good regression coefficients.

6) General comments and further investigation:

1. The way how to compare different systems on a Fsav / FSC' diagram has to be further investigated:

- For SCS using a constant (storage size / collector area) ratio, it has been shown that a simple correlation Fsav = f (FSC') gives a good representation of the systems' behaviour.

  The diagram hereunder visualizes the characteristic curves for the Template Solar System (TSS) and for Robert's system using a constant (storage size / collector area) ratio:

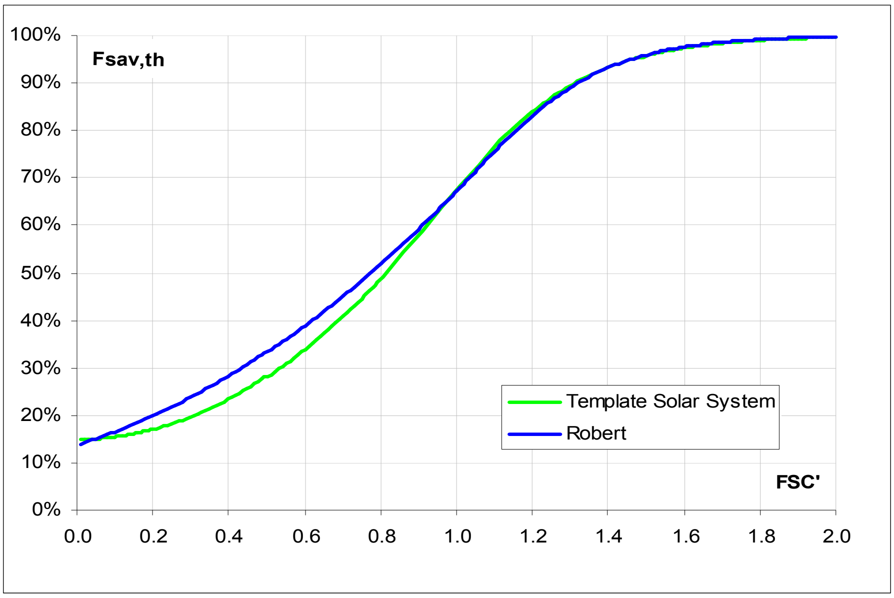


Fig. 20: Comparison of 2 different solar combisystems with a $F_{sav,th}$/FSC diagram

Robert's SCS shows a similar behaviour as the TSS for large FSC' values, whereas performances are better for smaller FSC' values.

- For SCS using a variable ratio storage size / collector area, results have to be sorted according this ratio.

2. The method is also valid for the extended fractional energy savings $F_{sav,ext}$

REFERENCES

Duffie J. A., Beckman W. A. (1991) *Solar Engineering of Thermal processes*, 919 p. Wiley Interscience, New-York.

Letz T. (2003): *Validation and Background Information on the FSC Procedure, A Report of IEA SHC* - Task 26 Solar Combisystems, December 2002, 23 p