QAiST - Deliverable D.3.3.A.

Improved extrapolation procedure for the determination of the performance of factory made systems -

Description and guidelines

Jan Erik Nielsen, 2/12 2009

Contents

Introduction

The deliverable 3.3 is divided into two parts:

- ❑ D.3.3.A Improved extrapolation procedure for the determination of the performance of factory made systems - Description and guidelines
- ❑ D.3.3.B Improved extrapolation procedure for the determination of the performance of factory made systems - Revised description and guidelines (to be proposed to the Solar Keymark Network.

The starting point for this sub task was work done in the Solar Keymark II project. Here a proposal was made for an extrapolation procedure for the determination of the performance of factory made systems - BUT this proposal was NOT approved by the Solar Keymark Network and the CEN Certification Board.

It was very important for the industry to have such a procedure a fast as possible, so this was given high priority in the project - and some co-financing from ESTIF to speed up this process.

During summer 2009 such procedure was developed and tried out by the participants. In September 2009 the procedure was approved at the Solar Keymark Network meeting - and in October also approved at the CEN Certification board meeting.

Already in November 2009 at least 5 test labs had received requests for “flexible system testing” showing the big interest for this issue amongst the industry.

In the following is enclosed:

- ❑ Section 4.4. of the “System families”
- ❑ ANNEX D of the extrapolation procedure for the determination of the performance of factory made systems “Solar Keymark System Families”
- ❑ ”Detailed guidelines and examples for f-chart system performance extrapolation”
- ❑ ”Detailed guidelines and examples for DST system performance extrapolation”

As things was made very quickly, it can be expected that improvements are possible. So a questionnaire will be send out to the test labs performing system testing and system performance in order to have their feed back and experience. The answers will be analysed and compiled into a revised version of the procedure description and guidelines.

Elaboration of on D 3.3.B will done at the end of the project.

4.4 System “families”

If the manufacturer produces the “same” system in different sizes, the different sizes of the system is considered being the same type (within the same system “family”); the different sizes of the system type are sub types. Detailed requirements for systems to be of the same type are given in Annex D.

Testing requirements for systems of the same type are:

- High temperature and safety tests (according to EN 12976) shall be performed on the sub system having the highest collector area to store volume ratio.
- All other tests (according to EN 12976 and including performance test) shall be performed on the “medium” sub system. Detailed testing requirements are given in Annex D.

Performance indicators for the system sub types which are not performance tested can be determined based on the performance test result on the “medium” sub system according to the procedures described in Annex D.

[Specific CEN Keymark Scheme Rules for Solar Thermal Products, Version 11.03 – October 2009]

ANNEX D. SOLAR KEYMARK SYSTEM FAMILIES

D.1 System family, system type, system subtype

A system family is a family of different system configurations / sizes of the same system type. Each different system configuration in a system family is a system subtype.

In D.2 the requirements for considering systems as being of the same type are given.

D.2 Requirements for grouping different system configurations into one system family

In the following the indices max and min indicates maximum and minimum values of the parameter for all systems in the family.

Values to be used to check the below requirements are taken from:

- Collector parameters: EN 12975 test report
- Other values: Manufacturers declaration; check of values shall be performed by test lab based on drawings and other material/information provided by manufacturer.

- Hydraulics:
    - same principle layout of solar and load loops

- Heat transfer fluid :
    - same type of liquid (same brand and same water mixing percent)

- Heat exchanger(s) (if any):
    - same type of heat exchanger (mantel / spiral / external)
    - heat transfer coefficient of heat exchanger shall - for each system configuration - be known/declared and large enough to fulfil:
        - $(UA)_{hx} > 10\ K_{50}\eta_{0a}(\ A_a\ a_c + U_{loop,total})$ (determination of $(UA)_{hx}$, see D.4.2.1)

    where:
        - $(UA)_{hx}$: Heat transfer coefficient of the solar loop heat exchanger, W/K
        - K_{50} : Collector incidence angle modifier at 50°, -
        - η_{0a} : Collector zero heat loss efficiency coefficient, -
        - A_a : Collector aperture area of collector array, m²
        - a_c: Collector heat loss coefficient at $T_m - T_a = 40$ K, W/(K m²); $a_c = a_{1a} + a_{2a} * 40$
        - T_a: Air temperature, °C,
        - T_m: Collector mean temperature, °C
        - a_{1a} : 1st order collector loss heat coefficient based on aperture area, W/(K m²)
        - a_{2a} : 2nd order collector heat loss coefficient based on aperture area, W/(K² m²)
        - $U_{loop,total}$: Total heat transfer coefficient of solar loop; $U_{insu} + U_{un\text{-}insu}$, W/K
        - $U_{un\text{-}insu}$: Heat loss coefficient of un-insulated part of collector loop piping, W/K

- U_{insu}: Heat loss coefficient of insulated part of collector loop piping, W/K

- Tank(s):
  - same brand
  - same tank orientation (vertical or horizontal)
  - same tank material
  - same inside coating
  - same insulation material (same material specifications)
  - restricted tank heat loss coefficient for tanks with integrated supplementary heating:
    - $UA_{tank} < 0.32 * (V_{tot})^{½}$
  - restricted variation from tank to tank of average thickness of tank insulation:
    - $(t_{insu,tank,max} - t_{insu,tank,min})/t_{insu,tank,min}) \leq 25\%$ ($\sim t_{insu,tank,max} \leq 1.25* t_{insu,tank,min}$)
  - similar relative position of solar heat exchanger; variation to be accepted:
    - ± 20 % variation (relative to average positions) allowed in relative positions of lower and higher points of heat exchanger (positions taken relative to tank height)
  - restricted variation in total tank volume,:
    - $(V_{tot,max} - V_{tot,min})/V_{tot,min} \leq 200\%$ ($\sim V_{tot,max} \leq 3* V_{tot,min}$)
  - restricted variation in relative supplementary heated tank volume, V_{aux}/V_{tot} (the indices max and min indicates maximum and minimum values):
    - $((V_{aux}/V_{tot})_{,max} - (V_{aux}/V_{tot})_{,min})/(V_{aux}/V_{tot})_{,min} \leq 25\%$ ($\sim(V_{aux}/V_{tot})_{,max} \leq 1.25* (V_{aux}/V_{tot})_{,min}$)

- Collectors:
  - shall have Keymark
  - shall same Keymark licence no. (i.e. same collector type for all systems)
  - limitation on collector heat loss coefficient, a_c:
    - $a_c < 8$ W/(K m²) (to limit dependence on wind); $a_c = a_{1a} + a_{2a}*40$
  - restricted variation in collector aperture area of collector array, A_a:
    - $(A_{a,max} - A_{a,min})/A_{a,min} \leq 300\%$ ($\sim A_{a,max} \leq 4* A_{a,min}$)

- Pipes/piping[1]:
  - same insulation material (same material specifications)

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[1] Guidelines for calculating piping losses:

Heat loss coefficient per m² un-insulated pipe surface (and other un-insulated surfaces) can be determined as:

- $U_{un-insu} = 15 * A_{surface-un-insu}$ [W/(m²K)]

Heat loss coefficient per m² insulated pipe surface (and other insulated surfaces) can be determined as:

- Pipes: $U_{insu-pipe} = 2*pi*lambda_{insu}*L_{pipe} /\ln((d_{pipe} +2t_{insu,pipe})/d_{pipe})$, [W/K]
- Plane surfaces: $U_{insu-plane} = A_{plane} *lambda_{insu}/t_{insu,plane}$, [W/K]

Is lambda (heat conductivity of insulation) not known, use 0,04 W/(K*m)

- pipe diameter, D_{pipe} and pipe length, L_{pipe} for a system with a given collector aperture area shall be smaller than or equal to D_{pipe} and L_{pipe} respectively for a system with a bigger aperture collector area.
- total collector loop piping heat loss coefficient, $U_{loop,total}$ (total heat loss coefficient from pipes, etc. between collectors and store/heat exchanger) shall be less than 25% of the total collector heat loss coefficient:
  - $U_{loop,total} < 0.3\ A_a\ a_c$
- similar total collector loop piping heat loss coefficient **per m² collector aperture area** ($U_{loop,total}/A_a$; total heat loss coefficient from pipes, etc. between collectors and store/heat exchanger **per m² collector aperture area**); variation accepted is:
  - $([U_{loop,total}/A_a]_{,max} - [U_{loop,total}/A_a]_{,min}) / [U_{loop,total}/A_a]_{,min} \leq 50\%$
- heat loss coefficient of un-insulated parts in the collector loop shall be less than the heat loss coefficient of the insulated part:
  - $U_{loop,un\text{-}insu} < U_{loop,insu}$

- Controller(s) (if any):
  - same brand, type and settings of controller(s)
  - same brand, type and same/similar location of sensors; restriction on relative location(s) of sensor(s) in the tank:
    - ± 10 % variation (relative to average positions) allowed in positions relative to tank height
  - overheating protection / temperature limiting functions:
    - same principle(s)/functions for all system configurations

- Pump(s) (if any)
  - same brand
  - restriction on nominal power, P_{NOM}:
    - $(P_{NOM,max} - P_{NOM,min})/P_{NOM,min} \leq 100\%$ ($\sim P_{NOM,max} \leq 2^* P_{NOM,min}$)
  - P_{NOM} for a system with a given collector aperture area shall be smaller than or equal to P_{NOM} for a system with a bigger aperture collector area.

D.3 Testing requirements

The “medium system configuration” shall be tested according to all requirements in EN 12976 - except for “Over temperature protection” (EN 12976-2 section 5.2).

The “medium system configuration” is the configuration having the ratio of collector aperture area to total store volume closest to the average value of this ratio calculated for all configurations in the family. If several configurations are equally close to the average, the configuration with the highest ratio shall be chosen.

Testing the over temperature protection and safety (EN 12976-2 5.2) shall be carried out on the configuration having the highest ratio of collector aperture area to total store volume.

Note D.3.1: Normally two system configurations have to be sampled for (parallel) testing, but in some cases one configuration could at the same time be both the "medium system configuration" and the configuration with the highest ratio of collector aperture area to total store volume. In such case it is possible to sample only one configuration and perform all testing on this configuration.

Note D.3.2: Collector aperture area is defined in EN 12975; total store volumes is declared by manufacturer for all tank sizes in the system family.

D.4 Methods for determination of performance of system configurations which are not tested

The performance of the system configurations which are not tested is determined using one of two calculation methods:

- Method I: Based on EN 15316-4-3 - in the following named "Method I (f-chart)"
- Method II: Based on EN 12976-2 / ISO 9459-5 in the following named "Method II (DST)"

The method to use depends on the test method used in D.3 and whether the system is a forced circulated system or a thermo-siphon system - see table below.

Test method applied:	ISO 9459-2 (CSTG)		ISO 9459-5 (DST)			
Solar only / int. back-up:	Solar only		Solar only		Int. back-up	
Forced Circ. / Thermo-Siphon:	FC	TS	FC	TS	FC	TS
Method I (f-chart) valid:	√		√		√	
Method II (DST) valid:			√	√	√	√

Table D.4.1
Applicable extrapolation method depending on system type and test method

It is seen from the table that:

- Method I (f-chart) is only applicable for forced circulated systems
- Method II (DST) is only applicable in connection with the ISO 9459-5 (DST) performance test method

The method used for performance calculation shall be specified when reporting the results.

The two methods are described in the following.

D.4.1 Method I (f-chart)

If the system is a pumped system Method I (f-chart) can be used. This method is based on the method B in the EN 15316-4-3 and is illustrated in the figure below:

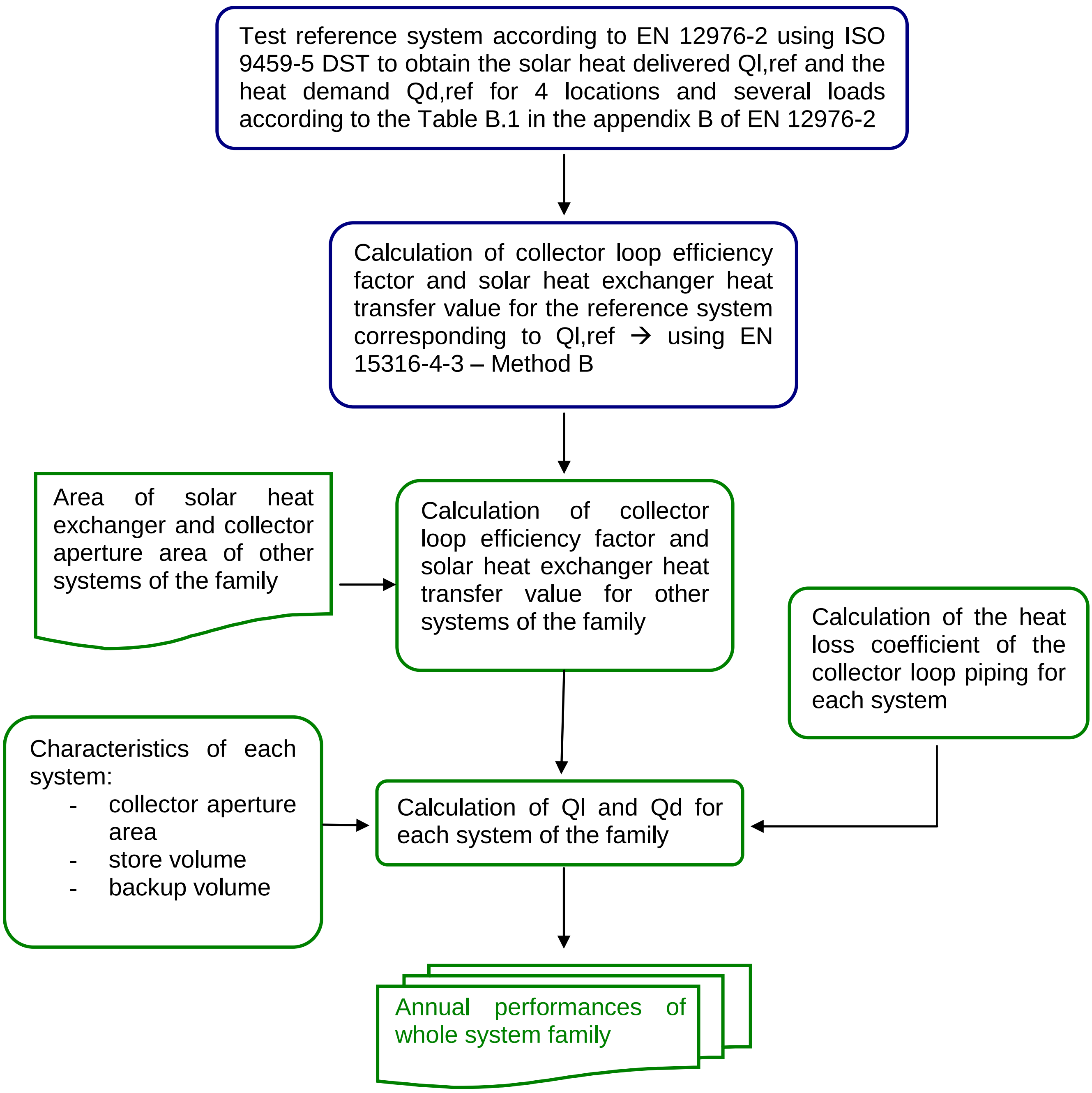

Fig. D.4.1.1 Principle of Method I (f-chart)

Method I is organised in three stages:

a) Pre-processing of test data:

Inputs for the method I are $Q_{sol,out}$ and $Q_{sol,us}$ as defined in the EN15316-4-3, method B. Two cases have to be separated:

Preheat systems:

$Q_{sol,out} = Q_L / 3.6$ [kWh/year]
$Q_{sol,us} = Q_D / 3.6$ [kWh/year]

Where:

Q_D is heat demand (result from EN12976) [MJ/year]
Q_L is heat delivered by the solar heating system (according to EN12976) [MJ/year]

Solar plus supplementary systems

$Q_{sol,out} = (Q_D + Q_{st,ls,aux} – Q_{aux,net}) / 3.6$ [kWh/year]
$Q_{sol,us} = Q_D / 3.6$ [kWh/year]

Where:

$Q_{st,ls,aux}$ is heat losses of the store part heated by the back-up heater [MJ/year]
$Q_{aux,net}$ is net auxiliary energy demand [MJ/year]

$Q_{st,ls,aux}$ is calculated using the formula given in the EN 15316-4-3 § 6.3.5 using the control strategy adopted for the system, the surrounding air temperature, the set temperature, the fraction of the store volume heated by the back-up heater and the heat loss coefficient of the store. This coefficient is calculated using the following formula:

$$U_{st} = 1.2 \times \frac{\lambda_{iso} \times A_{sto}}{d_{iso}}$$

Where:

- λ_{iso} is the heat transfer coefficient of the insulation material [W/m.K]
- A_{sto} is the outside area of the auxiliary part of the store [m²]
- d_{iso} is the thickness of the insulation material [m]

If these three parameters are not known, the following formula can be applied:

$$U_{st} = 0.16 \times \sqrt{V_{bu}}$$

Where V_{bu} is the volume of the auxiliary part of the store [L]

b) Processing:

The collector loop efficiency factor η_{loop} for the reference system is fitted using the annual outputs resulting from the EN 12976 test for each location and each load ($Q_{sol,out}$ calculated as described above).
From these fitted factors η_{loop} of the reference system, an apparent solar heat exchanger heat transfer value $(U_{st})_{hx}$ is calculated for each location and load using the calculation formula given in the appendix B.2 1 of EN 15316-4-3:

$$\eta_{loop} = 1 - \Delta\eta \qquad (1)$$

With:

$$\Delta\eta = \frac{\eta_0 \times A \times a_1}{(U_{st})_{hx}}$$

Where:

- A is the total collector aperture area [m²]
- $(U_{st})_{hx}$ is the apparent solar heat exchanger heat transfer value for the actual location and load [W/K]
- a_1 is the1st order collector heat loss coefficient based on aperture area, [W/(K.m²)]
- η_0 is the optical efficiency based on collector aperture area

The $(U_{st})_{hx}$ coefficient for each system of the family is determined using the following formula :

$$(U_{st})_{hx,x} = (U_{st})_{hx,ref} \times \frac{A_{hx,x}}{A_{hx,ref}}$$

Where:

- $(U_{st})_{hx,x}$ is the solar heat exchanger heat transfer value of the actual system [W/K]
- $(U_{st})_{hx,ref}$ is the solar heat exchanger heat transfer value of the reference system [W/K]
- $A_{hx,x}$ is the area of the heat exchanger of the actual system [m²]
- $A_{hx,ref}$ is the area of the heat exchanger of the reference system [m²]

If the area of the heat exchanger of the actual system is unknown, its $(U_{st})_{hx}$ coefficient is considered equal to the $(U_{st})_{hx}$ of the reference system.

The collector loop efficiency factors η_{loop} can then be calculated for each other system of the family for each location and load using its collector aperture area with the calculation formula (1).

$$\eta_{loop,x} = 1 - \frac{\eta_0 \times A_x \times a_1}{(U_{st})_{hx,x}} \qquad (2)$$

Where:

- A_x is the collector aperture area of the actual system [m²]

This collector loop efficiency factor is one of the elements used to calculate the solar heat delivered by the actual system. For each system, the collector aperture area, the store volume, the backup volume and the heat loss coefficient of the collector loop pipes have also to be known to carry out this calculation. The first three of these elements are provided by manufacturers.

The collector loop pipe losses can be calculated using:

$$U_{loop,p} = \mathrm{U}_{\mathrm{insu}} + \mathrm{U}_{\mathrm{un\text{-}insu}}$$

Where:

- $U_{loop,p}$ is the heat loss coefficient of the collector loop piping [W/K]
- U_{insu} is the heat loss coefficient for insulated part of collector loop piping [W/K]
- $U_{un-insu}$ is the heat loss coefficient for the un-insulated part of collector loop piping [W/K]

If no qualified values are available for the coefficients U_{insu} and $U_{un-insu}$, $U_{loop,p}$ can also be calculated using the following formula:

$$U_{loop,p} = 5 + 0.5 \times A_x$$

Finally, by using the $\eta_{loop,x}$,the collector aperture area, the store volume, the backup volume and the heat loss coefficient of the collector loop pipes, the solar heat delivered by each system of a family $Q_{sol,out,x}$ can be calculated with e.g. the software SOLEN[2].

All the equations and mathematical models used to calculate this solar heat delivered by each SDHW system of a family are written on the EN 15316-4-3 – Method B and examples of implementation of this method B are available on the appendix A of this standard.

c) <u>After processing</u>

The output of EN15316-4-3, method B is translated for each system of a family in terms of EN12976 according to:

<u>Preheat systems:</u>

$Q_L = Q_{sol,out,x} \times 3.6$ [MJ/year]
$Q_D = Q_{sol,us,x} \times 3.6$ [MJ/year]

<u>Solar plus supplementary systems:</u>

[2] The software SOLEN has been developed by the CSTB, is free and can be downloaded at the following website link : http://enr.cstb.fr/webzine/preview.asp?id_une=217

$Q_{aux,net,} = (Q_D + Q_{st,ls,aux,x} – Q_{sol,out,x}) \times 3.6$ [MJ/year]
$Q_D = Q_{sol,us,x} \times 3.6$ [MJ/year]

Finally, for preheat and solar plus supplementary systems, the auxiliary energy consumption by pumps Q_{par} has also to be calculated for each system of the family:

$$Q_{par} = \frac{P_{aux} \times t_{aux}}{1000} \times 3.6$$

Where:

- Q_{par} is the auxiliary energy consumption by pumps [MJ/year]
- P_{aux} is the total nominal input power of pumps [W]
- t_{aux} is the annual pump operation time, fixed to 2000 h

D.4.2 Method II (DST)

When the system performance test (in D.3) is done according to ISO 9459-5 (DST), the Method II (DST) can be used for both pumped systems and thermo-siphon systems. This method is based on the ISO 9459-5 procedure for performance calculation, which is one of the two methods for performance calculation already used in the EN 12976. The principle of the method is illustrated in the figure below.

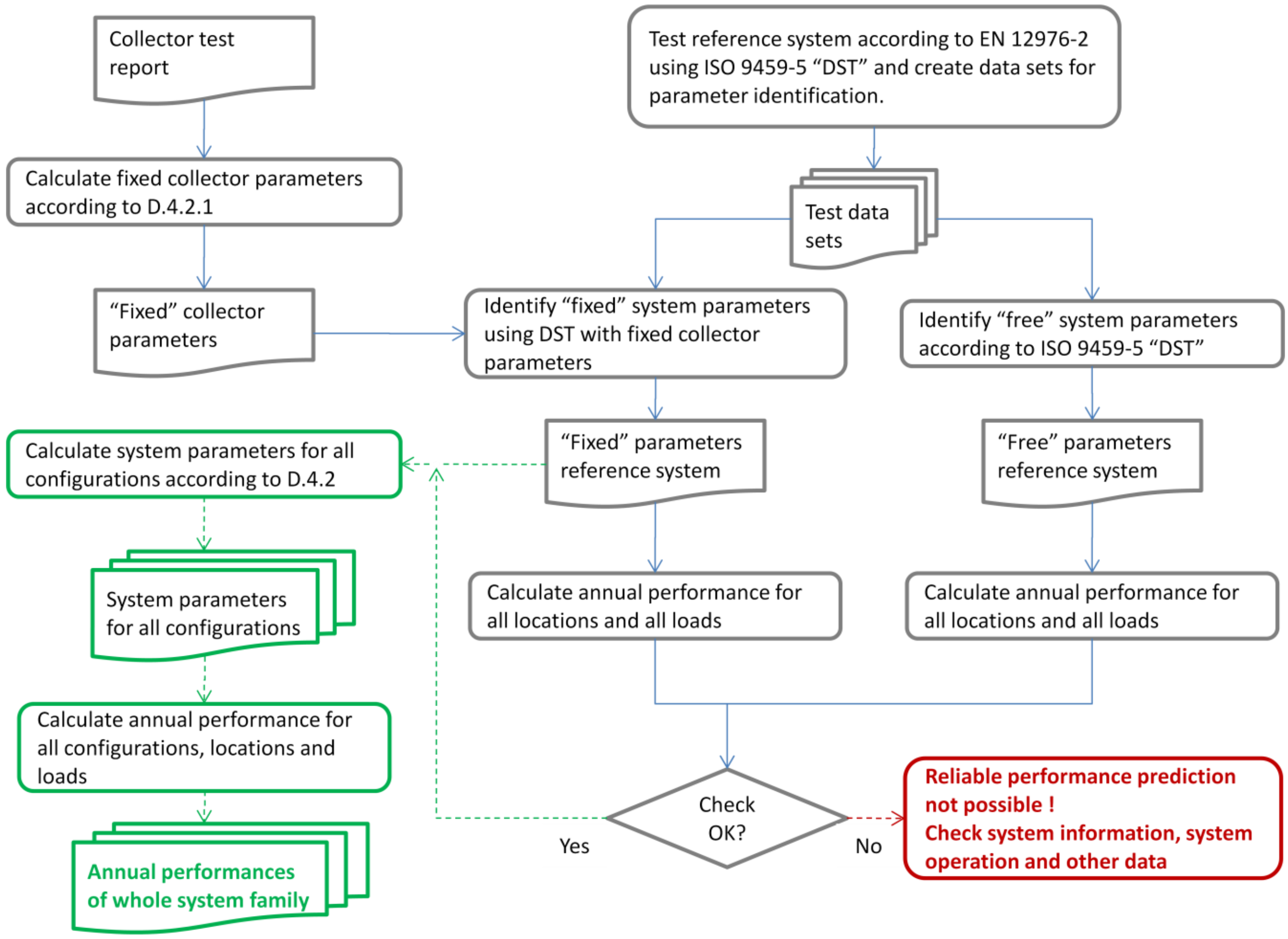

Fig. D.4.2.1 Principle of Method II (DST)

The reference system is chosen and tested (see D.3). Two sets of system parameters are identified:

- "Free" reference system parameters - these are the parameters determined according to EN 12976 / ISO 9459-5.
- "Fixed" reference system parameters. These parameters are determined **fixing the collector parameters (A_C^* and u_C^*)** according to D.4.2.1 and identifying the rest of the system parameters using the same test data as used for determination of the "free" system parameters.

Next phase is a comparison of the annual performances determined using the two sets of system parameters.

If the deviation for any location/load is higher than 15%, reliable performance prediction for other configurations is not likely to be reliable. The information/data used should be checked as well as the operation of the tested system.

If the deviation for any location/load is lower than 15%, proceed to next phase of the method.

In this phase the system parameters for all system configurations in the system family are determined:

- The collector parameters (A_C^* and u_C^*) are determined according to D.4.2.1 for all configurations (beware that these parameters also depends on heat exchanger and pipe losses - and number of collectors).
- The store heat loss parameter (U_s) is determined as:
  - $U_{s,x} = U_{s,ref,fix} * A_{x,surface}/A_{ref,surface}$
- The store heat capacity parameter (Cs) is determined as:
  - $C_{s,x} = C_{s,ref,fix} * V_x/V_{ref}$
- The parameter for back-up volume (f_{AUX}) is in all cases set to the value of $f_{AUX,fix}$ already determined using the fixed collector parameters for the reference system
- The parameters for stratification (D_L and S_L) are in all cases set to the values already determined using the fixed collector parameters for the reference system
- The parameter for load side heat exchanger (R_L) is determined as:
  - $R_{L,x} = R_{L,ref,fix} * A_{lshx,x}/A_{lshx,ref}$
- The parameter u_v is not taken into account

where:

- $U_{s,x}$: Store heat loss parameter to be determined for the actual configuration
- $U_{s,ref,fix}$: Store heat loss parameter determined for the reference system using fixed collector parameters
- $A_{x,surface}$: Surface area of store in the actual configuration
- $A_{ref,surface}$: Surface area of store in the reference configuration
- $C_{s,x}$: Store heat capacity parameter to be determined for the actual configuration
- $C_{s,ref,fix}$: Store heat capacity parameter determined for the reference system using fixed collector parameters
- V_x : Store volume in the actual configuration
- V_{ref} : Store volume in the refernce configuration
- $R_{L,x}$: Load side heat exchanger parameter to be determined for the actual configuration
- $R_{L,ref,fix}$: Load side heat exchanger parameter determined for the reference system using fixed collector parameters
- $A_{lshx,x}$: Surface area of load side heat exchanger in the actual configuration
- $A_{lshx,ref}$: Surface area of load side heat exchanger in the reference configuration

Now with the system parameters determined, the annual performances of all system configurations, locations and loads can be done using the LTP part of the DST software [InSitu Scientific Software, Dynamic testing Program].

D.4.2.1 Calculation of "Fixed" collector parameters A_C^* and u_C^*

When doing the extrapolation calculations, fixed values for the parameters A_C^* and u_C^* are used in the result file DFR and DST-LTP program. The way to calculate these fixed values is shown in the following.

D. 4.2.1.1 Calculation of A_C^*

In ISO 9459-5 A_C^* is defined as:

- $A_C^* = F_R^* * (\tau\alpha) * A_C$

where:

- A_C: Collector aperture area of collector array in m^2
- F_R^*: Heat removal factor of the collector loop
- $(\tau\alpha)$: Effective transmission-absorbtance product

Expressing A_C^* in an approximate way in terms of collector test results related to EN 12975 and the heat exchanger factor F''':

- $A_C^* = F''' * \eta_{0a} * K_{50°} * A_a$

where:

- A_a: Total collector aperture area in m^2
- η_{0a} : Optical efficiency based on aperture area
- $K_{50°}$: Incidence angle modifier at 50°

The heat exchanger factor F''' is defined in the following:

- $F''' = 1 - \Delta\eta_{hx}$
- $\Delta\eta_{hx} = \frac{\eta_{0a}\, K_{50°}(A_a\, a_c + U_{loop,total})}{(UA)_{hx}}$
- $U_{loop,total} = U_{insu} + U_{un\text{-}insu}$

where

- a_c = $a_{1a} + a_{2a}*40$; collector heat loss coefficient at $T_m - T_a = 40$ K, W/(K m²), T_a: air temperature, °C; T_m: collector mean temperature, °C.
- a_{1a} : 1st order collector heat loss coefficient based on aperture area, W/(K m²)
- a_{2a} : 2nd order collector heat loss coefficient based on aperture area, W/(K² m²)
- η_{0a} : Collector zero loss efficiency based on aperture area
- $K_{50°}$: Incidence angle modifier at 50° incident angle
- A_a : Collector aperture area, m²
- $(UA)_{hx}$ = $U_{hx} * A_{hx}$; heat transfer coefficient of the heat exchanger, W/K
- U_{hx} : Heat transfer coefficient per m² of the heat exchanger, W/(K m²)
- A_{hx} : Total surface area of heat exchanger, m²
- $U_{loop,total}$: heat loss coefficient of the collector loop piping, W/K

- U_{insu} : heat loss coefficient for insulated part of collector loop piping, W/K
- $U_{un\text{-}insu}$: heat loss coefficient for the un-insulated part of collector loop piping, W/K

For external heat exchanger actual value of $(UA)_{hx}$ is used for the temperature set:

- Primary loop 25°C, 35°C (collector loop)
- Secondary loop 15°C, 25°C (tank loop)

For tanks with internal heat exchangers a value of 200 W/K per m² heat exchanger surface (average of inner and outer surface) is chosen for U_{hx} if no qualified measurements (e.g. from EN 12977-3 test) are available for the $(UA)_{hx}$ for the heat exchanger. The test value to be used should comply with the conditions given in CEN/TS 12977-2 (6.3.6): "*$(UA)_{hx}$ to be chosen for store temperatures of 20°C, average temperature difference 10 K and a flow rate similar to the one used for the determination of the collector parameters*" (flow rate corresponding to the minimum number of collector modules applied to the tank within the system family).

Note: The value for U_{hx} : 200 W/(K m²) is based on test of 23 tanks with internal heat exchangers (tests performed at Danish Technological Institute).

D.4.2.1.2 Calculation of u_C^*

In ISO 9459-5 A_C^* is defined as:

- $u_C^* = \frac{a_{total}}{\eta_{0a}\, K_{50°}}$, W/(K m²)

where:

- a_{total}: Specific heat loss coefficient of the collector loop **including collector(s)**, W/(K m²)
- η_{0a} : Collector zero loss efficiency based on aperture area
- $K_{50°}$: Incidence angle modifier at 50° incident angle

Expressing u_C^* in an approximate way in terms of collector test results related to EN 12975:

- $u_C^* = \frac{a_c + U_{loop,total}/A_a}{\eta_{0a}\, K_{50°}}$,W/(K m²)

including also heat loss coefficients for collector piping, where:

- $a_c = a_{1a} + a_{2a}*40$ (heat loss coefficient at dT = 40 K), W/(K m²)
- a_{1a} :1st order collector heat loss coefficient based on aperture area, W/(K m²)
- a_{2a} :2nd order collector heat loss coefficient based on aperture area, W/(K² m²)
- A_a : Collector aperture area, m²
- $U_{loop,total}$ is heat loss coefficient of the collector loop piping, W/K
- U_{insu} is heat loss coefficient for insulated part of collector loop piping, W/K
- $U_{un\text{-}insu}$ is loss coefficient for the un-insulated part of collector loop piping, W/K

[Specific CEN Keymark Scheme Rules for Solar Thermal Products, Version 11.03 – October 2009]

Guidelines for extrapolation of test results according to the EN 15316-4-3 Method (f-chart)

Julien HEINTZ, CETIAT, October 2009

0. Introduction

In order to enable accurate yield prediction of different system subtypes on the basis of just a single system test the procedure for extrapolation is being described in the annex D „SOLAR KEYMARK SYSTEM FAMILIES“ in the scheme rules. The annex D gives general definitions for system families. It defines the requirements for grouping different system configurations into one system family and describes the method for choosing referent system representing particular system family. Two methods are selected and described for extrapolation of test results, (i) the Method I, based on f-chart method and (ii) the Method II, based on the DST -method. The method I is applicable for forced circulation system (preheat systems, and solar plus supplementary systems). This document aims at illustrating the extrapolation procedure of Method I for this kind of system.

1. Forced circulation, integrated back-up system family

1. Data sheets with characteristics of two systems, family members, are listed in Appendix I as Tab A and Tab B,

2. Requirements under the D.2. Section “Requirements for grouping of different system configurations into single system family” are fulfilled.

3. According to D.3. Section, the ratios of area/volume are to be calculated. Ratio of area/volume is 6/250 m²/l and 4/350 m²/l respectively. The system with higher ratio of area vs volume has to be selected for testing. And that is system with 350 liters and area of 6 m². 6/250=0.024 m²/l, 4/350=0.011 m²/l. The system 6/250 is chosen as “**reference system**”. This reference system is tested according to standards EN 12976-2 and ISO 9459-5. The DST-software is then run following strictly the procedure outlined in the Standard ISO 9459-5 in order to calculate the heat delivered by auxiliary heater Qaux,net and the heat demand Qd for 4 locations and several loads.

   The results for Qd and Qaux,net (in MJ) for the reference system are given in the table below:

Qd (MJ)		
Location	**load / day**	
	110l	**200l**
Davos, Yield /W	6653	12107
Athens, Yield /W	4572	8323
Stockh., Yield /W	6149	11164
Wuerzb.,Yield /W	5897	10688

Qaux,net (MJ)		
Location	**load / day**	
	110l	**200l**

Davos, Yield /W	504	2743
Athens, Yield /W	724	1987
Stockh., Yield /W	2081	4068
Wuerzb.,Yield /W	1768	3532

4. The heat losses of the store part heated by the back-up heater are calculated. The formula used to calculate these losses is :

$$Q_{st,ls,aux} = \frac{V_{bu}}{V_{store}} \times U_{st} \times (\frac{V_{load}}{V_{store}}) \times (T_{set} - T_{a,avg}) \times \frac{t_m \times 3.6}{1000}$$

Where:

- V_{bu} is the volume of the auxiliary part of the store [L]
- U_{st} is the heat loss coefficient of the store [W/K]
- V_{load} is daily draw-off volume [L]
- V_{store} is the volume of the store [L]
- T_{set} is the set point temperature of the integrated auxiliary [°C]: T_{set} = 52.5 °C (EN 12976 Table B.1)
- $T_{a,avg}$ is the average ambient air temperature [°C] (fixed to 20°C for the method)
- t_m is the number of hours of the year: 8760
- the coefficient 3.6/1000 is used to convert Wh to MJ

The values of $Q_{st,ls,aux}$ for the reference systems are then:

Load/day (l)	Qst,ls,aux (MJ)
110	316
200	574

The characteristics of systems, used to calculate the $Q_{st,ls,aux}$ values are listed in appendix as Tab A and Tab B.

5. The part a) of the appendix D4.1 of the scheme rules is then applied to calculate the values of $Q_{sol,out}$ and $Q_{sol,us}$:

Qsol,out (kWh)		
Location	load / day	
	110l	200l
Davos, Yield /W	1796	2761
Athens, Yield /W	1157	1919
Stockh., Yield /W	1218	2131
Wuerzb.,Yield /W	1235	2147
Qsol,us (kWh)		
Location	load / day	
	110l	200l
Davos, Yield /W	1848	3363
Athens, Yield /W	1270	2312
Stockh., Yield /W	1708	3101
Wuerzb.,Yield /W	1638	2969

6. From the values of $Q_{sol,out}$ and using the part b) of the appendix D4.1 of the scheme rules, the collector loop efficiency factors η0 are fitted for each load and each location for the reference system.

   To fit the η0, the following data of the reference system are needed:

   - the volume of the store and collector surface area
   - the ratio V_{bu}/V_{store}
   - the pipe heat losses coefficient $U_{loop,p}$ (W/K). The value for this coefficient is unknown for the reference system. It can be calculated using the formula given in the part b) of the appendix D4.1 of the scheme rules, $U_{loop,p} = 5+0.5*A_x$ where A_x is the collector surface area of the reference system. $U_{loop,p}$ is then equal to 8 W/K for the reference system

7. Choose a member of system family for which extrapolation has to be carried out. Let us consider a system differing from reference system in a number of collectors, collector pipes heat loss coefficient and storage volume (System Characteristics are listed in Appendix I in Tab. B)

   η0 for this second SDHW system is then calculated using the part b) of the appendix D4.1 of the scheme rules

   The method B of EN 15316-4-3 is then applied to calculate the $Q_{sol,out}$ for this second system.

   To apply this method, the following data about the second system are needed:

   - the value of η0 calculated above
   - the volume of the store and collector surface area of the system

- the ratio V_{bu}/V_{store}
- the pipe heat losses coefficient $U_{loop,p}$ (W/K). The value for this coefficient is unknown for the second system. It can be calculated using the formula given in the part b) of the appendix D4.1 of the scheme rules, $U_{loop,p} = 5+0.5*A_x$ where A_x is the collector surface area of the second system. $U_{loop,p}$ is then equal to 7 W/K for the second system

The results of $Q_{sol,out}$ for the second system for two loads are listed below:

Qsol,out (kWh)		
Location	load / day	
	110l	200l
Davos, Yield /W	1739	2438
Athens, Yield /W	1042	1675
Stockh., Yield /W	1081	1859
Wuerzb.,Yield /W	1139	1909

The values of heat losses of the store part heated by the back-up heater $Q_{st,ls,aux}$ have then to be calculated using the formula given in the part 4. above:

Load/day (l)	Qst,ls,aux (kWh)
110	90
200	163

The values of the heat demand $Q_{sol,us}$ for the second system are:

Qsol,us (kWh)		
Location	load / day	
	110l	200l
Davos, Yield /W	1849	3356
Athens, Yield /W	1269	2305
Stockh., Yield /W	1706	3094
Wuerzb.,Yield /W	1634	2968

These results for the second system are then translated in terms of EN 12976 according to part c) of the appendix D4.1 of the scheme rules

Qaux,net (MJ)	
Location	load / day

	110l	200l
Davos, Yield /W	720	3892
Athens, Yield /W	1141	2855
Stockh., Yield /W	2574	5033
Wuerzb.,Yield /W	2106	4399

Qd (MJ)		
Location	load / day	
	110l	200l
Davos, Yield /W	6656	12082
Athens, Yield /W	4568	8298
Stockh., Yield /W	6142	11138
Wuerzb.,Yield /W	5882	10685

Finally, the auxiliary energy consumption by pumps Q_{par} has also to be calculated.

8. Identical procedure (starting from point 7) is to be carried out separately for each further member of system family.

Appendix I. System data

Project:	**Flexible system certification - validation of procedure for system performance prediction extrapolation**							
Check / data list for system test								
	Solar + supplementary system		"6250" (6m2 collectors+250 litres storage) = REFERENCE SYSTEM					
Solar loop	Collector							
		Collector name/type						
		No. collector modules	3					
		Aperture area per collector module	2					m²
		Optical Efficiency	0.77					
		First-order heat loss coefficent	3.8					W/(m²K)
		Second-order heat loss coefficent	0.014					W/(m²K²)
		Thermal capacity of collector						kJ/K
		Incident Angle Modifier:	Angle °	30	50	70		
			IAM, ASHRAE b0=0.1, b1=0.		0.94			
	Collector loop pipes	Pipes Dimensions	Diameter					W/K
			Total pipe lenght					m
		Pipe insulation	Thickness of insulation					mm
			Heat conductivity of insulation					W/(m*K)
				0				m
		Overall heat loss coefficent	2.5					W/K
		Thermal capacity						kJ/K
	Heat Exchanger	Heat transfer coefficient or	115					W/K
		Heat transfer area						m²
	Type of circulation	Forced circulation/thermo-siphon	Forced circulation					
		Pump power						W
		Average flowrate						l/min
Storage	Total storage	Height (cilinder)	1.25					m
		Volume	250					litres
		Tank position - vertical/horizontal	vertical					
		Tank location - indoors/outdoors	indoors					
		Heat loss coefficient or	2.5 W/K					
		Insulation matirial & thickness						
	Back-up part of storage	Volume	70					litres
		(Recommende set temperature)	60					°C

Tab A. Data of Reference system representing whole system family (forced circulation with auxiliary)

<table>
<tr><td>Project:</td><td colspan="6">Flexible system certification - validation of procedure for system performance prediction extrapolation</td></tr>
<tr><td colspan="7">Check / data list for system test</td></tr>
<tr><td></td><td colspan="2">Solar + supplementary system</td><td colspan="3">"4350" (4m2 collectors+350 litres storage)</td><td></td></tr>
<tr><td rowspan="23">Solar loop</td><td rowspan="10">Collector</td><td>Collector name/type</td><td colspan="3"></td><td></td></tr>
<tr><td>No. collector modules</td><td colspan="3">2</td><td></td></tr>
<tr><td>Aperture area per collector module</td><td colspan="3">2</td><td>m²</td></tr>
<tr><td>Optical Efficiency</td><td colspan="3">0.77</td><td></td></tr>
<tr><td>First-order heat loss coefficent</td><td colspan="3">3.8</td><td>W/(m²K)</td></tr>
<tr><td>Second-order heat loss coefficent</td><td colspan="3">0.014</td><td>W/(m²K²)</td></tr>
<tr><td>Thermal capacity of collector</td><td colspan="3"></td><td>kJ/K</td></tr>
<tr><td rowspan="2">Incident Angle Modifier:</td><td>Angle °</td><td>30</td><td>50 | 70</td><td></td></tr>
<tr><td>IAM, ASHRAE b0=0.1, b1=0.</td><td></td><td>0.94</td><td></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="7">Collector loop pipes</td><td rowspan="2">Pipes Dimensions</td><td>Diameter</td><td colspan="2"></td><td>W/K</td></tr>
<tr><td>Total pipe lenght</td><td colspan="2"></td><td>m</td></tr>
<tr><td rowspan="3">Pipe insulation</td><td>Thickness of insulation</td><td colspan="2"></td><td>mm</td></tr>
<tr><td>Heat conductivity of insulation</td><td colspan="2"></td><td>W/(m*K)</td></tr>
<tr><td>Total length of unisulated pipes</td><td colspan="2">0</td><td>m</td></tr>
<tr><td>Overall heat loss coefficent</td><td colspan="3">1.7</td><td>W/K</td></tr>
<tr><td>Thermal capacity</td><td colspan="3"></td><td>kJ/K</td></tr>
<tr><td rowspan="2">Heat Exchanger</td><td>Heat transfer coefficient or</td><td colspan="3">175</td><td>W/K</td></tr>
<tr><td>Heat transfer area</td><td colspan="3"></td><td>m²</td></tr>
<tr><td rowspan="3">Type of circulation</td><td>Forced circulation/thermo-siphon</td><td colspan="3">Forced circulation</td><td></td></tr>
<tr><td>Pump power</td><td colspan="3"></td><td>W</td></tr>
<tr><td>Average flowrate</td><td colspan="3"></td><td>l/min</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="8">Storage</td><td rowspan="6">Total storage</td><td>Height (cilinder)</td><td colspan="3">1.25</td><td>m</td></tr>
<tr><td>Volume</td><td colspan="3">350</td><td>litres</td></tr>
<tr><td>Tank position - vertical/horizontal</td><td colspan="3">vertical</td><td></td></tr>
<tr><td>Tank location - indoors/outdoors</td><td colspan="3">indoors</td><td></td></tr>
<tr><td>Heat loss coefficient or</td><td colspan="3">3.5</td><td>W/K</td></tr>
<tr><td>Insulation matirial & thickness</td><td colspan="3"></td><td></td></tr>
<tr><td rowspan="2">Back-up part of storage</td><td>Volume</td><td colspan="3">100</td><td>litres</td></tr>
<tr><td>(Recommende set temperature)</td><td colspan="3">60</td><td>°C</td></tr>
</table>

Tab B. Data of a member of system family (forced circulation with auxiliary)

Guidelines for extrapolation of test results according to the DST method

Miroslav Bosanac / Jan Erk Nielsen, PlanEnergi, October 6, 2009

0. Introduction

In order to enable accurate yield prediction of different system subtypes on the basis of just a single system test the procedure for extrapolation is being described in the annex D „SOLAR KEYMARK SYSTEM FAMILIES". The annex D gives general definitions for system families. It defines the requirements for grouping different system configurations into one system family and describes the method for choosing referent system representing particular system family. Two methods are selected and described for extrapolation of test results, (i) the Method I, based on f-chart method and (ii) the Method II, based on the DST test. The method II, based on the DST test is applicable to both thermo-siphon systems and forced circulation system (preheat systems, and systems with supplementary auxiliary heater). This document is prepared to illustrate the extrapolation procedure with two families of systems: (i) thermo-siphon system without back-up and (ii) forced circulation system with integrated back-up. The guidelines are given separately for examples of two system types.

1. Thermo-siphon pre-heat system family

1. Data sheets of two systems, family members, are listed in Appendix as Tab A and Tab B,

2. Requirements under the D.2. Section "Requirements for grouping of different system configurations into single system family" are fulfilled.

3. According to D.3. Section, the ratios of area/volume are to be calculated. Ratio of area/volume is 6/350 m²/l and 2/150 m²/l respectively. The system with higher ratio of area vs volume has to be selected for testing. And that is system with 350 liters and area of 6 m². 6/350=0.017 m²/l, 2/150=0.013 m²/l, The system 6/350 is called "reference system".
   For the system "6/350", artificial test data according to the requirements of the **Standard (ISO 9459-5)** have been generated using the TRNSYS program. The output data files are ths635a.dat and ths635b.dat   Extensive output data set is thereafter compressed avoiding insignificant information - as by usual procedure for processing measurement data (using the SDHWP program available within the DST software).

4. The batch file **th635.bat** is created for data treatment according to the Standard. This batch file identifies set of \`free\` parameters of the reference system.

5. Execute this batchfile in order to identify the set of ´free´ parameters. Tab A.1 gives identified set of parameters (associated filename is **th635.dfr**).

```
\Results DF_P 2.7 Sep 97 @Copyright InSitu running 07.06.2009 18:01:36
\Value,Parameters,"AC*=4.09 uC*=4.78 US=2.78 CS=1.42 DL=0 SC=0.059 Obj=12.6"
* SDHW Plug Flow Model (V 2.1, Jun 1992)
frequency transform method............... Cosine
initial state value...................... 15
time base................................ 3600
filter type.............................. Gaussian, tf=4, CF=1.4E5
             Name   mode  tvf  t_start   t_skip    t_end    N*       Size
  ...\DAT\THS635A.D3   Mean  3.1       0      36      480  97.7   132..1786
  ...\DAT\THS635B.D3   Mean  1.7       0    36.56     720  81.9    67..1181
      AC*       uC*        US        CS        DL         SC  objective
     [mý]   [W/K/mý]     [W/K]     [MJ/K]       [-]       [-]       [W]
    4.091      4.778      2.778      1.424         0    0.05905     12.607
   0.0158     0.0291     0.0475    0.00569    0.00131     0.0015
Cross correlation matrix:
 1.0000000 -0.6057400  0.5671203  0.3901560  0.6349994 -0.4757712
-0.6057400  1.0000000 -0.4254539 -0.2255122 -0.5427860  0.5317664
```

0.5671203	-0.4254539	1.0000000	0.1943051	0.0030802	-0.1539413
0.3901560	-0.2255122	0.1943051	1.0000000	0.3855753	-0.1713679
0.6349994	-0.5427860	0.0030802	0.3855753	1.0000000	-0.3762893
-0.4757712	0.5317664	-0.1539413	-0.1713679	-0.3762893	1.0000000

Tab A.1. Identified set of 'free' parameters

6. All the above stated steps follow strictly the procedure outlined in the Standard. From this point on we start with extrapolation procedure.
   Procedure for extrapolation of test results requires fixing collector parameters as described in the Appendix: D.4.2.1. **Calculation of A_C^* and u_C^* for "DST-extrapolation procedure"**

7. Collector parameters are fixed for the reference system according to data listed in Tab. A.1. as it follows:

   - Collector: A_a = 6.0 m², η_{0a} = 0.77; a_{1a} = 3.33 W/(m²K); a_{2a} = 0.012 W/(m²K²);
   - $K_{50°}$ = 0.94
   - $U_{loop,rest}$ = 0.0, F'''=1
   - The fixed parameters are:
   - Ac* = 0.77 * 6 * 0.94 = 4.34 m²
   - uC* = (3.33 +40*0.012) / 0.77 / 0.94 = 5.26 W/Km²

8. Execute Dynamic Fitting (DF) program (within DST software) to identify set of parameters for reference system using fixed collector parameters. The windows batch filename is **th635f.bat**. The DST result file is processed requesting 80 local minima. The result file for above stated data files has filename **th635F.DFR.** This file represents a basis file for preparing substitute results files for other members of system family.

```
\Results DF_P 2.7 Sep 97 @Copyright InSitu running 21.09.2009 21:03:54
\Value,Parameters,"AC*=4.34 uC*=5.26 US=2.72 CS=1.44 DL=0.00744 SC=0.0591 Obj=17.4"
* SDHW Plug Flow Model (V 2.1, Jun 1992)
frequency transform method.............. Cosine
initial state value..................... 15
numerical precision..................... 1
time base............................... 3600
filter type............................. Gaussian, tf=4, CF=2.4E5
             Name   mode  tvf  t_start   t_skip   t_end    N*      Size
  ...\DAT\THS635A.D3   Mean  2.2      0      36      480  70.2   132..1786
  ...\DAT\THS635B.D3   Mean  1.4      0    36.56     720  68.1    67..1181
     AC*      uC*       US        CS        DL        SC  objective
    [mý]  [W/K/mý]    [W/K]    [MJ/K]      [-]       [-]       [W]
    4.34     5.26     2.723     1.444   0.007442   0.05912    17.434
      0        0      0.069    0.0113    0.0029    0.0032
Cross correlation matrix:
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000
 0.0000000  0.0000000  1.0000000 -0.0739756 -0.5828539  0.1863705
 0.0000000  0.0000000 -0.0739756  1.0000000  0.2714022  0.1384388
 0.0000000  0.0000000 -0.5828539  0.2714022  1.0000000  0.2974880
 0.0000000  0.0000000  0.1863705  0.1384388  0.2974880  1.0000000
```

Tab 2. Identified set with the 'fixed' collector parameters

9. The energy yields computed by two sets of (1) free and (2) with fixed collector parameters are now computed. The reference batch file is **ths-ltp.bat.** The results are given in the following table:

Location	Free	Fixed	free	Fixed	free	fixed	free	fixed	free	fixed
Daily draw-off	50l	50l	110l	110l	200l	200l	300l	300l	400l	400l
Davos, Yield /W	95.3	95.1	206	206	357	357	489	490	572	578
Athens, Yield /W	63.6	63.3	135	134	228	228	318	319	386	389
Stockh., Yield /W	69	68.8	142	142	232	232	309	310	362	365
Wuerzb.,Yield /W	66.6	67	137	137	224	225	305	305	368	368
Max. Error in %	**Ref.**	**-0.6**	**Ref.**	**0.7**	**Ref.**	**0.4**	**Ref.**	**0.3**	**Ref.**	**-1.0**

10. The maximum error in prediction is 1%. Criterion is that maximum error in predicted yields should not reach 15% for any load and/or location. Therefore, we may proceed with the next step of the extrapolation procedure.

11. Choose a member of system family for which extrapolation is to be carried out.
Let us consider a system differing from reference system in a number of collectors, collector pipes heat loss coefficient and storage volume (System Characteristics are listed in Appendix in Tab. B)

12. The corresponding values for effective collector area and storage heat loss coefficient and heat capacity are:
    - AC* = (2 m²)*(0.77)*(0.94) = 1.45 m²
    - uC* = (3.33 +40*0.012) / 0.77 / 0.94 = 5.26 W/K m²
    - CS = 150 l *4.191 kJ/kg/K*1/1000 = 0.628 MJ/K

    The identified heat loss coefficient of the storage will be used in the extrapolation procedure for estimating heat loss coefficient of other family member:

    - Us = Us(350l) * Area (150) / Area (350l) = 2.723 W/K * 1.76/2.86 = 1.7 W/K
      Where Us(350l) is identified value of storage heat loss coefficient by fixed collector parameters, see point 8.

    Copy the result-file (**<u>th635f.dfr</u>**) with a new filename th2150.DFR and enter computed values under point 12, keeping other parameters unchanged. The file **<u>th2150.dfr</u>** is now representing the result file for system with 2 m² collector area and 150 l storage volume corresponding to data listed in the Tab B.

    Execute program LTP for long term prediction (**<u>LTP-2150.bat</u>**). Informative result for given meteorological and operational conditions for three loads are listed bellow.

Location	Daily draw-off volume	Prediction
	Liters/day	[W]
Davos	50	89.3
Davos	110	169
Davos	200	217
Stockholm	50	58.2
Stockholm	110	107
Stockholm	200	140
Athens	50	56.8
Athens	110	111

Athens	200	162
Wuerzburg	50	56.3
Wuerzburg	110	106
Wuerzburg	200	147

13. Identical procedure (starting from point 12) is to be carried out for each further member of system family.

2. Forced circulation, integrated back-up system family

9. Data sheets of two systems, family members, are listed in Appendix as Tab C and Tab D,

10. Requirements under the D.2. Section “Requirements for grouping of different system configurations into single system family” are fulfilled.

11. According to D.3. Section, the ratios of area/volume are to be calculated. Ratio of area/volume is 6/250 m²/l and 4/350 m²/l respectively. The system with higher ratio of area vs volume has to be selected for testing. And that is system with 350 liters and area of 6 m². 6/250=0.024 m²/l, 4/350=0.011 m²/l, The system 6/250 is chosen as “reference system”.
For the system “6/250”, artificial test data according to the requirements of the **Standard (ISO 9459-5)** have been generated using the TRNSYS program. The output data files are au625a.dat, au625b.dat and au625c.dat. This extensive output data set is thereafter compressed avoiding insignificant information - as by usual procedure for processing measurement data (using the SDHWP program available within the DST software).

12. The batch file **6250nfix.bat** is created for data treatment according to the Standard. This batch file identifies set of `free` parameters of the reference system.

13. Execute this batchfile in order to identify the set of ´free´ parameters. Tab B.1. gives identified set of parameters (associated filename is **6250nfix.dfr**).

```
\Results DF_P 2.7 Sep 97 @Copyright InSitu running 08.10.2009 16:46:06
\Value,Parameters,"AC*=3.55 uC*=6.27 US=1.7 CS=1.04 faux=0.318 DL=0.101 SC=0
Obj=10.6"
* SDHW Plug Flow Model (V 2.1, Jun 1992)
frequency transform method............... Cosine
initial state value...................... 15
numerical precision...................... 1
time base................................ 3600
filter type.............................. Gaussian, tf=4, CF=1E6
          Name   mode  tvf  t_start   t_skip   t_end    N*      Size
      AU6250A.D3   Mean  1.4       0     30.1      720  66.4   401..3781
      AU6250B.D3   Mean  1.1       0    30.36      720  56.3   298..1866
      AU6250C.D3   Mean  1.2       0    30.09      360  27.3   337..1147
    AC*       uC*         US        CS       faux        DL      SC  objective
   [mý]   [W/K/mý]     [W/K]    [MJ/K]       [-]       [-]      [-]       [W]
  3.553     6.267      1.703      1.04    0.3179    0.1006       0    10.605
  0.043     0.129     0.0907   0.00567   0.00862   0.00608    0.0117
Cross correlation matrix:
```

1.0000000	0.3522315	-0.1428583	-0.1159083	-0.2161553	0.5126954	-0.7558252
0.3522315	1.0000000	-0.8531725	0.1550799	0.0764832	0.0953980	0.2356101
-0.1428583	-0.8531725	1.0000000	-0.0661884	-0.0099385	-0.2318446	-0.2571335
-0.1159083	0.1550799	-0.0661884	1.0000000	0.1072539	0.1063516	0.3551103
-0.2161553	0.0764832	-0.0099385	0.1072539	1.0000000	-0.5872346	0.2539770
0.5126954	0.0953980	-0.2318446	0.1063516	-0.5872346	1.0000000	-0.4270209
-0.7558252	0.2356101	-0.2571335	0.3551103	0.2539770	-0.4270209	1.0000000

Tab B.1. Identified set of 'free' parameters

14. All the above stated steps follow strictly the procedure outlined in the Standard. From this point on we start with extrapolation procedure.
Procedure for extrapolation of test results requires fixing collector parameters as described in the Appendix: **Calculation of A_C^* and u_C^* for "DST-extrapolation procedure"**

15. Collector parameters are fixed for the reference system according to data listed in Tab. C. as it follows:

-
- Collector: A_a = 6.0 m², η_{0a} = 0.77; a_{1a} = 3.80 W/(m²K); a_{2a} = 0.014 W/(m²K²);
- $K_{50°}$ = 0.94

- U_{misc} = 0.0
- $U_{loop,rest}$ = 0 W/K
- $(AU)_{hx}$ = 110 W/K
- F''' = 0.811
- Ac* = 0.811 * 0.77 * 6 * 0.94 = 3.52 m²
- uC* = 6.02 W/K m²

16. Execute Dynamic Fitting (DF) program (within DST software) to identify set of parameters for reference system using fixed collector parameters. Batch filename is, **6250fix.bat**. The DST result file is processed requesting a huge number of local minima, e.g. 80. The result file for above stated data files has filename **6250Fix.DFR.** This file represents a basis file for preparing substitute results files for other members of system family.

```
\Results DF_P 2.7 Sep 97 @Copyright InSitu running 08.10.2009 16:55:18
\Value,Parameters,"AC*=3.52 uC*=6.02 US=1.89 CS=1.04 faux=0.335 DL=0.0956 SC=0 Obj=12.2"
* SDHW Plug Flow Model (V 2.1, Jun 1992)
frequency transform method............... Cosine
initial state value...................... 15
numerical precision...................... 1
time base................................ 3600
filter type.............................. Gaussian, tf=6, CF=1E5
         Name   mode  tvf  t_start  t_skip  t_end   N*     Size
   AU6250A.D3   Mean  6.4       0   20.08     720  213  290..3781
   AU6250B.D3   Mean  3.4       0   20.09     720  112  207..1866
   AU6250C.D3   Mean  3.7       0   20.07     360  59.2  226..1147
  AC*     uC*       US       CS      faux      DL       SC  objective
 [mý]  [W/K/mý]    [W/K]   [MJ/K]     [-]      [-]      [-]     [W]
 3.52    6.02     1.889    1.043     0.335   0.09555     0    12.221
   0       0     0.0282   0.00446  0.00368   0.00282  0.00324
```

Cross correlation matrix:

```
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000  0.0000000
 0.0000000  0.0000000  1.0000000  0.1437257 -0.0641513 -0.4309959  0.4990773
 0.0000000  0.0000000  0.1437257  1.0000000 -0.1023397  0.3713648  0.4403850
 0.0000000  0.0000000 -0.0641513 -0.1023397  1.0000000 -0.3661457 -0.2015836
 0.0000000  0.0000000 -0.4309959  0.3713648 -0.3661457  1.0000000  0.1075661
 0.0000000  0.0000000  0.4990773  0.4403850 -0.2015836  0.1075661  1.0000000
```

Tab B.2. Identified set with the 'fixed' collector parameters

17. The energy yields computed by two sets characterized by (1) free identified and (2) with fixed collector parameters are now computed. The reference batch file is **thauxltp.bat.** The results are given in the following table:

Location	Free Qs/Qa	Fixed Qs/Qa	Free Qs/Qa	Fixed Qs/Qa	Free Qs/Qa	Fixed Qs/Qa	Free Qs/Qa	Fixed Qs/Qa
Daily draw-off	110l	110l	200l	200l	300l	300l	400l	400l
Davos, Yield /W	193/16	192/18	286/87	281/91	339/181	346/176	386/266	382/276
Athens, Yield/W	121/23	119/25	198/63	196/66	260/105	257/111	300/182	297/191
Stockh, Yield/W	117/66	115/71	182/129	179/135	223/211	220/219	242/284	238/295
Wuerzb, Yield/W	122/56	120/60	194/112	191/118	243/177	246/169	270/257	266/261

18. Criterion that maximum error in predicted yields should not reach 15% is fulfilled. Therefore, we may proceed with the next step of the extrapolation procedure

19. Choose a member of system family for which extrapolation is to be carried out.
    Let us consider a system differing from reference system in a number of collectors, collector pipes heat loss coefficient and storage volume (System Characteristics are listed in Appendix in Tab. D)

12. The corresponding values for effective collector area and storage heat loss coefficient and heat capacity are:

- Collector: $A_a = 4.0$ m², $\eta_{0a} = 0.77$; $a_{1a} = 3.80$ W/(m²K); $a_{2a} = 0.014$ W/(m²K²);
- $K_{50°} = 0.94$
- $U_{misc} = 0.0$ W/K
- $U_{loop,rest} = 0.0$ W/K
- $(AU)_{hx} = 175$ W/K
- F''' = 0.92
- Ac* = 0.92 * 0.77 * 4 * 0.94 = 2.66 m²
- uC* = 6.02 W/K m²
- CS = 350 l *4.191 kJ/kg/K*1/1000 = 1.47 MJ/K

  Us = Us(250l) * Area (350) / Area (250l) = 1.9 W/K * 1.21 = 2.3 W/K, Where Us(250l) is identified value of storage heat loss coefficient by batchfile 625nfix.bat (e.g. identification with fixing collector parameters).

  Copy the result file (**625fix.dfr**) with a new filename 4350.DFR and enter computed values under this point, keeping other parameters unchanged. The file **4350-c.dfr** is now representing the result file for system with 4 m² collector area and 350 l storage volume corresponding to data listed in the Tab B.2.

  Execute program LTP for long term prediction (**LTP-4350.bat**). Result for given meteorological and operational conditions for three loads are listed bellow.

Location	Daily draw-off volume	Prediction Qsol/Qaux
	Liters/day	[W]
Davos	110	177/34
Davos	200	268/109
Davos	400	329/335
Stockholm	110	99/94
Stockholm	200	155/170
Stockholm	400	202/367
Athens	110	108/38
Athens	200	176/88
Athens	400	265/214
Wuerzburg	110	106/80
Wuerzburg	200	170/150
Wuerzburg	400	231/310

13. Identical procedure (starting from point 11) is to be carried out separately for each further member of system family.

Appendix I. System data

Project: **Flexible system certification - validation of procedure for system performance prediction extrapolation**

Check / data list for system test

	Solar preheater thermosyphon		"6350" (6m2 collectors+350 litres storage)				
Solar loop	Collector	Collector name/type					
		No. collector modules	3				
		Aperture area per collector module	2				m²
		Optical Efficiency	0.77				
		First-order heat loss coefficent	3.33				W/(m²K)
		Second-order heat loss coefficent	0.012				W/(m²K²)
		Thermal capacity of collector					kJ/K
		Incident Angle Modifier:	Angle °	30	50	70	
			IAM, ASHRAE b0=0.1, b1=0.		0.94		
	Collector loop pipes	Pipes Dimensions	Diameter				W/K
			Total pipe lenght				m
		Pipe insulation	Thickness of insulation				mm
			Heat conductivity of insulation				W/(m*K)
			Total length of unisulated pipes	0			m
		Overall heat loss coefficent					W/K
		Thermal capacity					kJ/K
	Heat Exchanger	Heat transfer coefficient or					W/K
		Heat transfer area					m²
	Type of circulation	Forced circulation/thermo-siphon	Thermosiphon				
		Pump power					W
		Average flowrate					l/min
Storage	Total storage	Height (cylinder) 1.2					m
		Volume	350				litres
		Tank position - vertical/horizontal	vertical				
		Tank location - indoors/outdoors	indoors				
		Heat loss coefficient or					
		UA	2.8				W/K
	Back-up part of storage	Volume					litres
		(Recommende set temperature)					°C

Tab A. Data of Reference thermo siphon system representing system family

Project: **Flexible system certification - validation of procedure for system performance prediction extrapolation**

Check / data list for system test

	Solar preheater thermosyphon		"2150" (2m2 collectors+150 litres storage)				
Solar loop	Collector	Collector name/type					
		No. collector modules	1				
		Aperture area per collector module	2				m²
		Optical Efficiency	0.77				
		First-order heat loss coefficent	3.33				W/(m²K)
		Second-order heat loss coefficent	0.012				W/(m²K²)
		Thermal capacity of collector					kJ/K
		Incident Angle Modifier:	Angle °	30	50	70	
			IAM, ASHRAE b0=0.1, b1=0.		0.94		
	Collector loop pipes	Pipes Dimensions	Diameter				W/K
			Total pipe lenght				m
		Pipe insulation	Thickness of insulation				mm
			Heat conductivity of insulation				W/(m*K)
			Total length of unisulated pipes	0			m
		Overall heat loss coefficent	0				W/K
		Thermal capacity					kJ/K
	Heat Exchanger	Heat transfer coefficient or					W/K
		Heat transfer area					m²
	Type of circulation	Forced circulation/thermo-siphon	Thermosiphon				
		Pump power					W
		Average flowrate					l/min
Storage	Total storage	Height (cilinder)	1.2				m
		Volume	150				litres
		Tank position - vertical/horizontal	vertical				
		Tank location - indoors/outdoors	indoors				
		Heat loss coefficient or					
		UA	1.5				W/K
	Back-up part of storage	Volume					litres
		(Recommende set temperature)					°C

Tab B. Data of a member of thermo siphon system family

Project: **Flexible system certification - validation of procedure for system performance prediction extrapolation**

Check / data list for system test

	Solar + supplementary system		"6250" (6m2 collectors+250 litres storage) = REFERENCE SYSTEM					
Solar loop	Collector							
		Collector name/type						
		No. collector modules	3					
		Aperture area per collector module	2					m²
		Optical Efficiency	0.77					
		First-order heat loss coefficent	3.8					W/(m²K)
		Second-order heat loss coefficent	0.014					W/(m²K²)
		Thermal capacity of collector						kJ/K
		Incident Angle Modifier:	Angle °	30	50	70		
			IAM, ASHRAE b0=0.1, b1=0.		0.94			
	Collector loop pipes	Pipes Dimensions	Diameter					W/K
			Total pipe lenght					m
		Pipe insulation	Thickness of insulation					mm
			Heat conductivity of insulation					W/(m*K)
				0				m
		Overall heat loss coefficent	0					W/K
		Thermal capacity						kJ/K
	Heat Exchanger	Heat transfer coefficient or	115					W/K
		Heat transfer area						m²
	Type of circulation	Forced circulation/thermo-siphon	Forced circulation					
		Pump power						W
		Average flowrate						l/min
Storage	Total storage	Height (cilinder)	1.25					m
		Volume	250					litres
		Tank position - vertical/horizontal	vertical					
		Tank location - indoors/outdoors	indoors					
		Heat loss coefficient or	2.5 W/K					
		Insulation matirial & thickness						
	Back-up part of storage	Volume	70					litres
		(Recommende set temperature)	60					°C

Tab C. Data of Reference system representing whole system family (forced circulation with auxiliary)

Project:	**Flexible system certification - validation of procedure for system performance prediction extrapolation**						
Check / data list for system test							
	Solar + supplementary system		"4350" (4m2 collectors+350 litres storage)				
Solar loop	Collector	Collector name/type					
		No. collector modules	2				
		Aperture area per collector module	2				m²
		Optical Efficiency	0.77				
		First-order heat loss coefficent	3.8				W/(m²K)
		Second-order heat loss coefficent	0.014				W/(m²K²)
		Thermal capacity of collector					kJ/K
		Incident Angle Modifier:	Angle °	30	50	70	
			IAM, ASHRAE b0=0.1, b1=0.		0.94		
	Collector loop pipes	Pipes Dimensions	Diameter				W/K
			Total pipe lenght				m
		Pipe insulation	Thickness of insulation				mm
			Heat conductivity of insulation				W/(m*K)
			Total length of unisulated pipes	0			m
		Overall heat loss coefficent	0				W/K
		Thermal capacity					kJ/K
	Heat Exchanger	Heat transfer coefficient or	175				W/K
		Heat transfer area					m²
	Type of circulation	Forced circulation/thermo-siphon	Forced circulation				
		Pump power					W
		Average flowrate					l/min
Storage	Total storage	Height (cilinder)	1.25				m
		Volume	350				litres
		Tank position - vertical/horizontal	vertical				
		Tank location - indoors/outdoors	indoors				
		Heat loss coefficient or	3.5				W/K
		Insulation matirial & thickness					
	Back-up part of storage	Volume	100				litres
		(Recommende set temperature)	60				°C

Tab D. Data of a member of system family (forced circulation with auxiliary)