The extended FSC procedure for large storage capacity

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

December 2007

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A technical report of Subtask A

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Executive Summary

In task 26 "Solar Combisystems", a new characterization method had been proposed, allowing summarizing 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.

IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first “oil shock,” the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia	Finland	Portugal
Austria	France	Spain
Belgium	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	United States
European Commission	New Zealand	
Germany	Norway	

A total of 39 Tasks have been initiated, 30 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

The Tasks of the IEA Solar Heating and Cooling Programme, both underway and completed are as follows:

Current Tasks:

Task 32	*Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33	*Solar Heat for Industrial Processes*
Task 34	*Testing and Validation of Building Energy Simulation Tools*
Task 35	*PV/Thermal Solar Systems*
Task 36	*Solar Resource Knowledge Management*
Task 37	*Advanced Housing Renovation with Solar & Conservation*
Task 38	*Solar Assisted Cooling Systems*
Task 39	*Polymeric Materials for Solar Thermal Applications*

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 22	*Building Energy Analysis Tools*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 28	*Solar Sustainable Housing*
Task 27	*Performance of Solar Facade Components*
Task 29	*Solar Crop Drying*
Task 31	*Daylighting Buildings in the 21st Century*

Completed Working Groups:
CSHPSS, ISOLDE, Materials in Solar Thermal Collectors, and the Evaluation of Task 13 Houses

To find Solar Heating and Cooling Programme publications and learn more about the Programme visit **www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy, e-mail: pmurphy@MorseAssociatesInc.com

September 2007

What is IEA SHC Task 32
“Advanced Storage Concepts for solar and low energy buildings” ?

The main goal of this Task is to investigate new or advanced solutions for storing heat in systems providing heating or cooling for low energy buildings.

- The first objective is to contribute to the development of advanced storage solutions in thermal solar systems for buildings that lead to high solar fraction up to 100% in a typical 45N latitude climate.

- The second objective is to propose advanced storage solutions for other heating or cooling technologies than solar, for example systems based on current compression and absorption heat pumps or new heat pumps based on the storage material itself.

Applications that are included in the scope of this task include:

- new buildings designed for low energy consumption
- buildings retrofitted for low energy consumption.

The ambition of the Task is not to develop new storage systems independent of a system application. The focus is on the integration of advanced storage concepts in a thermal system for low energy housing. This provides both a framework and a goal to develop new technologies.

The Subtasks are:

- Subtask A: Evaluation and Dissemination
- Subtask B: Chemical and Sorption
- Subtask C: Phase Change Materials
- Subtask D: Water tank solutions

Duration

July 2003 - December 2007.

www.iea-shc.org look for Task32

IEA SHC Task 32 Subtask A
Evaluation and dissemination

This report is part of Subtask A of the Task 32 of the Solar Heating and Cooling Programme of the International Energy Agency dealing with evaluation of new storage concepts.

The work in this report is based on previous works of the Task 26 "Solar combisystems" of IEA SHC, where a common methodology to caracterize any type of solar combisystem was first derived.

The method is based on the concept of the "Fractionnal Solar Consumption" introduced in Task 26, but improved to take into account larger storage capacity than current state-of-the-art diurnal storage.
This report shows in details the improvements brought by the work of Task 32.

The Operating Agent would like to thank the main author and all contributors of this report for their input to this new method during the Task 32 period (2003-2007).They have managed to derive a new concept and validate it and to bring not only to IEA participants but to the whole solar energy community, a common method for analyzing any solar active system with short or long term storage capacity.

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Contents

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

1.1. Introduction of the concept

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' ($\mathbf{Q}_{\mathbf{solar,usable}}$)
③ : solar energy in excess in summer time

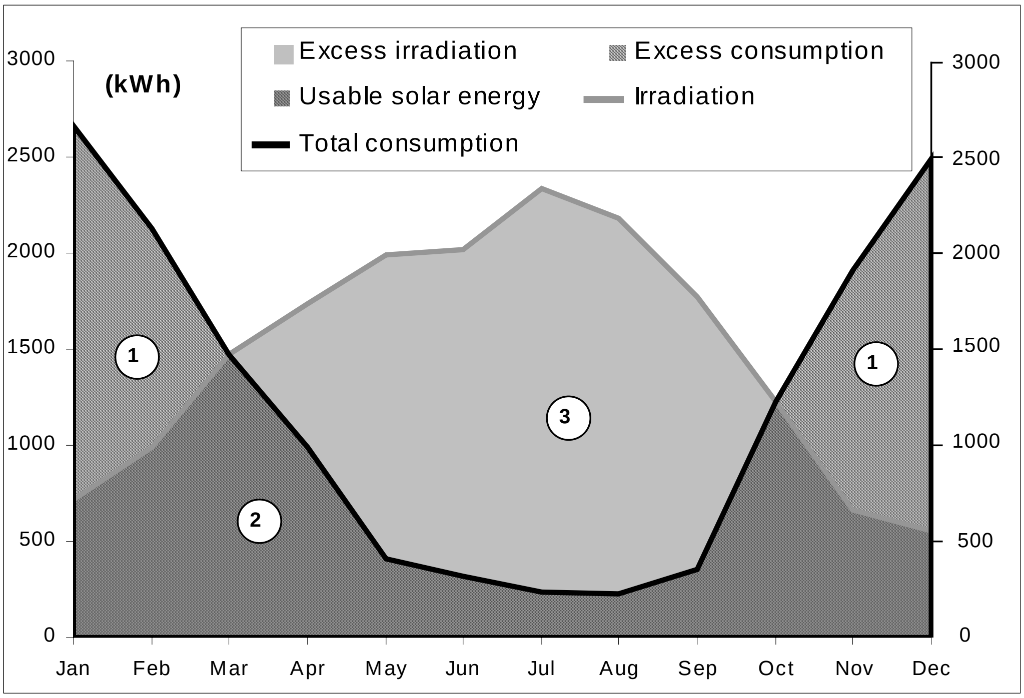


Fig. 1: Monthly plot of final energy consumption for a reference system and solar radiation on a specific collector area, azimuth and slope

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 similar to the Y dimensionless group defined in the f-chart method (Duffie and Beckman, 1991). Y is the ratio between the solar energy transmitted by the absorber to the fluid in the solar collector, and the load (space heating and domestic hot water), calculated on a monthly timestep.

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 these 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: $FSC = \frac{[(2)]}{[(1)+(2)]}$ 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: $$ENC = \frac{\left[\sum_{1}^{12} E_{ref,\,month}\right]}{Q_{store,\,cap}}$$

1.2. *Definition of the storage capacity*

The storage capacity is defined depending on the type of storage material used (contribution from Robert Weber):

<u>For sensible and latent heat storages</u>:

equ.4: $$Q_{store,\,cap} = m \cdot \int_{20}^{90} C_P \cdot dT$$

With m : mass of the storage material (kg)

C_p : specific heat capacity of the storage material (kWh/kg.K for sensible heat capacity, kWh/kg for latent heat capacity)

T : temperature (°C)

<u>For thermo-chemical storages (proposed by Robert Weber):</u>

$Q_{store,cap}$ is the enthalpy of the chemical reaction :

equ.5: $$Q_{store,\,cap} = \int_{low\,conc}^{high\,conc} m(conc) \,.\, h_{abs}(conc,\theta) \,.\, dconc$$

Where :

Q = Energy capacity of the storage
low conc = Lowest possible concentration of the sorbent material
high conc = Highest possible concentration of the sorbent material
m(conc)= Mass of the desorbed water or mass difference of the sorbent
$h_{abs}(conc,\theta)$ = Enthalpy of ab-/adsorption of the sorbent material (sometimes given in literature)

Notes:

low conc : This concentration is typically a design parameter. It is determined at the time, when the storage is filled with the ab-/adsorbent material and water. If all existing water is absorbed by the sorbent material, the lowest concentration of the sorbent material is reached.

high conc : This concentration is not mandatory a design parameter. The concentration might depend on different conditions of the surrounding. There are mainly two parameters which have influence on the storage capacity: temperature level of the heat source (type of solar collector), temperature level of the heat sink (efficiency of the ground heat exchanger or cooling tower).

If it is temperature dependent, the following reference temperatures are considered: 150 °C for the heat source, 30 °C for the heat sink unless the material/process is not designed for that high temperature.

Other boundaries are phase changes in the sorbent (liquid / solid), corrosion problems, etc….

$h_{abs}(conc,\theta)$: The enthalpy of ab-/adsorption of the sorbent material depends on the concentration of the sorbent and the temperature. If there are any values for the enthalpy in the literature or elsewhere, they are given for 20°C. To avoid discussion at which temperature the storage is charged, we should use them also for 20°C. Unfortunately, for most of our sorbents, the needed values of enthalpy of ab-/adsorption are anyway not available in literature

An approximate solution to get the (unknown) enthalpy of ab-/adsorption might be:

equ.6: $h_{abs,sorbent}(conc,\theta) = h_{v,water} + h_{Mix,sorbent}(conc,\theta)$ for liquid sorbents

equ.7: $h_{abs,sorbent}(conc,\theta) = h_{v,water} + h_{Bind,sorbent}(conc,\theta)$ for solid sorbents

Where:

$h_{v,water}$ = Enthalpy of evaporation of water (given in literature)
$h_{Mix,sorbent}(conc,\theta)$ = Mixing enthalpy of the sorbent (sometimes given in literature)
$h_{Bind,sorbent}(conc,\theta)$ = Binding enthalpy of the sorbent (sometimes given in literature)

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.8:
$$FSC' = FSC + \frac{1}{ENC^{\alpha}} \frac{\left[\sum_{1}^{12} Q_{solar,excess}\right]}{\left[\sum_{1}^{12} E_{ref,\,month}\right]}$$

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} against FSC'.

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)

1.3. Validity range

When doing simulations, the different parameters (climates, loads, collector area, heat capacity of the store) can be chosen in a wide range. But not all sets of parameters correspond to well dimensioned systems. A simple way to sort between simulation results is to consider that a **system efficiency** η smaller than 15 % reveals that the system is not well dimensioned, whatever it is due to an oversized collector compared to the load, or to an undersized storage. This value has been chosen by reference to a well functioning PV system connected to the grid, considering that a well dimensioned thermal system cannot be less efficient as a PV system.

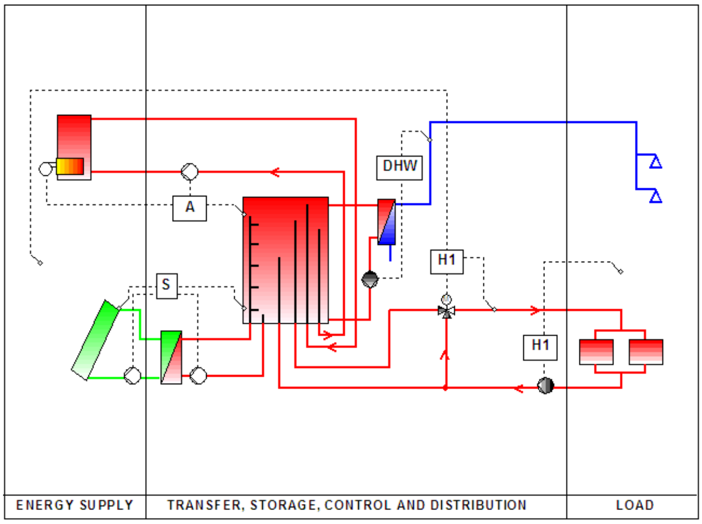
System efficiency is defined by:

equ.9: $\eta = F_{sav,th} \,.\, E_{ref} / H$

with: $F_{sav,th}$: thermal fractional energy savings
E_{ref} : reference annual consumption of the system (kWh)
H : annual irradiation available on the collector area (kWh)

2 Analysis with Template Solar System (simulations made by Thomas Letz):

In a first step, 61 simulations have been performed with Template Solar System developed by Richard Heimrath, with sets of parameters taken in the following list.



- 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.

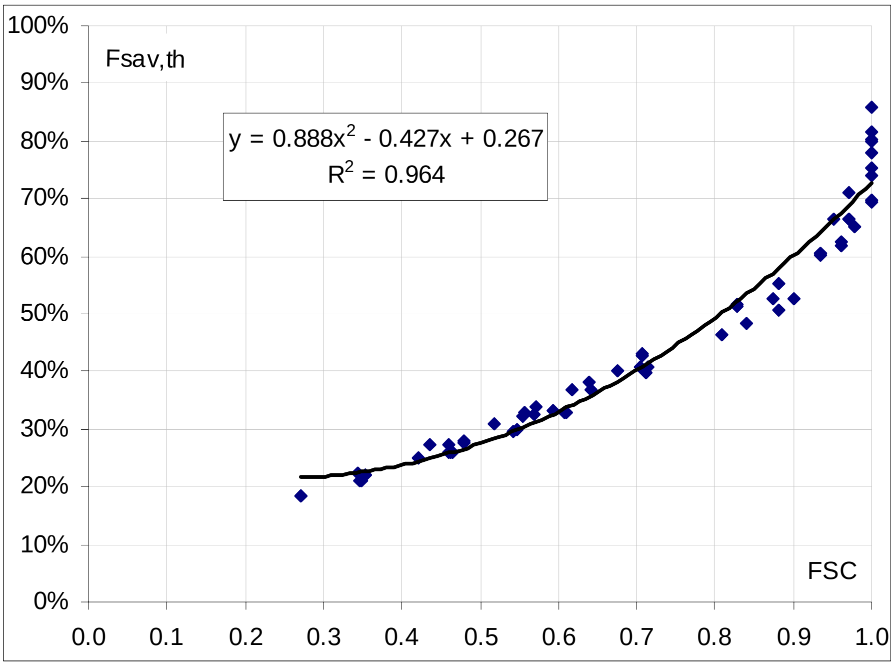


Fig. 2: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

2.2 New FSC' proposal

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

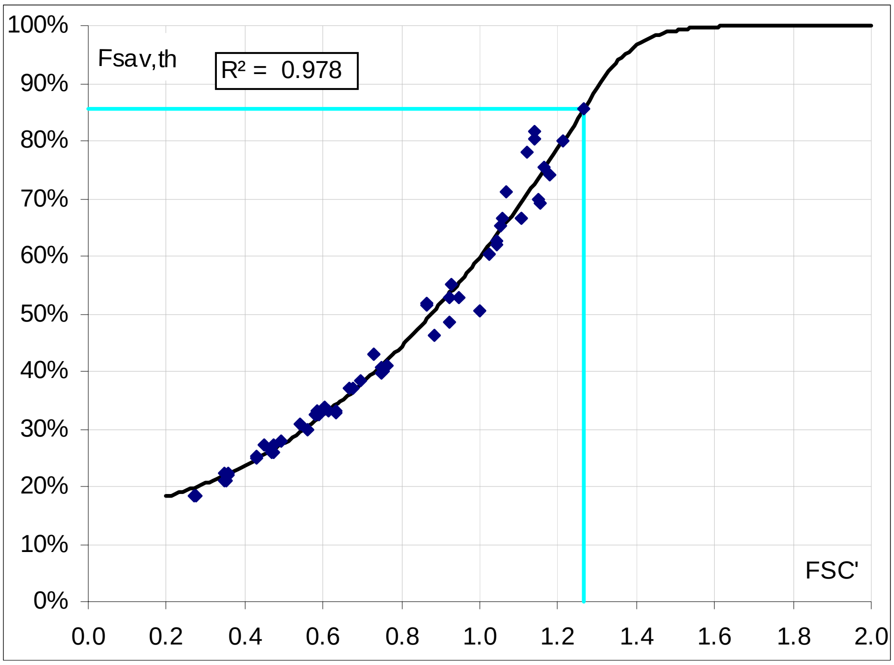


Fig. 3: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 2/3)

<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.10: $$F_{sav,th} = a\ FSC'^2 + b\ FSC' + C$$

For FSC' > X, a sigmoid part, in order that $F_{sav,th}$ remains under 1 even for high FSC' values:

equ.11: $$F_{sav,th} = f - \frac{1-f}{1+\exp(-d(FSC'-X))}$$

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

equ.13: $$f = 2(a X^2 + b X + c) - 1$$

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:

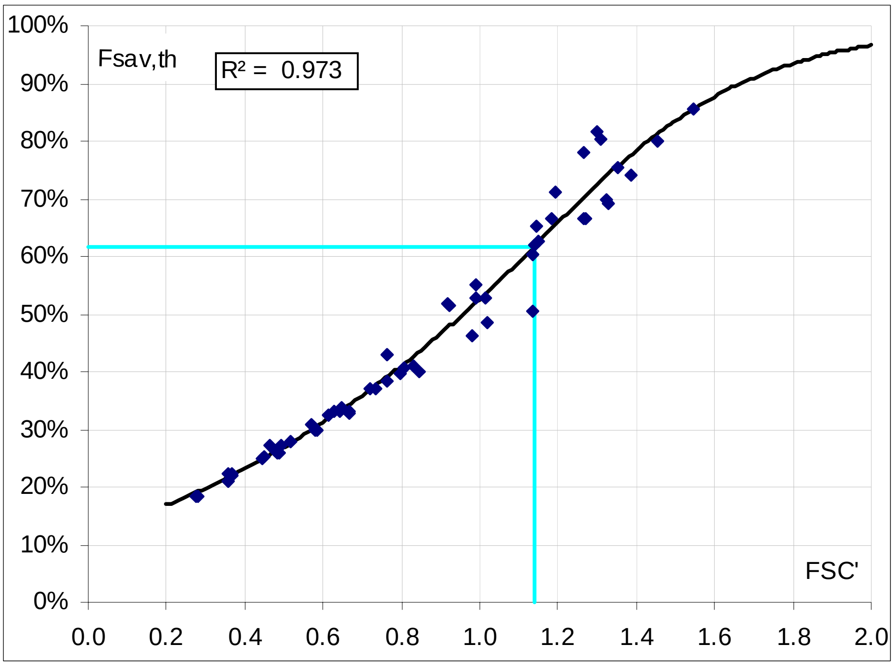


Fig. 4: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 1/2)

With α = 1, the following diagram is obtained:

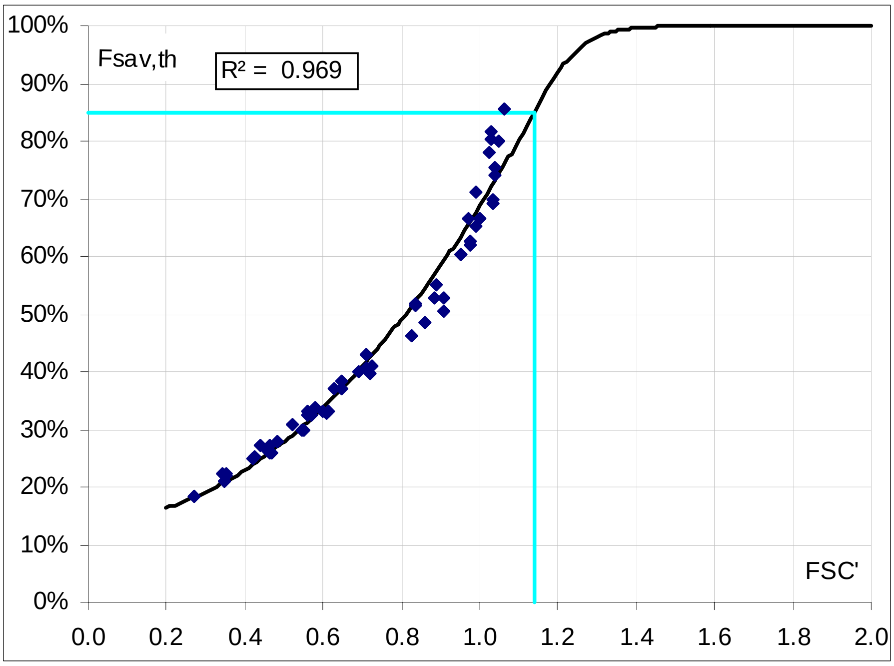


Fig. 5: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 1)

There is no clear reason to justify the choice of α = 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. <u>The value α = 2/3 is used in the following part of this document.</u>

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.

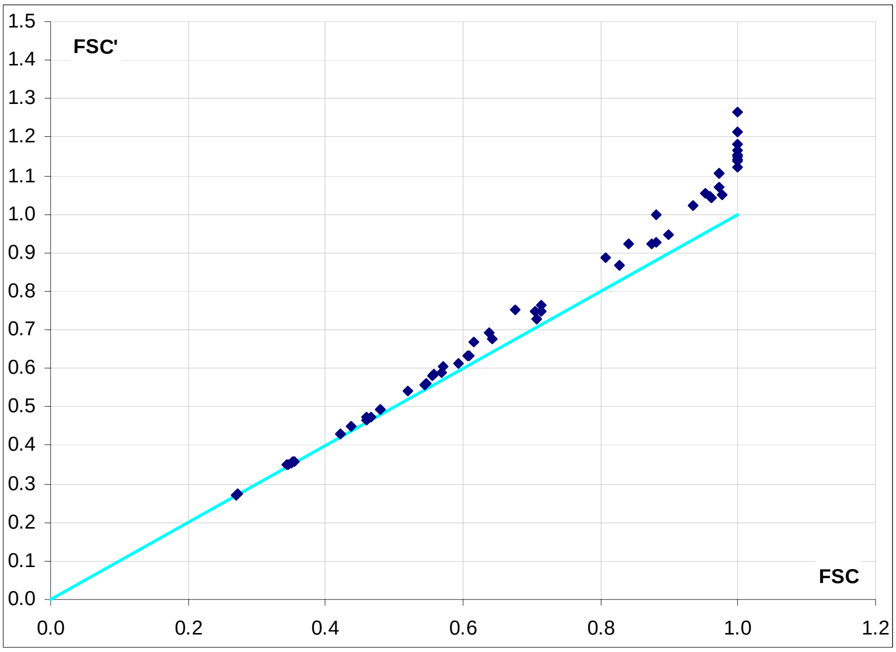


Fig. 6: Comparison between FSC and FSC'

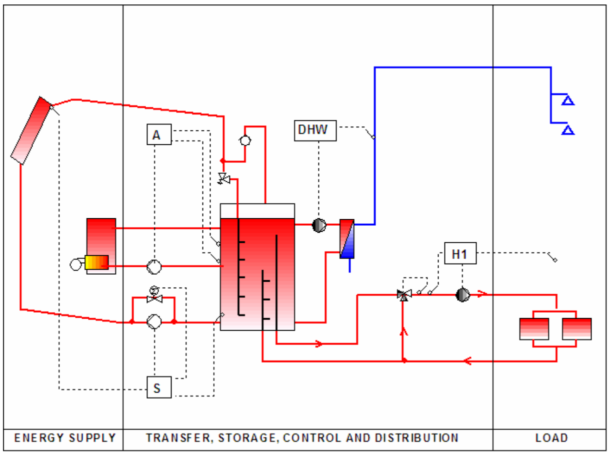
3 Analysis with SPF results (SCS and water storage tank)

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, 102 simulations have been performed by Robert Haberl, with sets of parameters taken in the following list:

- 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

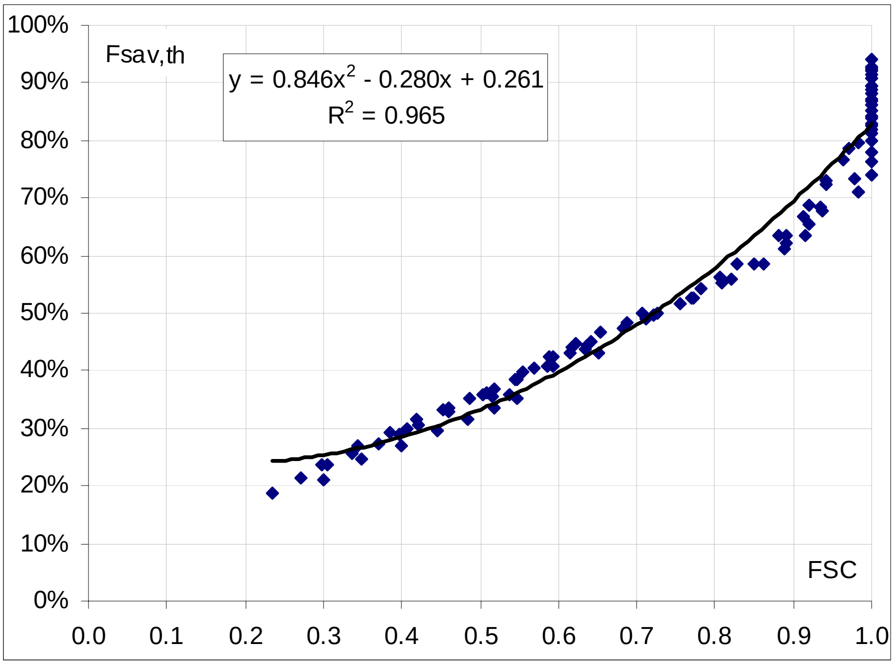


Fig. 7: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

3.1.2 New FSC' proposal

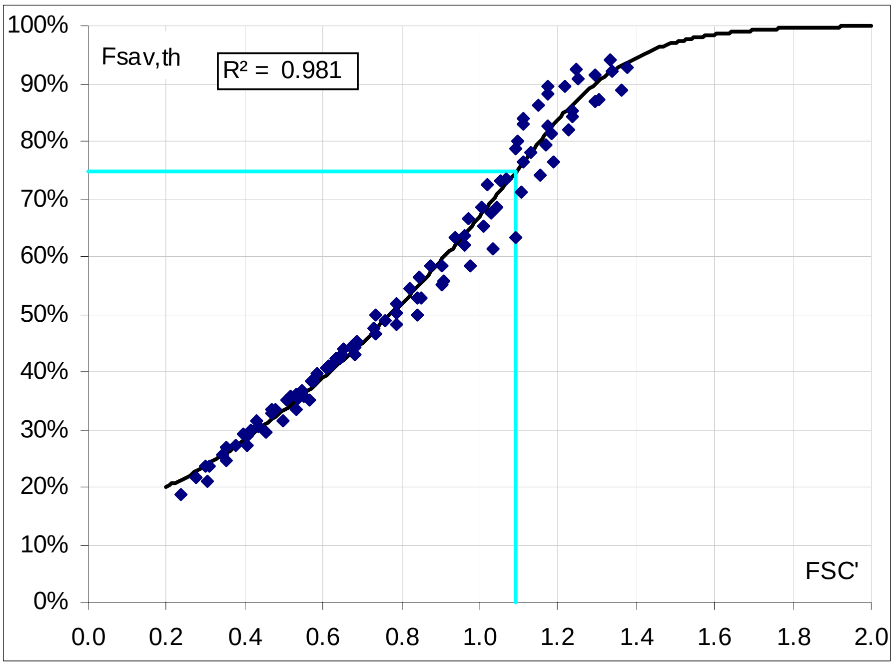


Fig. 8: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC'

<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, 73 simulations have been performed by Robert Haberl, with sets of parameters taken in the following list:

- 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

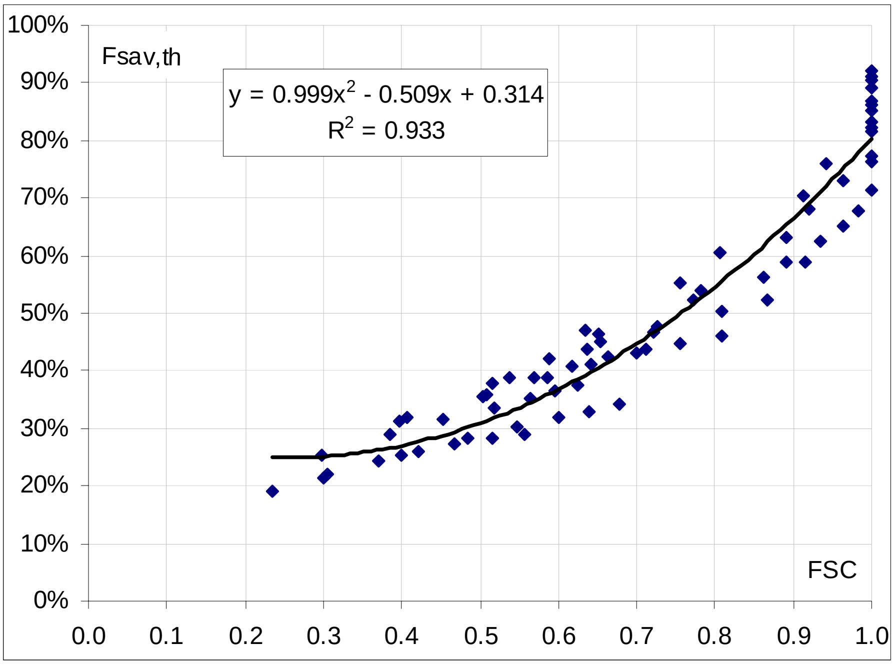


Fig. 9: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

3.2.2 New FSC' proposal

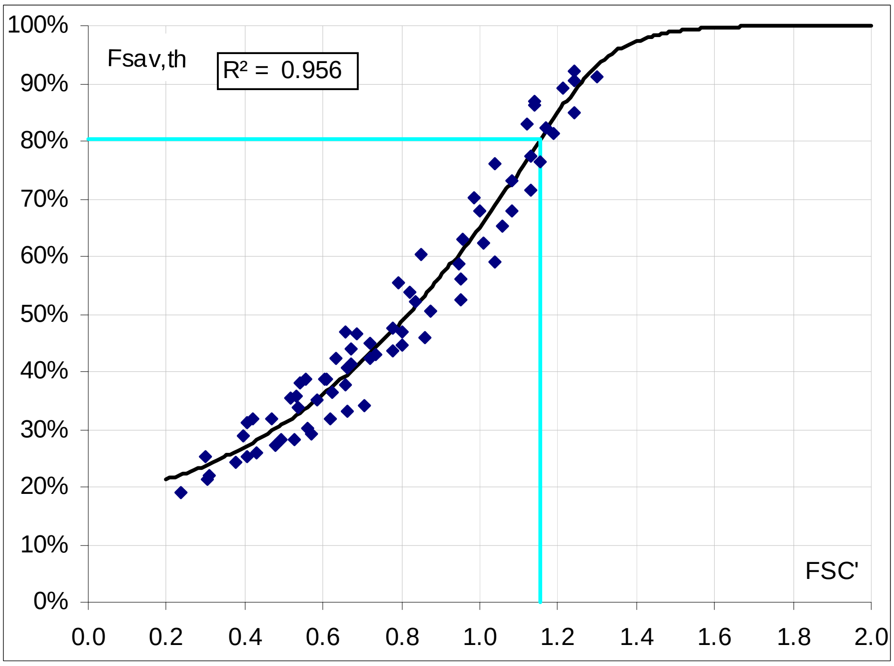


Fig. 10: Thermal fractional energy savings $F_{sav,th}$ as a function oft FSC'

<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 :

4 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.14: $f_{sav,therm} = SC\ (a' . FSC^2 + b' . FSC + c')$

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

equ.15: $$SC = \left(\frac{V}{\alpha . A} + \beta\right)^{\gamma} - \gamma\,(1+\beta)^{(\gamma-1)}\left(\frac{V}{\alpha . A} + \beta\right) + 1 - (1-\gamma)(1+\beta)^{\gamma}$$

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.

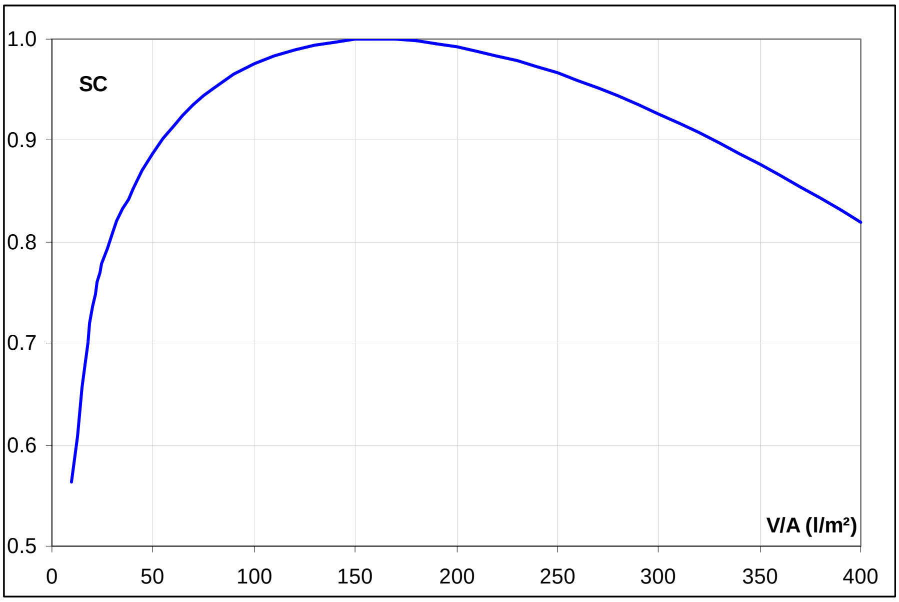


Fig. 11: Storage size correction factor

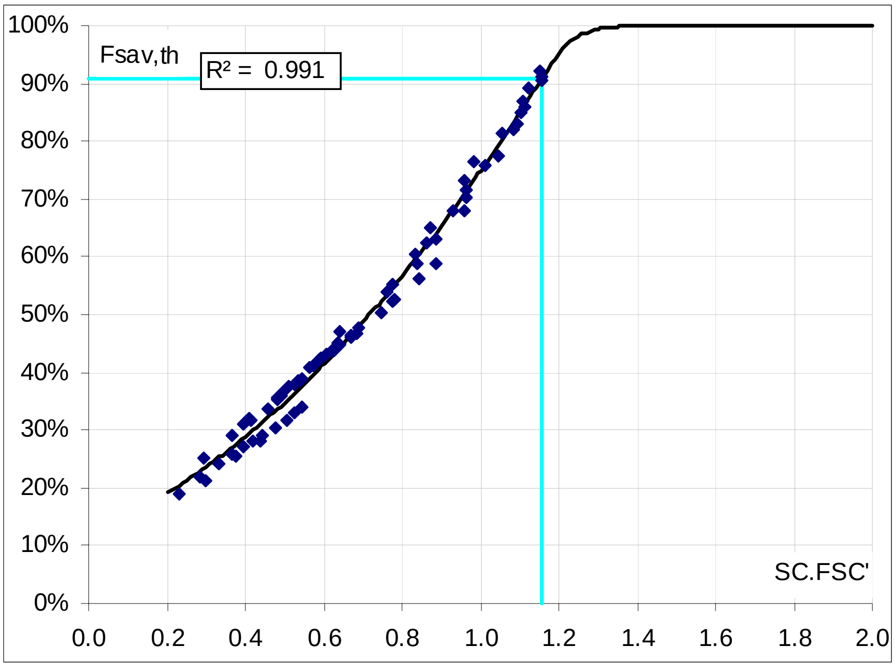


Fig. 12: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC'

<u>Comments:</u>

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. As it could be expected, increasing the storage ratio improves the performances of the system.

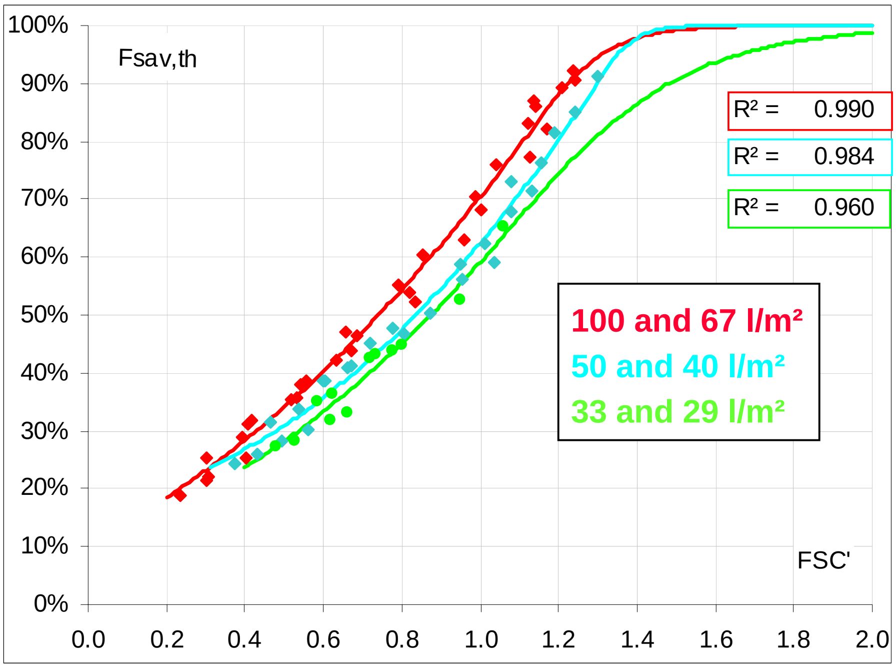
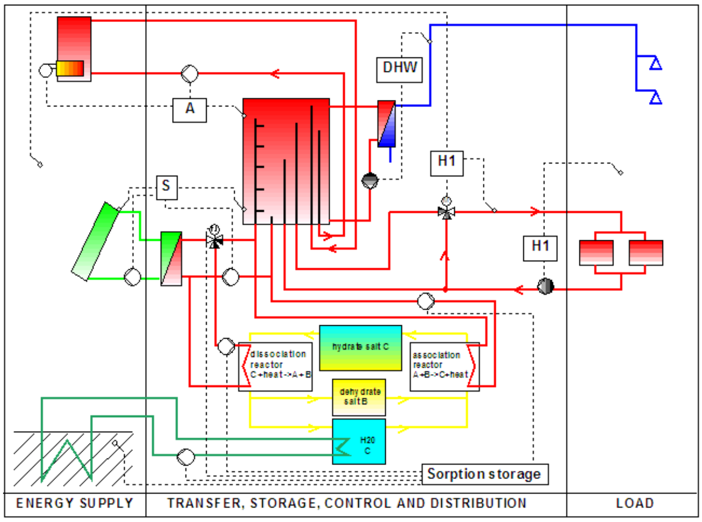


Fig. 13: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC', simulation results sorted by ratio storage size / collector area

5 Analysis with ECN 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 = 66 kJ/mol
- TCM storage capacity: 6.6 GJ
- assuming almost ideal case: assuming unload temperature of 60 °C and DH = 66 kJ/mol (load temperature a little above 80 °C)
- effects of heat transfer and moisture transfer have been ignored.
- limited storage energy losses only due to lost sensible heat of dehydration products
- Variable borehole temperature (calculated with TRNSYS type 557) Sensible losses due to cp TCM material not taken into account (but found to be very small in a parametric study; see report B6).

30 simulations have been performed by Herbert Zondag:

- 3 climates (ST, ZÜ and MA)
- 3 buildings (SFH 15, SFH 60, SFH 100)
- 1 storage size : $Q_{store,cap}$ = 6,6 GJ = 1833 kWh
- 4 systems sizes (5 m², 10 m², 20 m², 40 m²)

5.1 Current FSC method

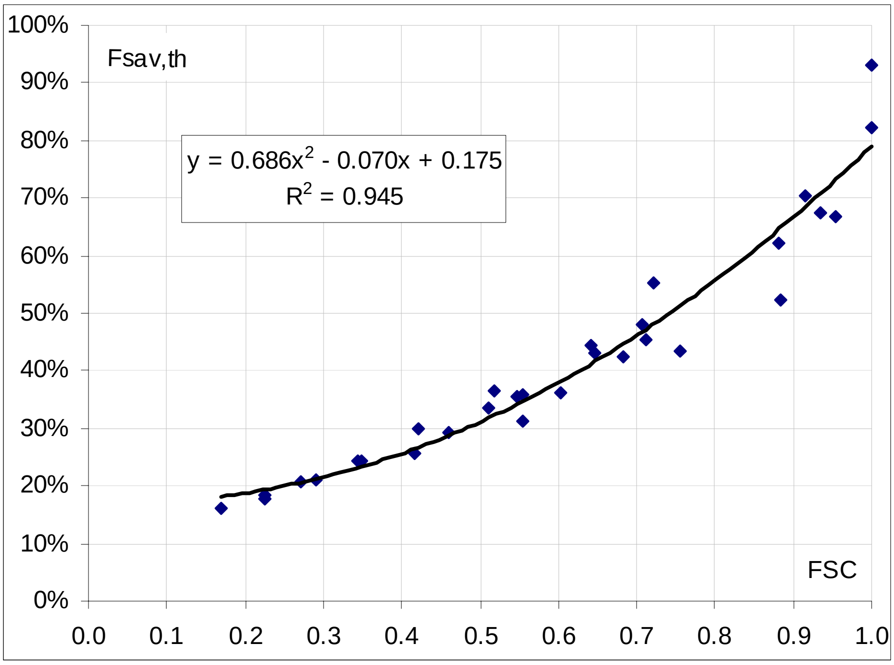


Fig. 14: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC

The previous FSC method is limited to FSC = 1

5.2 New FSC' proposal

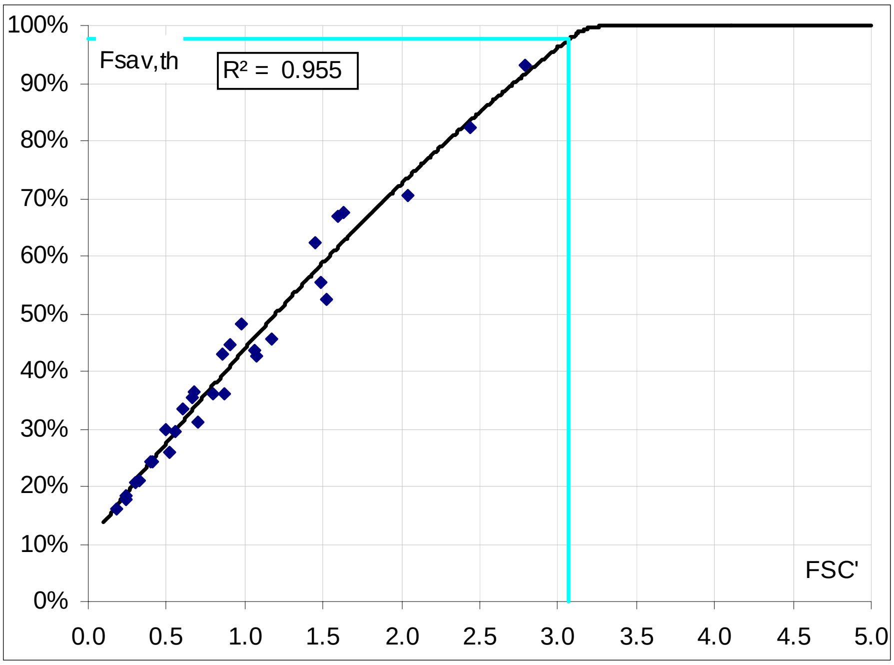


Fig. 15: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC'

<u>Comments :</u>

1) The new proposal gives a slightly better fitting of points than the older one, and allows to have 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 (1833 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 :

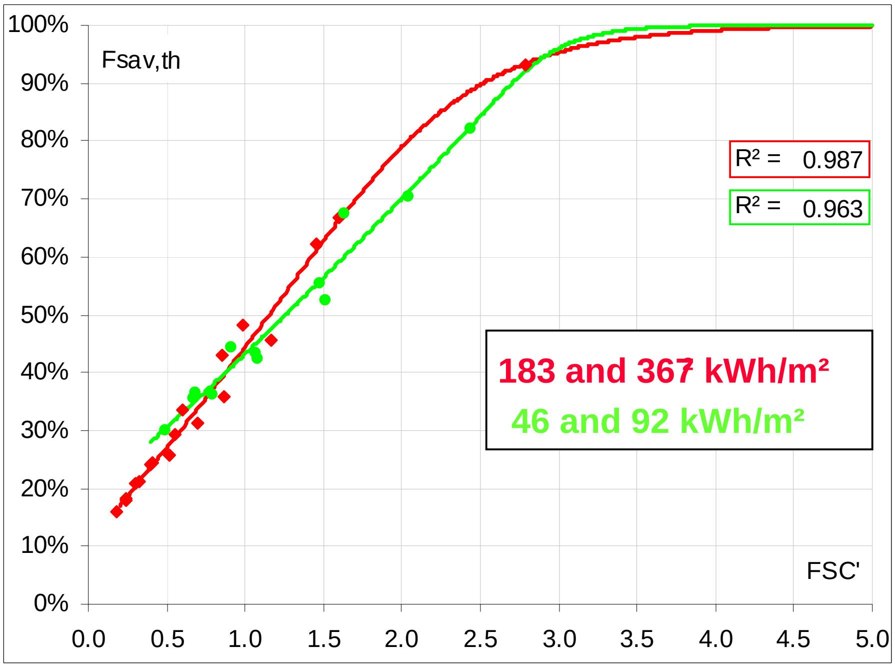


Fig. 16: Thermal fractional energy savings $F_{sav,th}$ as a function of FSC', simulation results sorted by ratio storage size / collector area

6 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).

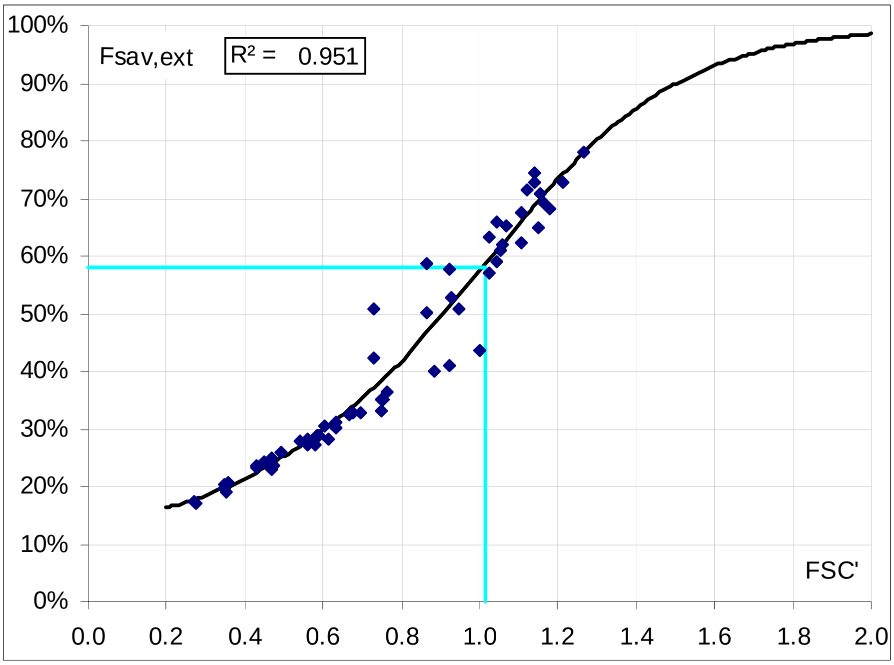


Fig. 17: Extended fractional energy savings $F_{sav,ext}$ as a function of FSC' (α = 2/3)

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

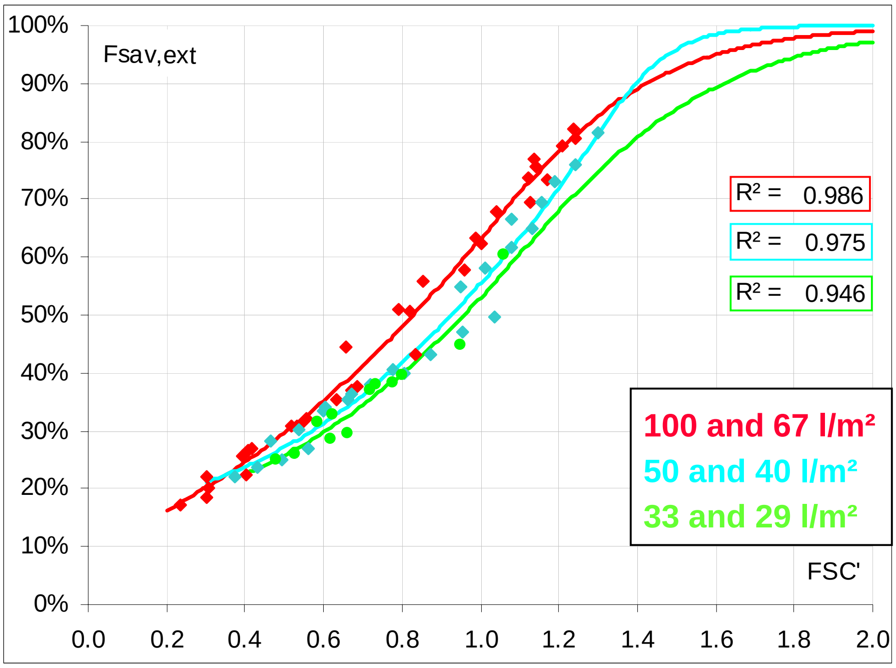


Fig. 18: Extended fractional energy savings $F_{sav,ext}$ as a function of FSC'

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

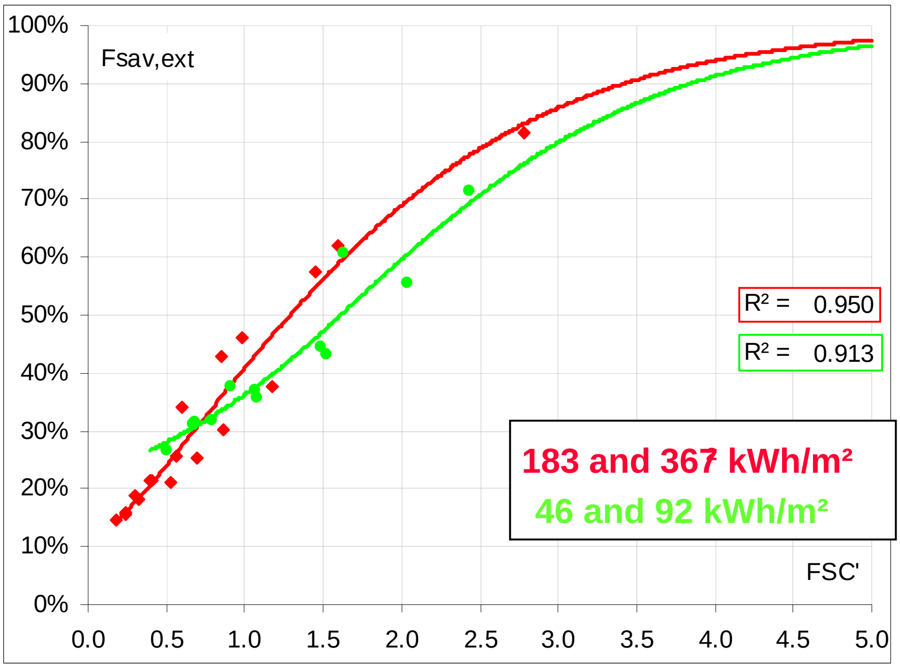


Fig. 19: Extended fractional energy savings $F_{sav,ext}$ as a function of FSC'

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

7 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 SPF system using a constant (storage size / collector area) ratio:

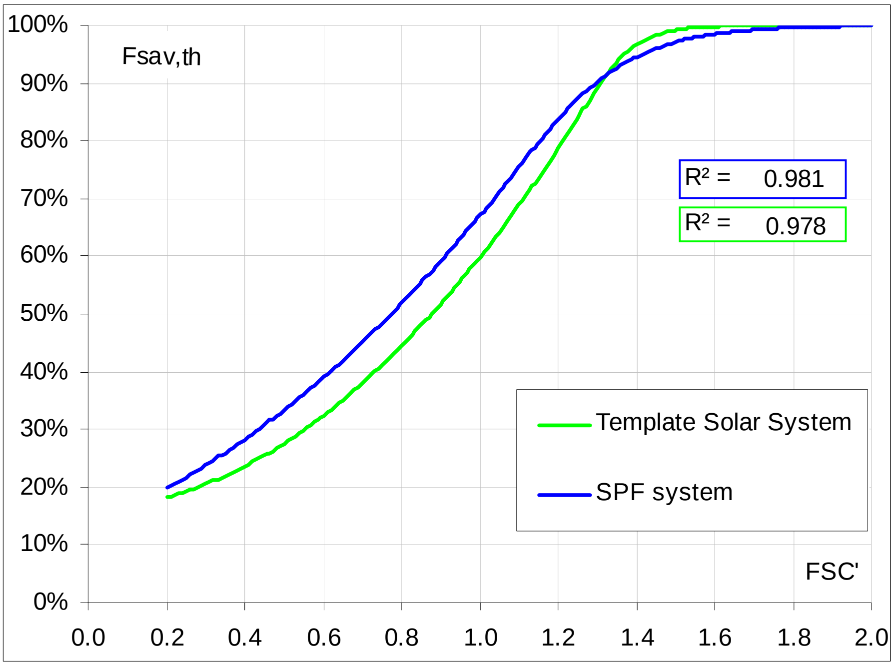


Fig. 20: Comparison of 2 different solar combisystems with a $F_{sav,th}$/FSC diagram

      SPF solar combisystem 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. This way, comparisons for a given ratio storage size / collector area or a ratio in a limited range, make sense.

2. The method is also valid for the extended fractional energy savings $F_{sav,ext.}$, allowing thus to visualize the influence of the parasitic electricity consumed by pumps, valves, etc…

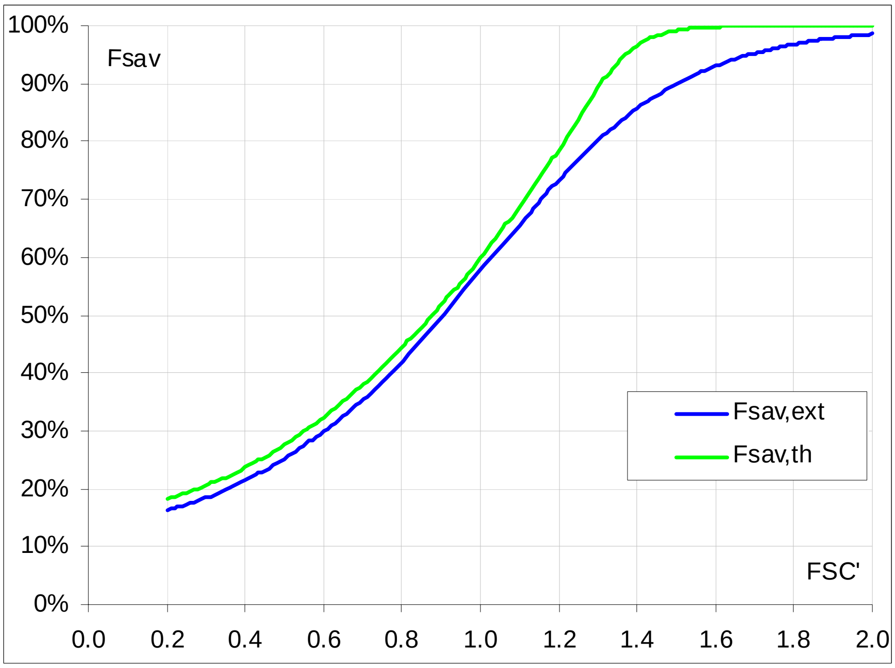


Fig. 21: Visualization of the influence of parasitic electricity used on performances

8 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