

## D4.2 : Guidelines for calculation of savings indicators

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## Symbol list

Symbol	Definition	Unit
A	area	m <sup>2</sup>
C	consumption	kWh
C	effective heat capacitance of a conditioned space	J/K
DD	degree-days	K
DH	thousands of degree-hours	10 <sup>3</sup> K.h
F	fractional energy savings	-
FSC	fractional solar consumption	-
H	mean heat transfer coefficient	W/K
I <sub>sol</sub>	solar irradiation	kWh/m <sup>2</sup> .d
N	number	-
P	power	W
Q	energy quantity, load, loss	kWh
UA	heat loss rate	W/K
v	volume	m <sup>3</sup>
W	electric consumption	kWh
X	ratio irradiation/reference consumption	-
δ	difference	
θ	temperature	°C
η	efficiency, utilization factor	%
τ	time constant	h
Δt	time step	h
Φ	heat flow rate, thermal power	W/m <sup>2</sup>
<b>Suffixes</b>		
aux	auxiliary	
bur	burner	
c	solar collector	
conv	conventional	
d	day, daily	
d	design	
e	external	
el	electrical	
eq	equivalent	
ext	extended (thermal and electrical)	
f	floor	
ge	generation	
gn	gain	
H	space heating	
hs	heating season	
i	internal (temperature)	
in	intermediate	
inj	injected	
int	internal (heat)	
loc	local	
ls	loss	
m	month, monthly	
m	mass-related conductance or capacitance	
max	maximum	
n	nominal	
nd	need	

nH	non heating	
on	on	
p	penalty	
real	real	
ref	reference	
s	south	
sav	saved	
set	set-point	
sol	solar	
st	storage, stored	
stby	standby	
sv	spatial variation	
th	thermal	
tv	temporal variation	
v	vertical	
W	Domestic Hot Water	
w	week, weekly	
*	used when a definition is slightly modified	
<b>Fonts</b>		
normal	calculated values	
<b>bold</b>	<b>identified or estimated values</b>	
<i>italic</i>	<i>measured values</i>	

Annual and monthly values:

In general, energy balances can be calculated on a yearly or monthly period, with same formula. If the annual formulas are ambiguous, the symbol  $\Sigma$  is placed before the concerned figure.

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## Introduction

In order to be in coherence with the ranking and comparison criteria proposed in Task 26, a method for monitoring solar combisystems (SCS) has been elaborated in the frame work of the Altener Combisystems project, which gives as an output a value for the annual fractional energy savings  $F_{sav}$  according to the Fractional Solar Consumption FSC [1]. This method is based on the measurements of monthly energy balances [3].  $F_{sav}$  is evaluated by comparison between the auxiliary energy used by the SCS and the one used by a conventional system without solar collector, using the same energy.

The aim of the FSC method is to give an evaluation of the behaviour of the SCS

FSC does not depend on the SCS and the auxiliary energy used. It only characterizes the solar potential compared to a reference consumption necessary for space heating and DHW production. It is for this reason that it doesn't take into account the real auxiliary energy used by the SCS.

The estimation of the conventional load is presented. Next the reference systems are described in details. Then, the estimation of the conventional consumption is presented (the word "conventional" means that a conventional space heating and DHW system is considered, but installed in the "same" house as the monitored one). At last, the indicators are calculated.

## 1. Monitoring diagram

Diagram in figure 1 and 2 presents the methodology proposed for measurements analysis, in order to determine the parameters FSC and  $F_{sav}$ .

- The first step consists in calculating the monthly values for the solar irradiation available on the collector area.

The best method is to use a pyranometer located in the collector plane. A calibrated PV cell can also be used, but provides usually a worse accuracy.

If no irradiation measurements are done on site, the meteorological data from the nearby station will be used: monthly sun duration or monthly irradiation available on the horizontal plane. Shading should be taken into account when calculating corresponding irradiances in the collector plane.

- The second step consists in calculating reference monthly consumptions. Two options are possible depending on whether solar heat is stored in the building itself (heating floors or walls) (figure 2) or not (figure 1). In that last case, the real space heating load can be assessed with the energy injected in the space heating loop. At the opposite, if the building is used as space heating storage for solar heat, the real space load must be assessed by using an identification process, which allows determining the real parameters describing the thermal behaviour of the building: heat loss coefficient of the building, internal gain factor, equivalent South area used to estimate the passive solar gains.
- The third step consists in calculating the Fractional Solar Consumption.
- The fourth step consists in calculating thermal and extended Fractional Energy Savings

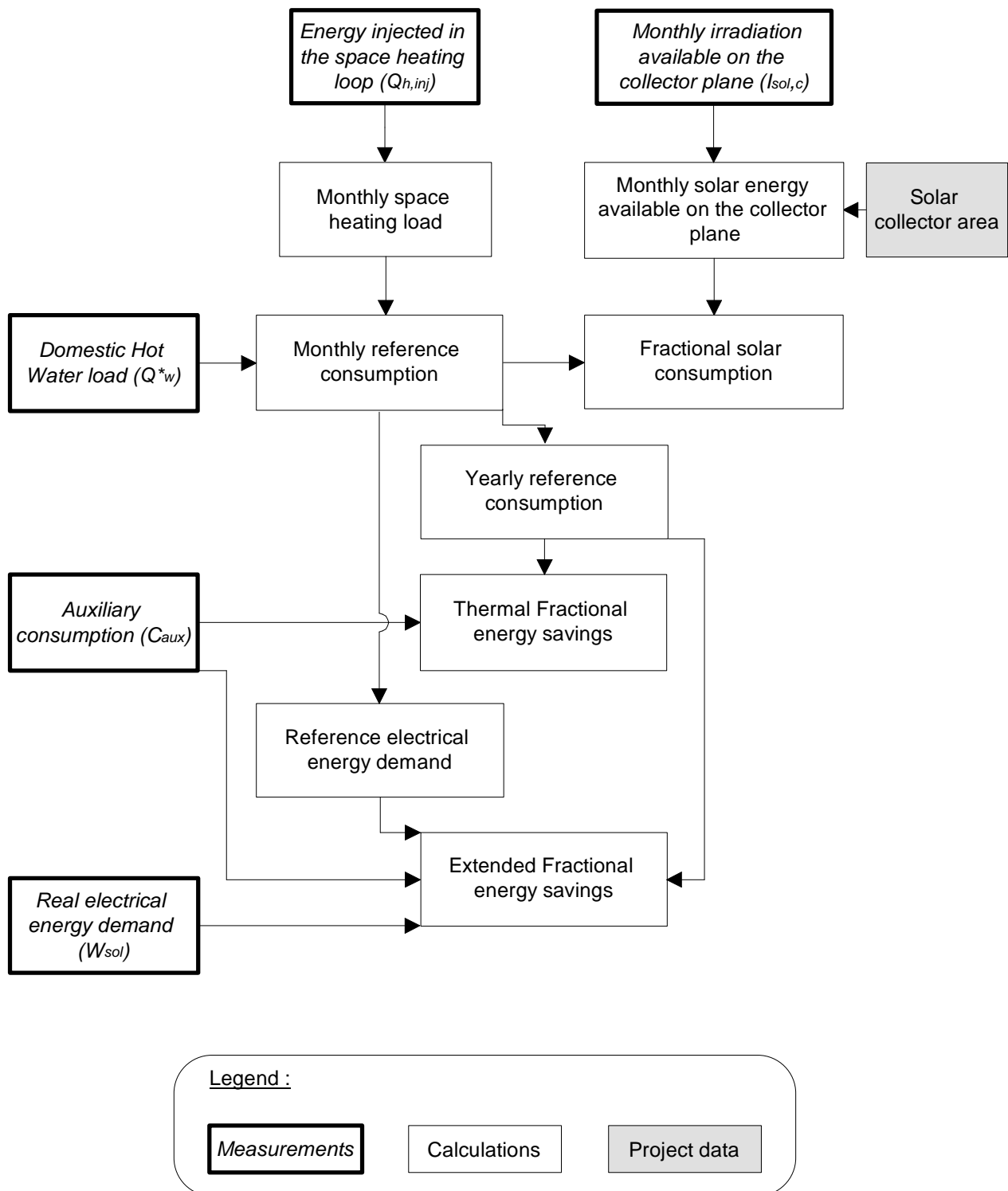


Figure 1: Monitoring diagram for systems without storage for space heating in the building

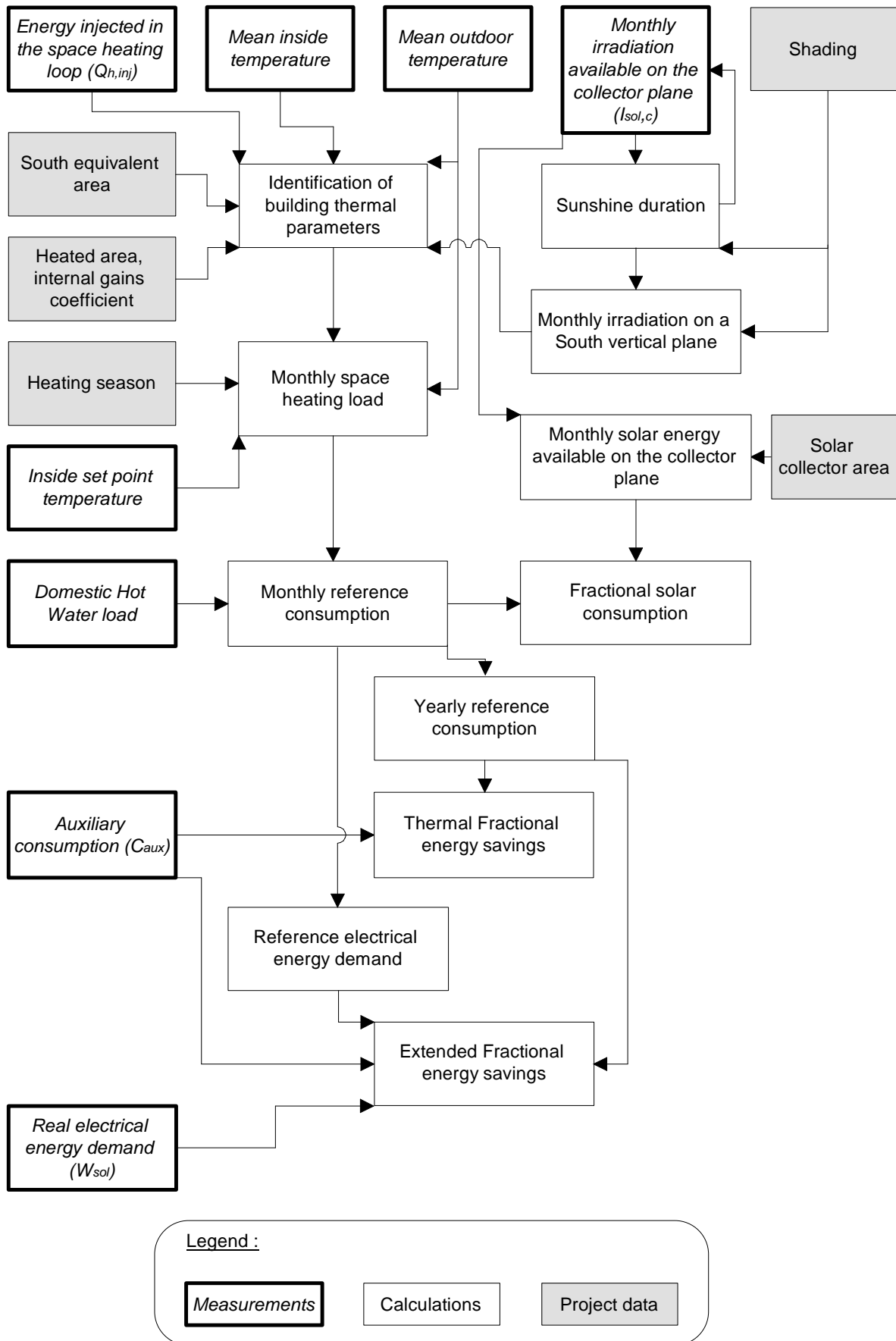


Figure 2: Monitoring diagram for systems with storage for space heating in the building

## 2. Conventional load calculation (space heating and Domestic Hot Water)

In this paragraph, all benchmarks for heat meters refer to figures given in [1]

### 2.1. Conventional space heating load

#### 2.1.1. SCS not using the building itself as storage

For SCS not using the building itself as storage, the energy injected in the space heating loop, and measured directly by the heat meters C3 and C3', can be considered as space heating load  $Q_h$ . This quantity is not strictly the space heating load, because it takes into account the distribution and emission losses.

#### 2.1.2. SCS using the building itself as storage

For SCS using the building itself as storage for space heating, or a part of it like the heating floor, the internal air temperature is sometimes higher than the set point air temperature, especially if the control device allows to inject more energy in the floor that strictly needed to maintain the internal temperature at the setpoint value, when solar energy is available. The conventional load must be then calculated with a three steps procedure:

- Identification of the real thermal coefficients of the house (heat loss coefficient of the building, internal gain factor, equivalent South area used to estimate the passive solar gains.)
- Determination of the length of the heating season
- Calculation of the space heating load

This special method should be used for example with SCS #1 and #3, so-called Direct Solar Floors [2], where solar energy is stored directly in the heating floor.

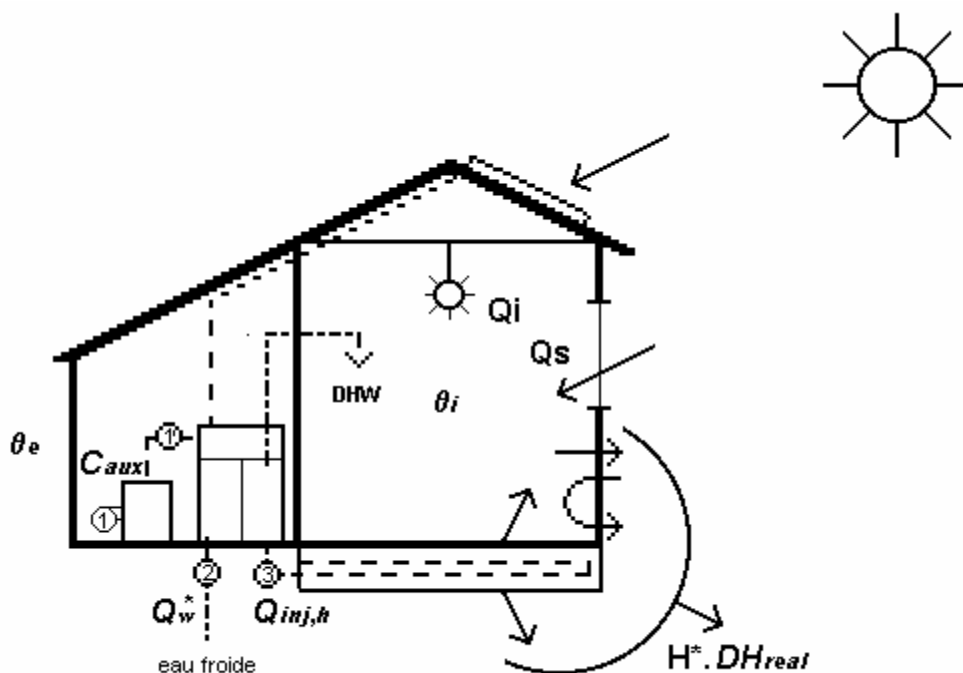


Figure 3: Location of the heat meters and other sensors

### 2.1.2.a Identification of the real thermal coefficients of the house

The method presented hereunder is based on the calculation method developed in the French thermal regulation Th-C 2000 [9], which is closed to [10].

For a period integrally heated, the space heating load  $Q_{H,nd}$  is calculated according an internal equivalent temperature  $\theta_{i,eq}$  and according the external ambient temperature  $\theta_e$  with

Equ. 1 :

$$\text{Equ. 1} \quad Q_{H,nd} = H \cdot (\theta_{i,eq} - \theta_e) \cdot 0,024 \cdot N_d - \eta_{H,gn} \cdot (Q_{sol} + Q_{int}) \quad (\text{kWh})$$

with  $Q_{sol}$  : passive solar gains (kWh)  
 $Q_j$  : internal gains (kWh)  
 $H$  : mean heat transfer coefficient (W/K)  
 $\eta_{H,gn}$  : utilization factor of free heat gains  
 $N_d$  : length of the period (days)

Passive solar gains can be calculated using the equivalent South area  $A_{s,eq}$  the mean vertical South irradiation  $I_{sol,s,v}$  and the number of days of the considered period  $N_d$ :

$$\text{Equ. 2} \quad Q_{sol} = A_{s,eq} \cdot I_{sol,s,v} \cdot N_d$$

Internal gains are proportional to the heated area  $A_f$ , using a coefficient  $\Phi_{int}$  which represents the mean daily internal gains per square meter of heated area.

$$\text{Equ. 3} \quad Q_{int} = 0,024 \cdot \Phi_{int} \cdot A_f \cdot N_d$$

Equ. 1 shows that the three characteristic, parameters of the house  $H$ ,  $A_{s,eq}$  et  $\Phi_{int}$  are necessary to calculate the space heating load.

We present hereunder an identification method for these parameters.

With a heat meter, we can measure the energy sent in a space heating loop  $Q_{H,inj}$ . (If space heating is brought with two different loops,  $Q_{H,inj}$  will gather the two corresponding measured quantities.)

This energy  $Q_{H,inj}$  is used to complement the free heat gains (passive solar gains and internal gains) in order to compensate the heat losses of the house. The observed internal temperature and the heating degree-hours calculated with this temperature are the result of the contribution of these three energy quantities:

$$\text{Equ. 4} \quad H^* \cdot DH_{real} = Q_{H,inj} + Q_{sol} + Q_{int}$$

with  $DH_{real}$  : thousands of degree-hours calculated with the real internal temperature  
 $H^*$  : mean heat transfer coefficient, with losses of the space heating loop integrated

The energy injected in the space heating loop is given by Equ. 5:

$$\text{Equ. 5} \quad Q_{H,inj} = H^* \cdot DH_{real} - (A_{s,eq} \cdot I_{sol,s,v} + 0,024 \cdot \Phi_{int} \cdot A_f) \cdot N_d$$

First step of the evaluation of the space heating load consists in determining the real value of the three parameters ( $H^*$ ,  $A_{s,eq}$  et  $\Phi_{int}$ ), which minimize the gap between the injected energy calculated with Equ. 5

and the measured injected energy  $Q_{H, inj}$ . This is done by searching the minimum value of the mean quadratic difference between the two series of values.

In this adjustment procedure,  $DH_{real}$  represents the value of the real heating degree-hours calculated with the real internal temperature on a given time step,  $I_{sol, s, v}$  represents the value of the mean vertical South irradiation integrated in the same time step, calculated from the measured irradiation on the collector area. In this procedure, the periods at the beginning and at the end of the heating period are eliminated when they are not fully heated.

Comparisons made using different time steps have shown that the best compromise is to work on a weekly basis: on a monthly basis, there are too less figures to have a reliable determination of the characteristic parameters. On a daily basis, the effects of heat storage in the building mass cannot be neglected. So  $N_d$  represents the number of days in a week  $N_{d, w}$ .

### 2.1.2.b Determination of the length of the heating period

To calculate the space heating load, the dates of beginning and end should be known. Ideal for operating a monitoring is to be informed by the occupant of the dates of beginning and end of the heating period. If this is impossible, the following method can be used. It is based on the notion of heating "signature". It can be defined as the line characterizing the space heating load according to the difference internal temperature - external temperature.

If we draw, on a monthly time step, a graph with that difference on a horizontal axis and the total energy injected into the space heating loop on the vertical axis, points are quite properly aligned. The regression line obtained from these points cuts the x-axis at a point representative of the non-heating temperature  $\theta_{nH}$ . To determine the day corresponding to that temperature, we proceed as follows:

- determination of the two consecutive months in which the external mean temperatures, reached on the 15th of the month, are on both sides of  $\theta_{nH}$
- assuming a linear variation of temperature between these two dates, calculation of the day where the external temperature is  $\theta_{nH}$

The calculation is done separately for the beginning and end of the heating season, because the behavior of the user is not necessarily identical in these two periods.

### 2.1.2.c Estimation of the internal equivalent temperature

Rigorously, calculation of equivalent temperature must take into account many parameters:

- The set point temperature for occupancy,
- The set point temperature during the night
- The set point temperature during the week-ends
- The lengths of period with reduced set point temperatures
- The heat capacity of the building
- The heat transfer coefficient of the building
- Etc ...

This calculation is very complicated and involves parameters that can theoretically be calculated. Rigorously, some of these parameters (the fifth and the sixth) should be identified, similarly to what has been proposed for the real thermal coefficients of the house.

Other parameters, particularly the four firsts, can be modified by the occupant, making it very difficult to interpret the measures. However, the chosen values must be known, and it has to be asked to the occupant to inform about any changes in these values.

The internal equivalent temperature  $\theta_{i, eq}$  is equal to the set point temperature chosen by the occupying  $\theta_{i, set}$ , plus  $\delta\theta_{sv}$  for the spatial variations and  $\delta\theta_{tv}$  for the temporal variations, according to types of heat emitters and the quality of control device for space heating.

$$\text{Equ. 6} \quad \theta_{i,eq} = \theta_{i,set} + \delta\theta_{sv} + \delta\theta_{tv}$$

As indicated above, the consumption of reference shall be calculated for a reference system providing the same comfort. So if the SSC uses a floor heating, the reference will also be equipped with floor heating. Similarly, if the SSC uses radiators, the reference will also be equipped with radiators.

According to these considerations and from indications in the Thermal Regulations 2005 [3], [8], values for  $\delta\theta_{sv}$  and  $\delta\theta_{tv}$  are given in Table 1:

1.1.1.c.1 Heat emitter	Spatial variations (K)	Temporal variations (K)
Electric radiator	0,2	0,9
Heating floor	0	1,8
Low temperature radiator	0,2	1,2
High temperature radiator	0,4	1,2

Table 1: Spatial and temporal variations

### 2.1.2.d Calculation of the space heating load

After the determination of the characteristic parameters of the house, the space heating load  $Q_{H,nd}$  is calculated using Equ. 1, but is limited to the energy injected in the floor.

$$\text{Equ. 7} \quad Q_{H,nd} = \min ( H \cdot (\theta_{i,eq} - \theta_e) \cdot 0,024 \cdot N_d - \eta_{H,gn} \cdot (Q_{sol} + Q_{int}) ; Q_{H,inj} ) \quad (\text{kWh})$$

For incomplete months (first and last months of the heating season), the number of days considered in Equ. 1 is the one determined in paragraph 2.1.2.b.

$\eta_{H,gn}$  is the utilization factor of free heat gains. It is based on the heat balance ratio called  $\gamma_H$ , and the time constant,  $\tau$ , characterizing the thermal inertia of the inner heated space:

$$\text{Equ. 8} \quad \gamma_H = (Q_{sol} + Q_{int}) / (H^* \cdot (\theta_{i,eq} - \theta_e) \cdot 0,024 \cdot N_{d,m})$$

$$\eta_{H,gn} = (\tau + 16) / (\tau + 32) \quad \text{if } \gamma_H = 1$$

$$\eta_{H,gn} = \frac{1 - \gamma_H^{(1 + \tau/16)}}{1 - \gamma_H^{(2 + \tau/16)}} \quad \text{if } \gamma_H \neq 1$$

$\tau$  is given by Equ. 9 :

$$\text{Equ. 9} \quad \tau = C_m / H$$

With  $C_m$  : internal heat capacity of the building, which depends on the inertia class, given in Table 2.

Inertia class	Thermal daily capacity $C_m$ (J/K)
Very light	80 / 3,6 . $A_f$
light	110 / 3,6 . $A_f$
Mean	165 / 3,6 . $A_f$
Heavy	260 / 3,6 . $A_f$
Very heavy	370 / 3,6 . $A_f$

Table 2: Daily capacity of the building

The inertia class of the house is determined from the composition of the walls, using Table 3.

Floor	Ceiling	Vertical wall	Inertia class
Heavy	Heavy	Heavy	Very heavy
-	Heavy	Heavy	Heavy
Heavy	-	Heavy	Heavy
Heavy	Heavy	-	Heavy
-	-	Heavy	Average
-	Heavy	-	Average
Heavy	-	-	Average
-	-	-	Very light

Table 3: Inertia class of a building

To help determining the inertia class for private houses, one can follow the following rules:

- The category "very heavy" is never encountered in practice for individual houses
- The vertical walls will be considered as "heavy" or not depending on whether the insulation is located outside the walls or not
- A house with heavy floors is in the class "heavy" or "average" depending on whether the walls are externally insulated or not
- A house with light floors (wood) is in the class "average" or "very light" depending on whether the walls are externally insulated or not.

#### 2.1.2.e Indication for the determination of the internal set point temperature

If the set point internal temperature selected by the user is not known, or if there is a doubt about its value, one can make an estimate based on the following assumptions:

It is possible to estimate the contribution of free gains  $\delta\theta_i$  to the increase of the internal temperature beyond the set point value. According to the previous paragraph, recovered free gains are  $\eta_{H,gn} \cdot (Q_{sol} + Q_{int})$ . Free gains not utilised to reduce the space heating load and therefore creating the overheating  $\delta\theta_i$  are :  $(1 - \eta_{H,gn}) \cdot (Q_s + Q_i)$ .  $\delta\theta_i$  is calculated with Equ. 10:

$$\text{Equ. 10} \quad \delta\theta_i = (1 - \eta_{H,gn}) \cdot (Q_{sol} + Q_{int}) / (H^* \cdot 0,024 \cdot N_{d,m})$$

An upper limit of the set point internal temperature will be obtained by determining the minimum value of monthly  $\theta_i - \delta\theta_i$ .

#### 2.1.2.f Penalty for non respect of internal set point temperature

A SSC may not be able to maintain the internal temperature at the set point value chosen by the user. In this case, energy actually injected into the space heating loop is less than it would normally be if the set point value had been met.

A complementary load must be added to the calculated space heating load, based on the difference between the chosen set point temperature and the internal temperature actually observed. The penalty proposed in task 26 "solar combisystems" of the IEA [4] is given by Equ. 11.

$$\text{Equ. 11} \quad Q_p = H^* \cdot \max [ 0 ; \max ( 0 ; \theta_{i,\text{set}} - \theta_i ) + \{ \max ( 0 ; \theta_{i,\text{set}} - \theta_i ) + 1 \}^2 - 1 ] \cdot 0,024 \cdot N_{d,m}$$

The first part of the expression between brackets is the missing energy for space heating, and the second is the penalty actually added to characterize the discomfort felt by the occupant.

## **2.2. Domestic Hot Water load**

The Domestic Hot Water load  $Q_w^*$  is measured directly by the heat meter C2. This quantity is not strictly the DHW load, because it takes into account the distribution losses. If a DHW loop is installed, the losses of the loop, measured by a heat meter C5, are included in the load  $Q_w^*$ .

## **3. Definition of conventional systems (without solar equipment)**

Proposed indicators  $F_{\text{sav,th}}$ ,  $F_{\text{sav,ext}}$  are calculated with regard to a conventional system, that must be exactly defined. The controllers of some combisystems not only manage the solar contribution, but also the operation of the auxiliary boiler. The question is then: which system without solar part should the combisystem be compared with? And how are the savings defined?

In order to be able to compare two different combisystems, it is necessary for the conventional systems to be independent of the studied combisystems. The conventional system will just be chosen to deliver the same comfort as the studied combisystem: same space heating emitter, Domestic Hot Water produced in a storage tank.

At a national level, one can use a national reference system, defined for example according the national thermal regulation. For international comparison, the definition of one common reference system is mandatory.

In this document, we will define different references, one for each country according to the thermal regulation applied in the country, and one "international" reference, based on definitions agreed on in the framework of task 26, with additional proposals to take into account a greater variety of systems.

### **3.1. SCS with separated auxiliary for space heating, based on Joule effect**

The conventional system includes electric convectors, and an electric Domestic Hot Water tank.

### **3.2. SCS with integrated auxiliary for space heating**

The conventional system includes a boiler burning the same energy as the auxiliary boiler of the SCS, and a Domestic Hot Water tank, heated up by the boiler.

Space heating emitters are the same as for the monitored SCS.

For SCS using biomass as auxiliary energy, a storage tank has to be included in the conventional system if it is necessary for a good working of the boiler (for example buffer storage tank for wood boiler using wood logs).

## **4. Conventional consumptions calculation (space heating and Domestic Hot Water)**

In order to estimate the consumption of the conventional system without solar, the losses of the Domestic Hot Water tank, the space heating tank and of the boiler must be added. This calculation is made on a **monthly** basis.

$$\text{Equ. 12} \quad C_{\text{conv}} = (Q_{\text{H,nd}}^* + Q_{\text{W}}^* + Q_{\text{ls,st}}) / \eta_{\text{bur,conv}}$$

with  $Q_{\text{ls,st}}$  : storage losses =  $Q_{\text{ls,st,W}} + Q_{\text{ls,st,H}}$  (kWh)  
 $Q_{\text{ls,st,W}}$  : DHW storage tank losses (kWh)  
 $Q_{\text{ls,st,H}}$  : space heating storage tank losses (kWh)  
 $\eta_{\text{bur,conv}}$  : boiler efficiency of the conventional system, depending on the auxiliary energy used (%)

### 4.1. DHW Tank losses

Conventional DHW tank losses are given by :

$$\text{Equ. 13} \quad Q_{\text{ls,st,W}} = 0,024 \cdot UA_{\text{W,ref}} \cdot (\theta_{\text{st,W}} - \theta_{\text{loc}}) \cdot N_{\text{d,m}} \quad (\text{kWh})$$

with  $UA_{\text{W,ref}}$  : reference heat loss rate (W/K)  
 $\theta_{\text{st,W}}$  : storage temperature (°C)  
 $\theta_{\text{loc}}$  : room temperature where the tank is located (°C)  
 $N_{\text{d,m}}$  : number of days in a month

In the European standard EN 12977, the reference conditions are defined:

- The storage temperature is 52.5 °C
- The size of the store  $v_{\text{st,W,ref}}$  is 0,75 times the daily hot water demand  $v_d$ . This recommendation cannot be used for a monitored installation, because the daily hot water consumption in real houses varies from a day to another and depends on the occupancy of the house.

So it seems more realistic to fix a volume related to the size of the house.

The size of the reference DHW tank  $v_{\text{st,W,ref}}$  is given in **Erreur ! Source du renvoi introuvable.** In France, it is a function of the number of main rooms in the houses, and of the SCS category.

Europe	Storage temperature (°C)	52.5 °C [EN 12977]		
	Storage size (l)	Size of the house	SCS with an separated auxiliary space heating, based on Joule effect [6]	SCS with an integrated auxiliary space heating
		1 room	100	50
		2 rooms	150	75
		3 rooms	200	100
		4 rooms	250	125
		5 rooms and more	300	150
Austria	Storage temperature (°C)	as Europe		
	Storage size (l)	as Europe	as Europe	as Europe
France	Storage temperature (°C)	55 °C [5]		
	Storage size (l)	Size of the house	SCS with an separated auxiliary space heating, based on Joule effect [6]	SCS with an integrated auxiliary space heating
		1 room	100	50
		2 rooms	150	75
		3 rooms	200	100
		4 rooms	250	125
	5 rooms and more	300	150	
Germany	Storage temperature (°C)	52.5 °C		
	Storage size (l)	1-4 rooms	200	150
		5 and more	300	150
Sweden	Storage temperature (°C)	No DHW store in reference system		
	Storage size (l)			

Table 4: Reference DHW tank volume

The heat loss rate of the reference DHW tank  $UA_{W,ref}$  is given in table 2. In France, it depends on the auxiliary energy used and on the size of the storage tank in the case of electricity (figure 3).

<b>Europe</b>	$0.16 V_{st,W,ref}^{0.5}$	
<b>Austria</b>	as Europe	
<b>France</b>	<b>Auxiliary energy</b>	<b><math>UA_{W,ref}</math></b>
	Electricity, $V_{st,W,ref} \leq 500$ l	$0.052 V_{st,W,ref}^{0.67}$
	Electricity, $V_{st,W,ref} > 500$ l	$0.084 V_{st,W,ref}^{0.6}$
	Other fuels	$0.138 V_{st,W,ref}^{0.55}$
<b>Germany</b>	$0.16 V_{st,W,ref}^{0.5}$	
<b>Sweden</b>	0 W/K (reference is boiler with inbuilt DHW preparation)	

Table 5: Reference DHW tank losses

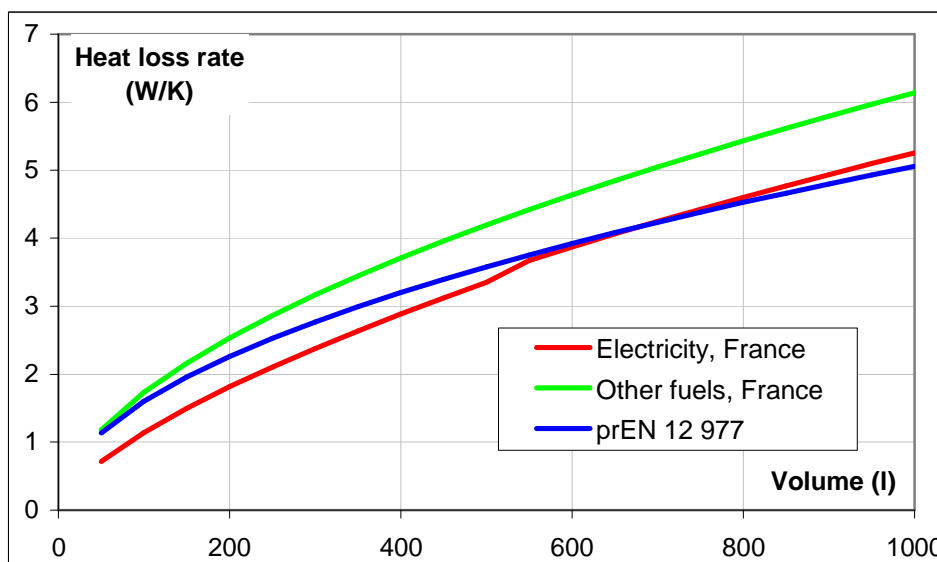


Figure 4: Heat loss rate of reference storage tanks

$\theta_{loc}$  is related to the tank location. It is given by :

$$\text{Equ. 14} \quad \theta_{loc} = \theta_{i,set} - b \cdot (\theta_{i,set} - \theta_e) \quad (^\circ\text{C})$$

with  $\theta_{i,set}$  : set point internal temperature  $(^\circ\text{C})$   
 $\theta_e$  : outdoor temperature  $(^\circ\text{C})$   
 b : location factor, given in Table 6.

Tank location	Location factor b
In the heated volume	0
In a non heated volume (garage, basement)	0,5
Outside	1

Table 6: Location factor

## 4.2. Space heating tank losses (for SCS using wood boiler with long running time)

Conventional tank losses are given by:

$$\text{Equ. 15} \quad Q_{\text{ls,st,H}} = UA_{\text{H,ref}} \cdot (\theta_{\text{st,SH,ref}} - \theta_{\text{loc}}) \cdot N_{\text{d,m}} \cdot 24 / 1000 \quad (\text{kWh})$$

with  $V_{\text{st,H,ref}}$  : storage volume, identical to the SCS storage volume (l)

$$\text{Equ. 16} \quad UA_{\text{H,ref}} = 0.16 \sqrt{V_{\text{st,H,ref}}} : \text{heat loss rate} \quad [\text{prENV 12977-1}] \quad (\text{W/K})$$

$\theta_{\text{st,SH,ref}}$  : storage temperature, fixed at **70 °C**

$\theta_{\text{loc}}$  : room temperature where the tank is located

$N_{\text{d,m}}$  : number of days in a month

## 4.3. Heat generation efficiency

### 4.3.1. Remote electric generators

The efficiency of remote electric generators is given in table 4.

Europe	100 %
Austria	as Europe
France	100 % [3]
Germany	100 %
Sweden	100 %

Table 7: Reference generation efficiency for remote Joule effect generators

### 4.3.2. Electric boiler

The efficiency of electric boilers is given in table 5.

Europe	90 %
Austria	as Europe
France	100 % [3]
Germany	90 %
Sweden	90 %

Table 8: Reference generation efficiency for electric boilers

### 4.3.3. Combustion generators

Method for the calculation of the generation losses :

Losses of the combustion generators are calculated according to prEN 14335 part 2-2.1 Annex 2 (Default values for parametering the case specific boiler efficiency method) [7]. This method is also used for the reference generator in the French Thermal Regulation RT 2005.

Generation losses  $Q_{ls,ge}$  are calculated according to the level of charge  $P_{ge}$  generator, with a linear interpolation between losses  $Q_{ls,P100}$ ,  $Q_{ls,Pin}$  and  $Q_{ls,P0}$  calculated respectively at 100% load, intermediate load  $P_{in}$  and no load.

$P_{ge}$  is the average power that the generator must provide. It incorporates the load (heating and Domestic Hot Water) and losses.

$$\text{Equ. 17} \quad P_{ge} = (Q_{H,nd}^* + Q_{W}^* + Q_{ls,st}) / 24 / N_{d,m} \quad (\text{kW})$$

If  $P_{ge}$  is between 0 and  $P_{in}$ ,  $Q_{ls,ge}$  is given by Equ. 18.

$$\text{Equ. 18} \quad Q_{ls,ge} = \frac{P_{ge}}{P_{in}} \cdot (Q_{ls,Pin} - Q_{ls,P0}) + Q_{ls,P0} \quad (\text{kW})$$

If  $P_{ge}$  is between  $P_{in}$  and the nominal power of the boiler  $P_n$ ,  $Q_{ls,ge}$  is given by equation Equ. 19.

$$\text{Equ. 19} \quad Q_{ls,ge} = \frac{(P_{ge} - P_{in})}{(P_n - P_{in})} \cdot (Q_{ls,P100} - Q_{ls,Pin}) + Q_{ls,Pin} \quad (\text{kW})$$

The losses at full load  $Q_{P100}$  are derived from the efficiency at full load  $\eta_{P100}$  and from the useful nominal power of the boiler  $P_n$  using equation Equ. 20.

$$\text{Equ. 20} \quad Q_{ls,P100} = \frac{(100 - \eta_{P100})}{\eta_{P100}} \cdot P_n \quad (\text{kW})$$

Similarly, losses at intermediate load  $Q_{Pin}$  are derived from the efficiency at intermediate load  $\eta_{Pin}$  and from the intermediate power  $P_{in}$  using Equ. 21.

$$\text{Equ. 21} \quad Q_{ls,Pin} = \frac{(100 - \eta_{Pin})}{\eta_{Pin}} \cdot P_{in} \quad (\text{kW})$$

The efficiency of the reference generator  $\eta_{bur,ref}$  is then obtained with Equ. 22:

$$\text{Equ. 22} \quad \eta_{bur,ref} = \frac{1}{1 + \frac{Q_{ls,ge}}{Q_{H,nd}^* + Q_{W}^* + Q_{ls,st}}} \quad (\%)$$

The efficiencies of combustion boilers are given in table 6. They depend on the nominal power of the boiler  $P_n$ . Figures refer to the lower calorific value of the fuel used.

<b>Europe</b>	$\eta_{P100} = A + B \cdot \log P_n$ $\eta_{Pint} = C + D \cdot \log P_n$ $Q_{Is,P0} = P_n \cdot (E - F \cdot \log P_n) / 100$ $P_{in} = G \cdot P_n$						
	The values of coefficients A, B, C, D, E, F and G are given hereunder [3]						
	A	B	C	D	E	F	G
Gas or oil	88.5	1.5	88.5	1.5	1,75	0,55	0,3
<b>Austria</b>	as Europe						
<b>France</b>	as Europe						
<b>Germany</b>	as Europe						
<b>Sweden</b>	85% gas (but irrelevant, because almost no gas used as auxiliary energy), 75% pellet boiler						

Table 9: Reference generation efficiency for oil or gas boilers

Choice of the nominal power of the reference generator:

Two options are possible:

- The nominal power of the reference generator is taken EQUAL TO the actual power of the installed auxiliary boiler. This method should be used if it is considered that the choice of the power of the auxiliary boiler is NOT part of the evaluation process. This can be the case either if the auxiliary boiler already exists, and is not a part of the new installed SCS, or if the auxiliary boiler is a component of the new installed SCS, but its power, chosen by the installer or the manufacturer, is just taken as an input figure of the evaluation process.
- The savings indicator should integrate the quality of the design of the SCS, and especially the auxiliary boiler that should have a power as low as possible in order to decrease losses. It can be used if the heat transfer coefficient of the house is known.  
The nominal power of the reference generator is chosen with table 7, according to the maximum heat losses of the house  $P_{max}$  given by:

$$\text{Equ. 23} \quad P_{max} = 1,2 \cdot H \cdot (19 - \theta_d)$$

Where  $\theta_d$  : ambient design temperature (°C)  
H : heat transfer coefficient of the house (W/K)

<b>Europe</b>	nominal power of the reference generator EQUAL TO the actual power of the installed auxiliary boiler	
<b>Austria</b>	as Europe	
<b>France</b>	<b><math>P_{max}</math></b>	<b>Nominal boiler power <math>P_n</math></b>
	$P_{max} < 14$	14
	$14 < P_{max} < 18$	18
	$18 < P_{max} < 23$	23
	$23 < P_{max} < 27$	27
	$27 < P_{max} < 36$	36
	$36 < P_{max} < 45$	45
<b>Germany</b>	as Europe	
<b>Sweden</b>	as Europe	

Table 10: Reference nominal boiler power

## 4.4. Parasitic electric consumptions

The approach presented here is based on the propositions made by Task 26 of the IEA [4].

### 4.4.1. Boiler

The monthly running time of the boiler  $\Delta t_{bur,on,ref}$  is given by:

$$\text{Equ. 24} \quad \Delta t_{bur,on,ref} = \frac{Q^*_{H,nd} + Q^*_W + Q_{Is,st}}{P_n}$$

with  $P_n$  : reference nominal boiler power (kW)  
 $Q^*_{H,nd}$  : space heating load (kWh)  
 $Q_W$  : Domestic Hot Water load (kWh)  
 $Q_{Is,st}$  : storage losses =  $Q_{Is,st,W} + Q_{st,SH}$  (kWh)

The electrical energy demand of the reference boiler is given by:

$$\text{Equ. 25} \quad W_{el,ur,ref} = P_{el,bur,on} \cdot \Delta t_{bur,on,ref} + P_{el,bur,stby} \cdot (24 \cdot N_{d,m} - \Delta t_{bur,on,ref}) \quad (\text{kWh})$$

with  $P_{el,bur,on}$  : electrical power of the reference boiler when working (kW)  
 $P_{el,bur,stby}$  : electrical power of the reference boiler when standby (kW)

Combining both equations 10 and 11,  $W_{bur,ref}$  is given by Equ. 26:

$$\text{Equ. 26} \quad W_{el,bur,ref} = \frac{Q^*_{H,nd} + Q^*_W + Q_{Is,st}}{P_n} \cdot (P_{el,on} - P_{el,stby}) + 24 \cdot N_{j,m} \cdot P_{el,stby} \quad (\text{kWh})$$

The electrical power of the conventional boiler is given by Equ. 27 and Table 11:

$$\text{Equ. 27} \quad \begin{aligned} P_{el,bur,stby} &= 9 \quad (\text{W}) \\ P_{el,bur,on} &= 0,8349 \times P_n + 22,257 \quad (\text{W}) \end{aligned}$$

Reference nominal boiler power	Electrical power of the boiler
14 kW	34 W
18 kW	37 W
23 kW	41 W
27 kW	45 W
36 kW	52 W
45 kW	60 W

Table 11: Electric power of the boiler

The electric power of the conventional pump of the DHW tank loop is given by:

$$P_{el,w} = 60 \text{ W}$$

The electric power of the pump of the space heating loop is given by:

$$P_{el,sh} = 95 \text{ W}$$

#### 4.4.2. DHW load pump

The yearly running time of the pump for DHW preparation is given by:

$$\text{Equ. 28} \quad \Delta t_W = \frac{Q_W^* + Q_{\text{ls,st,W}}}{P_n} \quad (\text{h})$$

The electrical energy demand of the reference pump for DHW preparation is given by:

$$\text{Equ. 29} \quad W_{\text{el,W,ref}} = \Delta t_W \cdot P_{\text{el,W}} \quad (\text{kWh})$$

with  $P_{\text{el,W}}$  : electrical power of the reference pump for DHW (kW)

#### 4.4.3. Space heating loop

The electrical energy demand of the reference pump of the space heating loop is given by:

$$\text{Equ. 30} \quad W_{\text{el,H,ref}} = \Delta t_{\text{sh}} \cdot P_{\text{el,H}} \quad (\text{kWh})$$

with  $P_{\text{el,H}}$  : electrical power of the reference pump of the space heating loop (kW)  
 $\Delta t_{\text{hs}}$  : length of the time heating season (h), considered to be the same as the real one

#### 4.4.4. Controller

The electrical energy demand of the controller is neglected.

#### 4.4.5. Global electricity consumption

The global electrical energy demand  $W_{\text{el,ref}}$  is calculated with :

$$\text{Equ. 31} \quad W_{\text{el,ref}} = W_{\text{el,bur,ref}} + W_{\text{el,H,ref}} + W_{\text{el,W,ref}} \quad (\text{kWh})$$

### 5. Indicators calculation

In order to be able to compare performances of different plants, the FSC method developed in the framework of task 26 is used, with some adaptations. Indicators are calculated in two different ways, according to the location of the meter for auxiliary energy. If auxiliary energy is measured at the boiler inlet, boiler efficiency is taken into account.

#### 5.1. Fractional solar consumption

FSC is calculated according to task 26 definitions, but using the reference efficiency calculated with equation 10.

### 5.1.1. With boiler efficiency

$$\text{Equ. 32} \quad \text{FSC} = \frac{\sum_1^{12} \min((Q^*_{H,nd} + Q^*_{W} + Q_{Is,st}) / \eta_{bur,ref}, A_c \cdot I_{sol,c})}{\sum_1^{12} (Q^*_{H,nd} + Q^*_{W} + Q_{Is,st}) / \eta_{bur,ref}}$$

### 5.1.2. Without boiler efficiency

$$\text{Equ. 33} \quad \text{FSC}^* = \frac{\sum_1^{12} \min((Q^*_{H,nd} + Q^*_{W} + Q_{Is,st}), A_c \cdot I_{sol,c})}{\sum_1^{12} (Q^*_{H,nd} + Q^*_{W} + Q_{Is,st})}$$

## 5.2. Fractional thermal energy savings

This indicator only takes into account the thermal behaviour of the SCS.

### 5.2.1. With boiler efficiency

$$\text{Equ. 34} \quad F_{sav,th} = 1 - \frac{C_{aux,(1)}}{(Q^*_{H,nd} + Q^*_{W} + Q_{Is,st}) / \eta_{bur,ref}}$$

$C_{aux}$  is measured with the meter  $n^{\circ}$

$\eta_{bur,ref}$  is the conventional efficiency defined in paragraph 4.

### 5.2.2. Without boiler efficiency

$$\text{Equ. 35} \quad F^*_{sav,th} = 1 - \frac{C_{aux,(1')}}{(Q^*_{H,nd} + Q^*_{W} + Q_{Is,st})}$$

$C_{aux}$  is measured with the meter  $n^{\circ}$ '

## 5.3. Extended fractional solar consumption

This indicator also takes into account the parasitic electricity used by the SCS for pumps, valves, controller, and the boiler. Electricity is calculated at the primary energy level, considering an efficiency  $\eta_{el}$  for electricity generation and distribution given in table 9.

Europe	40 %
Austria	40 %
France	1 / 2.58 = 38.8 % [3]
Germany	40 %
Sweden	40 %

Table 12: Efficiency for electricity generation and distribution

### 5.3.1. With boiler efficiency

$$\text{Equ. 36} \quad F_{\text{sav,ext}} = 1 - \frac{C_{\text{aux, (1)}} + W_{\text{sol}} / \eta_{\text{el}}}{(Q^*_{\text{H,nd}} + Q^*_{\text{W}} + Q_{\text{ls, st}}) / \eta_{\text{bur, ref}} + W_{\text{el, ref}} / \eta_{\text{el}}}$$

$C_{\text{aux}}$  is measured with the meter  $n^{\text{q}}$

### 5.3.2. Without boiler efficiency

$$\text{Equ. 37} \quad F^*_{\text{sav,ext}} = 1 - \frac{C_{\text{aux, (1')}} + W_{\text{sol}} / \eta_{\text{el}}}{(Q^*_{\text{H,nd}} + Q^*_{\text{W}} + Q_{\text{ls, st}}) + W_{\text{el, ref}} / \eta_{\text{el}}}$$

$C_{\text{aux}}$  is measured with the meter  $n^{\text{q}'}$

In Equ. 36 and Equ. 37,  $\eta_{\text{el}}$  is introduced ONLY if the auxiliary energy used is NOT electricity.

## 6. Extrapolations to get yearly energy balances from the real monitoring period

### 6.1. Monthly results diagram

When plotting the monthly fractional energy savings  $f_{\text{sav,th}}$  according to the ratio  $X$  defined by the total monthly irradiation on the collector area divided by the monthly conventional consumption for a chosen plant, a characteristic curve can be observed (figure 4).  $X$  is calculated according equation 24.

$$\text{Equ. 38} \quad X = \frac{A_{\text{c}} \cdot I_{\text{sol, c}}}{(Q^*_{\text{H,nd}} + Q^*_{\text{W}} + Q_{\text{ls, st}}) / \eta_{\text{bur, ref}}}$$

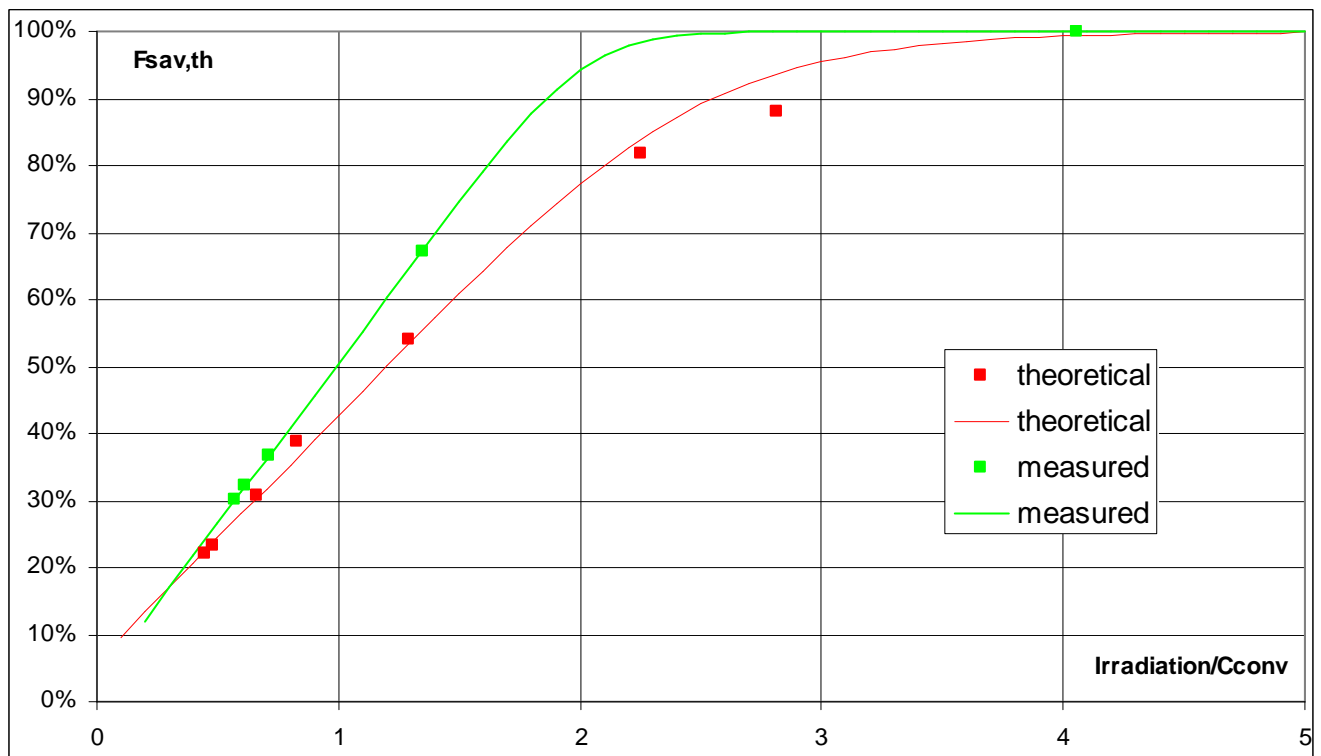


Figure 5: Example of characteristic curves of a plant

An analytic expression of the curve which interpolates best the monthly points is given by equation 25.

$$\text{Equ. 39} \quad F_{\text{sav, th, m}} = \frac{A (X - B) - [A (X - B)]^C}{1 - [A (X - B)]^C}$$

The coefficients of the curve A, B and C are adjusted to get the best fitting of the interpolating curve with real points.

This method can be used as well for the theoretical values resulting from the dimensioning study as for monitoring results. The curves can differ more or less, because of differences between the real space heating loads created by different internal set-point temperatures, and also differences in the DHW loads. In the example shown in figure 4, the curve extrapolated from measurements is slightly above the theoretical one, which shows that the system works quite well. However, the curve interpolated from measured values can be considered as more significant and representative of the real behaviour of the system. It will therefore be used for further extrapolations.

## 6.2. Yearly extrapolation from monthly results

To obtain yearly extrapolation from monthly monitoring results, the following method is used:

1. At the very least, 3 monthly data sets are necessary. But obviously more data sets will improve the accuracy of the extrapolation method. For each month, following measurements are needed:
  - Irradiation
  - "Real" degree-days, evaluated with measured internal air temperature and outdoor temperature

- Space heating load
- DHW load
- Auxiliary energy consumption

From these data, the space heating "signature" of the house is calculated, by plotting the measured space heating load according to the degree-days DD. Monthly space heating load can be represented as a linear function of degree-days:

$$\text{Equ. 40} \quad Q_{H,nd} = a \cdot DD + b \quad (\text{kWh})$$

In the given example (Figure 6), the signature is characterized by the values  $a = 7.24$  and  $b = -1362$ .

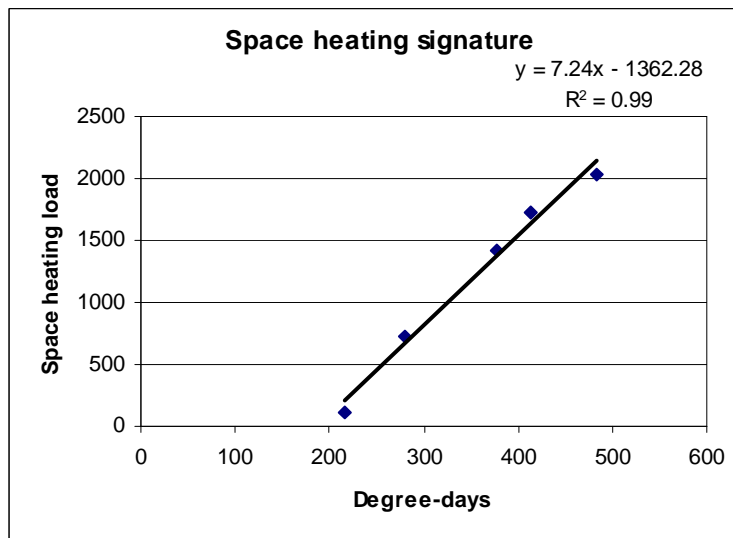


Figure 6: Space heating "signature" of a house

2. From the monitored DHW loads (or from the DHW draw-off and the cold and hot water temperatures), a mean value can be calculated for the DHW daily load.
3. From the monitored space heating and DHW loads, and using the reference DHW tank losses, the conventional energy consumption  $C_{conv}$  is calculated using Equ. 12.
4. The ratio total irradiation on the collector area divided by the conventional energy consumption  $C_{conv}$  can then be calculated, using Equ. 38. The coefficients of the curve A, B and C can be determined as explained in paragraph 6.1 (Equ. 39)
5. Extrapolation is made for missing monitoring months with following method, using theoretical degree-days and irradiances :
  - From the theoretical monthly degree-days, the conventional space heating load is calculated with Equ. 40, and parameters a and b calculated in step 1.
  - The conventional DHW load is calculated using the mean monthly value determined with first measurements.
  - The conventional energy consumption  $C_{conv}$  is calculated using Equ. 12.
  - The X ratio is calculated with Equ. 38
  - The monthly fractional energy savings  $f_{sav,th,m}$  are obtained from Equ. 39 and parameters A, B and C calculated in step 4.
  - The monthly energy savings come from Equ. 41:

$$\text{Equ. 41} \quad Q_{sav,th} = F_{sav,th,m} \cdot C_{conv}$$

It is now possible to calculate yearly extrapolations for FSC and  $F_{sav,th}$ , using monthly monitored data when there are available and monthly extrapolated data for other months in Equ. 32 and Equ. 34. Table 13: Example of extrapolation Table 13 gives an example.

		J	F	M	A	M	J	J	A	S	O	N	D	Total
<b>Number of days</b>		31	28	31	30	31	30	31	31	30	31	30	31	
<b>Degree-days</b>		484	414	281	188	0	0	0	0	0	216	280	377	2241
<b>Irradiation</b>	<b>kWh</b>	1721	1714	2343	2556	2652	2592	2866	2871	2507	2280	1690	1188	26980
<b>Reference DHW tank losses</b>	<b>kWh</b>	68	61	64	60	59	54	53	54	55	55	63	68	712
<b>Space heating load</b>	<b>kWh</b>	2032	1719	673	2	0	0	0	0	0	112	728	1414	6680
<b>DHW load</b>	<b>kWh</b>	277	257	287	278	287	278	287	287	278	311	277	276	3378
<b>Qaux</b>	<b>kWh</b>	1894	1518	87	0	0	0	0	0	0	0	411	1444	5354
<b>Cref</b>	<b>kWh</b>	2797	2396	1205	399	407	390	400	401	391	562	1257	2067	12671
<b>Usable irradiation</b>	<b>kWh</b>	1721	1714	1205	399	407	390	400	401	391	562	1257	1188	10034
<b>FSC</b>														<b>0.79</b>
<b>Cconv</b>	<b>kWh</b>	2797	2396	1205	399	407	390	400	401	391	562	1257	2067	12671
<b>Irradiation/Cconv</b>		0.615	0.715	1.944	6.406	6.523	6.649	7.161	7.163	6.415	4.057	1.345	0.575	
<b>Fsav,th (points)</b>		32.3%	36.7%	92.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	67.3%	30.1%	<b>57.7%</b>

**legend**

monitoring data
theoretical values
calculations

Table 13: Example of extrapolation

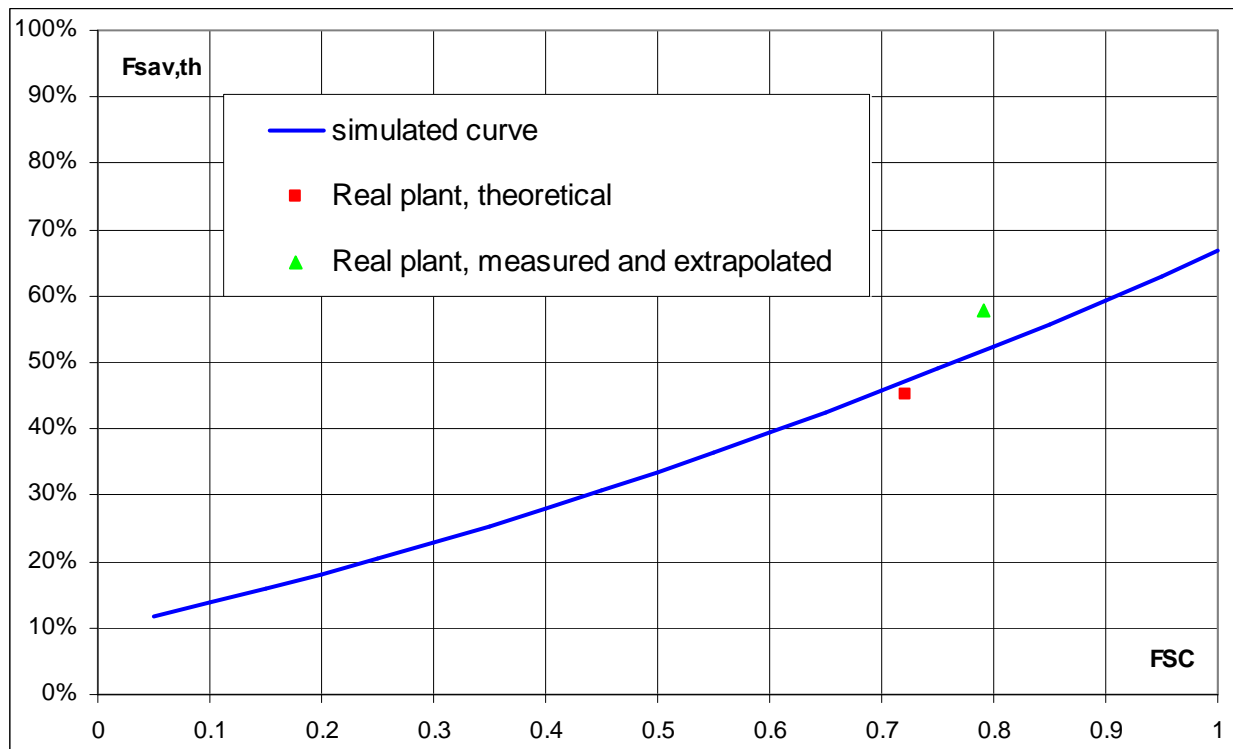


Figure 7: Example of extrapolated yearly results

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