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

- $U_{un-insu}$: 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:

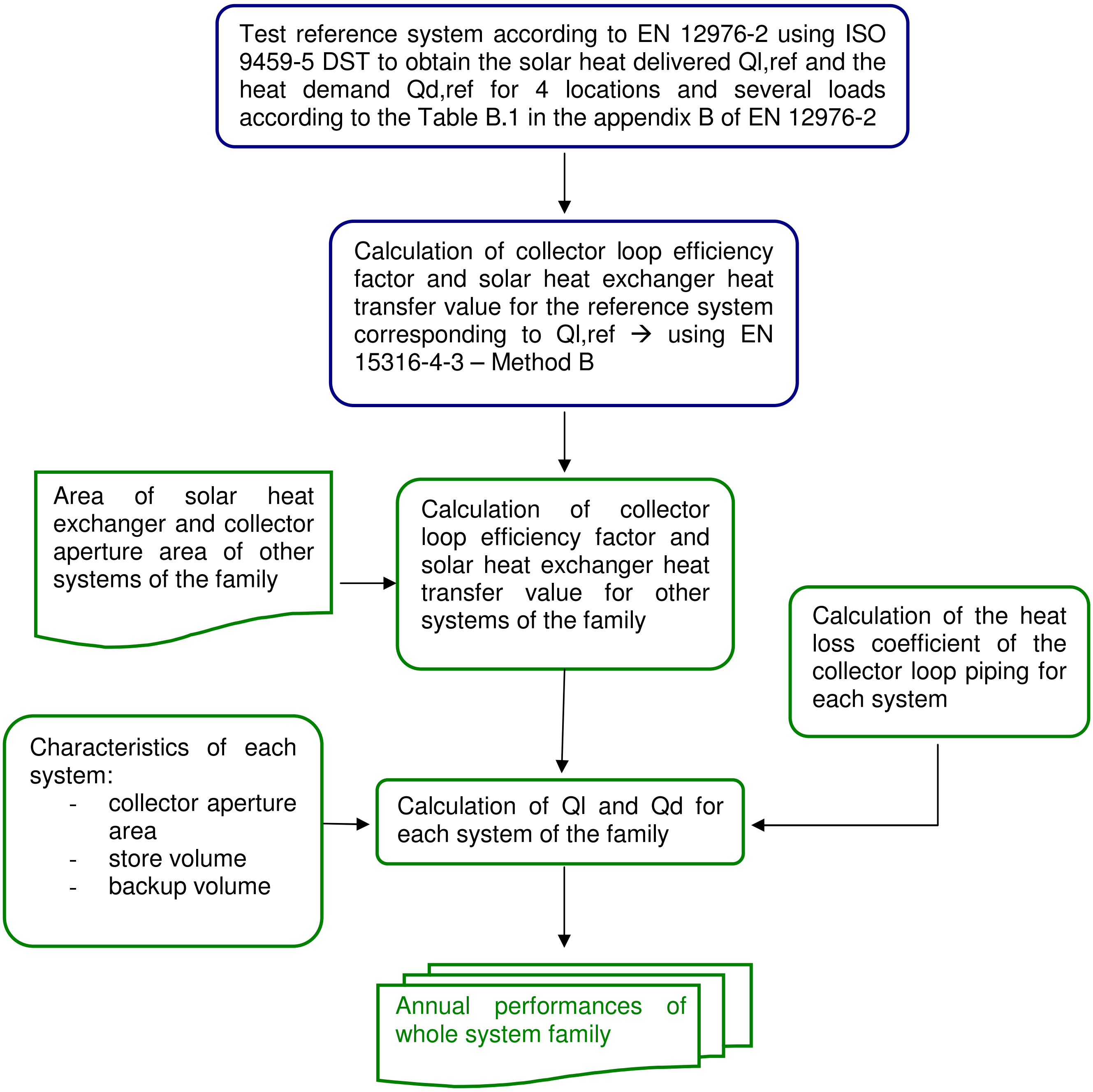

Fig. D.4.1.1 Principle of Method I (f-chart)

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:

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

With:

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

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 :

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

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).

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

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]
- $U_{un\text{-}insu}$ 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 $U_{un\text{-}insu}$, $U_{loop,p}$ 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]

[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

Solar plus supplementary systems:

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

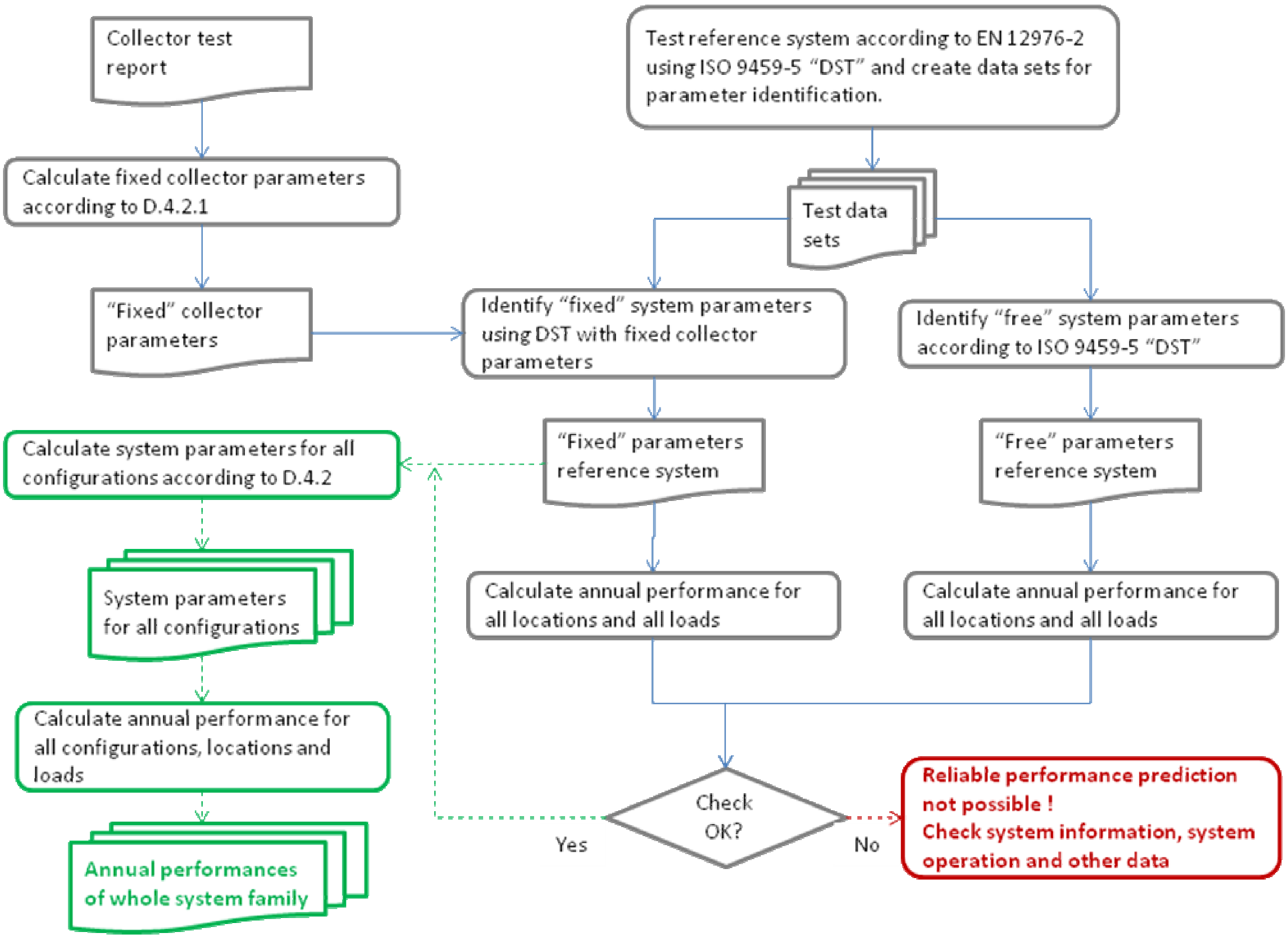

Fig. D.4.2.1 Principle of Method II (DST)

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

<u>For external heat exchanger</u> 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)

<u>For tanks with internal heat exchangers</u> 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