Energy Labelling of factory made systems

Deliverable D3.4 – Part 1

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Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments

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1 Summary

The energy consumed by water heaters and hot water storage tanks accounts for a significant share of the energy demand in the Union, and water heaters with equivalent functionality have a wide disparity in term of energy efficiency and standing loss. The energy efficiency of water heaters and the standing loss of hot water storage tanks can be significantly improved. Water heaters and hot water storage tanks should therefore be covered by requirements on energy labelling.

Solar water heaters are water heaters which use solar heat for heat generation and they are included in the scope of the regulation. The draft ANNEX IV1 on Eco-design implementing measures for dedicated water heaters, does not refer to the European standards for solar systems – but gives new procedures for testing solar systems. These new procedures require that each and every system configuration is tested (for each number of collectors, for each tank size, and for each boiler which can be used for back-up) – leading to a huge amount of system testing.

The test methods referred to the European standards for solar systems are the CSTG method (ISO 9459-2) which is not mentioned as a testing procedure to be applied to solar only/preheat systems in the ecodesign /energy labelling documents, and the DST test method (ISO 9459-5) which is mentioned as a measurement option.

In order to avoid the huge testing effort of the ecodesign new testing procedures, the QAIST project sets up the goal of finding a procedure to integrate the long term performance prediction (LTPP) of CSTG and DST methods for the performance testing of factory made solar thermal systems according to the EU energy labelling conditions and requirements.

The first approach for the CSTG LTPP method is to modify the daily calculation procedure in order to integrate the EU reference tapping profiles and the reference input data with the CSTG performance test results.

The first approach for the DST LTPP method is to use the In-situ[2] SW prediction to integrate the EU reference tapping profiles and reference input data with the DST performance test results.

[1] ANNEX IV on Eco-design implementing measures for dedicated water heaters. Draft v2. EC-16.9.2008

[2] Dynamic System Testing, Programme Manual, Version 2.7,In Situ Scientific Software

2 Introduction

Development of a procedure for integrating the performance test results of the existing (CSTG and DST) test methods, into results valid for the “EU reference tapping cycles”, necessary for labelling of systems according to the future European Directive

2.1 Ecodesign Directive

The 2005 Ecodesign directive covered energy-using products, which use, generate, transfer or measure energy, including consumer goods such as boilers, water heaters, computers, televisions, and industrial products such as transformers. The implementing measures focus on those products which have a high potential for reducing greenhouse gas emissions at low cost, through reduced energy demand.

The first Working Plan of the Ecodesign Directive was adopted on 21 October 2008, establishing a list of 10 product groups to be considered in priority for implementing measures in 2009-2011:

- Air-conditioning and ventilation systems
- Electric and fossil-fuelled heating equipment
- Food-preparing equipment
- Industrial and laboratory furnaces and ovens
- Machine tools
- Network, data processing and data storing equipment
- Refrigerating and freezing equipment
- Sound and imaging equipment
- Transformers
- Water-using equipment

The Ecodesign Directive has been extended in 2009 to all energy-related products (the use of which has an impact on energy consumption), including:

- energy-using products (EUPs): products which use, generate, transfer or measure energy (e.g. electricity, gas, fossil fuel), including consumer goods such as boilers, computers, TVs, washing machines, light bulbs and industrial products such as transformers, industrial fans, industrial furnaces.
- other energy related products (ERPs): products which do not necessarily use energy, but have an impact on energy consumption (direct or indirect) and can therefore contribute to saving energy, such as windows, insulation material or bathroom devices (e.g. shower heads, taps).

The Ecodesign Directive is a framework Directive: it does not set binding requirements on products by itself, but through implementing measures adopted on a case by case basis for each product group. All guiding principles for developing implementing measures are set in the framework Directive 2009/125/EC[3].

Standardisation supports the implementation of the Ecodesign Directive (notably through harmonised standards giving presumption of conformity with all or some Ecodesign legal requirements).

2.2 Water heaters and solar thermal systems

2.2.1 Starting point

A mandate (M/324, September 2002) was given from EC through CEN to adapt the European solar system standards (EN 12976 and ENV 12977) to the “EU reference tapping profile”. Work on revising the standards to fulfil this requirement, did not start.

Implementing measures for the EcoDesign Directive with respect to Dedicated Water Heaters and Boilers were developed by an EC external consultant. The draft ANNEX IV[4] on Eco-design implementing measures for dedicated water heaters does not refer to the European standards for solar systems – but gives new procedures for testing solar systems. These new procedures require that each and every system configuration is tested (for each number of collectors, for each tank size, and for each boiler which can be used for back-up) – leading to a huge amount of system testing.

There is a wish from the EC to base the implementing measures on European standards.

2.2.2 Gaps of the previous work

The Annex IV on Eco-design implementing measures for dedicated water heaters Draft v2 16/09 2008 the existing EN standards for factory made solar thermal systems are not taken into account. The Annex IV is not feasible for solar systems, as each and every system configuration has to be tested. Harmonised solar system standards need to be developed to assure feasible implementation of the Eco-design with respect to solar water heaters.

The EN standards for factory made solar thermal systems must be adapted according to requirements of the EC / CEN Mandate 324.

2.3 Ecodesign and Energy Labelling of water heaters and hot water storage tanks

The energy consumed by water heaters and hot water storage tanks accounts for a significant share of the energy demand in the Union, and water heaters with equivalent functionality have a wide disparity in term of energy efficiency and standing loss. The energy efficiency of water heaters and the standing loss of hot water storage tanks can be significantly

3 DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast)

4 ANNEX IV on Eco-design implementing measures for dedicated water heaters. Draft v2. EC-16.9.2008

improved. Water heaters and hot water storage tanks should therefore be covered by requirements on energy labelling.

Harmonised provisions for indicating the energy efficiency and consumption of water heaters and hot storage tanks by labelling and standard product information must be established in order to provide incentives for manufacturers to improve the energy efficiency of water heaters and hot water storage tanks, encourage end-users to purchase energy-efficient models, reduce the energy consumption of these products, and contribute to the functioning of the internal market.

2.3.1 Reference EC documents

Working Document COMMISSION REGULATION (EU) No …/…of … implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for water heaters and hot water storage tanks

The scope of this regulation should be limited to water heaters which are dedicated to provide hot drinking and sanitary hot water.

A water heater is a device which:

- is connected to an external supply of drinking or sanitary water
- generates and transfers heat to deliver drinking or sanitary hot water at certain temperature levels, quantities and flow rates during certain intervals
- has one or more heat generators, including cascades of the same type of heat generators
- provides drinking or sanitary hot water only, but does not provide heat for room heating

“solar water heater” means a water heater, which uses solar heat for heat generation;

"load profile" means a certain sequence of water draw-offs, as specified in Annex II, Table 1;

"water draw-off" means a certain combination of useful water flow rate, useful water temperature, useful water energy content and peak temperature, as specified in Annex II, Table 1;

"useful water temperature", T_m , means the water temperature for which hot water is contributing to the reference heat;

"peak temperature", T_p , means the minimum water temperature in degrees Celsius to be achieved during water draw-off;

"reference energy", Q_{ref} , means the sum of the energy content of water draw-offs in a specific load profile;

“maximum load profile” means the load profile with the largest reference energy Q_{ref} defined in Annex VI, Table 1, which a water heater is capable to provide under the thermostat settings specified in point 2(c) of Annex VI and fulfilling the minimum temperature and flow rate conditions of that load profile

ANNEX I - Ecodesign requirements for water heaters and storage tanks

Working Document COMMISSION DELEGATED REGULATION (EU) No …/.. of […] implementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of water heaters and hot water storage tanks

Measurement methods

The information to be provided under Articles 3 and 4 shall be obtained by reliable, accurate and reproducible measurement procedures, which take into account the recognised state of the art measurement methods, as set out in Annex VI.

"average climate conditions", "colder climate conditions" and "warmer climate conditions" mean the temperature and the global solar irradiance conditions characteristic for the cities of Strasbourg, Helsinki and Athens, respectively, as specified in point 4 of Annex VI.

"solar parameters" related to the methods pursuant to EN 13203, EN 15316-4-3 and ISO 9459-5:2007

Annex I Definitions Annex II Label

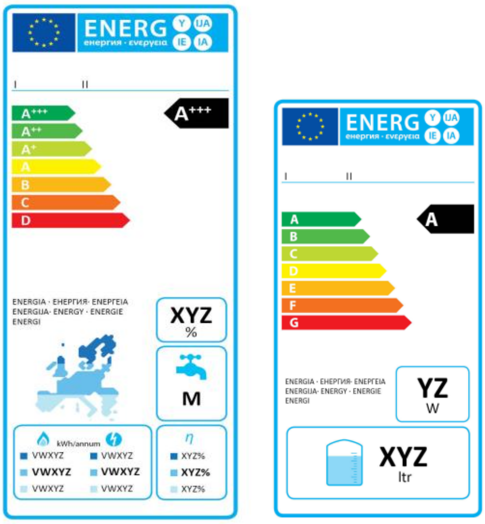

Figure 1 Energy labels for solar preheat system and hot water storage

Annex III Product fiche

Annex IV Technical documentation:

Test parameters for measurements as specified in point 5, 7 of Annex VI.

Annex V Information for the end-users in case of not displayed in the product

Annex VI Measurements

General conditions for testing water heaters

(a) measurements shall be carried out using the load profiles set out in Table 1;

(b) measurements shall be carried out using a 24-hour measurement cycle as follows:

(i) 00:00 hours to 06:59 hours: no water draw-off;

(ii) from 7:00 hours: water draw-offs according to the declared load profile;

(iii) from end of last water draw-off until 24:00 hours: no water draw-off;

(c) the mean temperature between the thermostat temperature setting which starts the water heating, and the thermostat temperature setting which stops the water heating, shall not fall below 55°C;

(d) the load profile applied for testing shall be the maximum load profile. ** In the new version of the working document (2/2012) one can use a "declared load profile": maximum load profile or (only for water heaters with maximum load profiles M to 4XL) the load profile below the maximum load profile.

Conditions for testing solar water heaters

Conditions for testing solar preheat systems

Solar preheat systems shall be tested under one of the following conditions:

[NB: measurements and calculations pursuant to EN 15316-4-3:]

(a) Solar collector, storage tank and solar pump shall be tested separately. The results shall be used for calculating Q_{sol} referred to in point 7 of Annex VIII under the conditions set out in Annex VII Tables 3 and 4.

Table 3 : Average daytime temperature in degrees Celsius

	January	February	March	April	May	June	July	August	September	October	November	December
Average climate conditions	2,8	2,6	7,4	12,2	16,3	19,8	21,0	22,0	17,0	11,9	5,6	3,2
Colder climate conditions	9,5	10,1	11,6	15,3	21,4	26,5	28,8	27,9	23,6	19,0	14,5	10,4
Warmer climate conditions	-3,8	-4,1	-0,6	5,2	11,0	16,5	19,3	18,4	12,8	6,7	1,2	-3,5

Table 4 : Average global solar irradiance in W/m²

	January	February	March	April	May	June	July	August	September	October	November	December
Average climate conditions	70	104	149	192	221	222	232	217	176	129	80	56
Colder climate conditions	22	75	124	192	234	237	238	181	120	64	23	13
Warmer climate conditions	128	137	182	227	248	268	268	263	243	175	126	109

[NB: measurements and calculations pursuant to ISO 9459-5:]

(b) Where solar collector and storage tank cannot be tested separately their combination shall be tested, and the solar pump shall be tested separately. The results shall be used for the calculating of Q_{sol} referred to in point 7 of Annex VIII under the conditions set out in Annex VII Tables 3 and 4

Technical parameters of solar preheat systems

The following technical parameters shall be established for solar preheat systems:

(i) the solar collector aperture area A_{sol} in m², measured to two decimal places;

(ii) the zero-load efficiency eta0, measured to three decimal places;

(iii) the first order coefficient a_1, measured to two decimal places;

(iv) the second order coefficient a_2, measured to two decimal places;

(v) the pump power consumption sol_{pump} in Watts, measured to two decimal places;

(vi) the standby power consumption, $sol_{standby}$ in Watts, measured to two decimal places in addition, for solar preheat systems tested under the conditions set out in point 4(b) of Annex VI:

(vii) the incidence angle modifier IAM, to one decimal place.

Annex VII Verification procedure for market surveillance purposes

Annex VIII Method for calculating the efficiency of water heaters

(4.) The energy efficiency of the water heater etawh is calculated as follows:

$$etawh = \frac{Q_{ref}}{(Q_{fuel} + prim \cdot Q_{elec})(1 - 0{,}07 \cdot smart) + Q_{distr} - (\mathrm{qrecov} \cdot Q_{rwaste})}$$

Annex IX Energy efficiency class

Table 8: Energy efficiency classes of water heaters

	3XS	XXS	XS	S	M	L	XL	XXL	3XL	4XL
A+++	$\eta > 62$	$\eta > 62$	$\eta > 69$	$\eta > 90$	$\eta > 96$	$\eta > 107$	$\eta > 112$	$\eta > 124$	$\eta > 140$	$\eta > 150$
A++	$53 \leq \eta < 62$	$53 \leq \eta < 62$	$61 \leq \eta < 69$	$72 \leq \eta < 90$	$79 \leq \eta < 96$	$90 \leq \eta < 107$	$92 \leq \eta < 112$	$104 \leq \eta < 124$	$110 \leq \eta < 140$	$120 \leq \eta < 150$
A+	$44 \leq \eta < 53$	$44 \leq \eta < 53$	$53 \leq \eta < 61$	$55 \leq \eta < 72$	$62 \leq \eta <-79$	$73 \leq \eta < 90$	$76 \leq \eta < 92$	$84 \leq \eta < 104$	$96 \leq \eta < 110$	$96 \leq \eta < 120$
A	$35 \leq \eta < 44$	$35 \leq \eta < 44$	$38 \leq \eta < 53$	$38 \leq \eta < 55$	$45 \leq \eta < 62$	$56 \leq \eta < 73$	$62 \leq \eta < 76$	$72 \leq \eta < 84$	$80 \leq \eta < 96$	$86 \leq \eta < 96$
B	$32 \leq \eta < 35$	$32 \leq \eta < 35$	$35 \leq \eta < 38$	$35 \leq \eta < 38$	$39 \leq \eta < 45$	$46 \leq \eta < 56$	$50 \leq \eta < 62$	$60 \leq \eta < 72$	$64 \leq \eta < 80$	$64 \leq \eta < 86$
C	$29 \leq \eta < 32$	$29 \leq \eta < 32$	$32 \leq \eta < 35$	$32 \leq \eta < 35$	$36 \leq \eta < 39$	$37 \leq \eta < 46$	$38 \leq \eta < 50$	$40 \leq \eta < 60$	$40 \leq \eta < 64$	$40 \leq \eta < 64$
D	$26 \leq \eta < 29$	$26 \leq \eta < 29$	$29 \leq \eta < 32$	$29 \leq \eta < 32$	$33 \leq \eta < 36$	$34 \leq \eta < 37$	$34 \leq \eta < 38$	$36 \leq \eta < 40$	$36 \leq \eta < 40$	$36 \leq \eta < 40$
E	$23 \leq \eta < 26$	$23 \leq \eta < 26$	$26 \leq \eta < 29$	$26 \leq \eta < 29$	$30 \leq \eta < 33$	$30 \leq \eta < 34$	$30 \leq \eta < 34$	$32 \leq \eta < 36$	$32 \leq \eta < 36$	$32 \leq \eta < 36$
F	$20 \leq \eta < 23$	$20 \leq \eta < 23$	$23 \leq \eta < 26$	$23 \leq \eta < 26$	$27 \leq \eta < 30$	$27 \leq \eta < 30$	$27 \leq \eta < 30$	$28 \leq \eta < 32$	$28 \leq \eta < 32$	$28 \leq \eta < 32$
G	$\eta < 20$	$\eta < 20$	$\eta < 23$	$\eta < 23$	$\eta < 27$	$\eta < 27$	$\eta < 27$	$\eta < 28$	$\eta < 28$	$\eta < 28$

Annex X Method for calculating the energy efficiency of combinations of solar preheat systems and water heaters with load profiles from M to 4XL placed on the market separately.

2.3.2 EU reference load profiles

For each tapping within a tapping profile, the amount of energy drawn-off is defined and also a minimum flow rate, so the duration of the tapping at the minimum flow rate must be calculated.

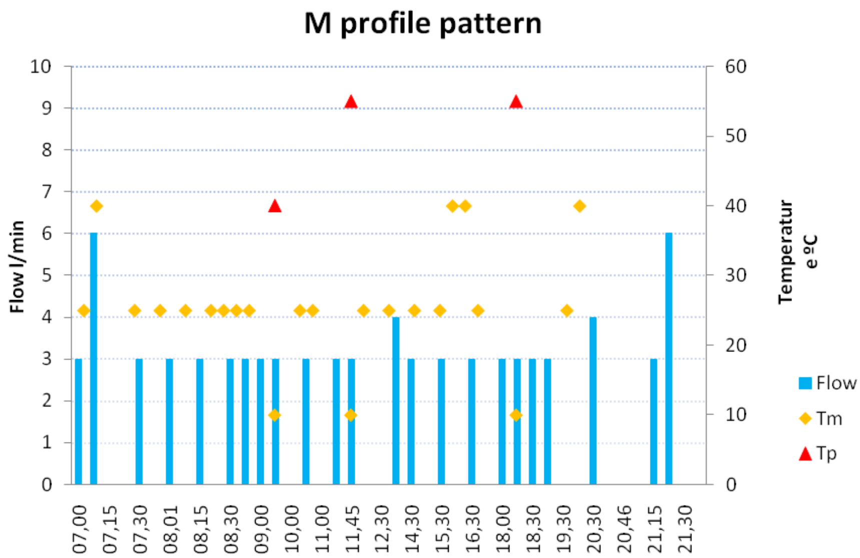

Figure 2 EU reference load profile M

The amount of energy delivered must be calculated from the measurements with the following requirements:

Demand profiles are defined:

–Daily withdrawn energy: Q_{ref} = sum(Q_{tap})

–Minimum tapping flow rate

–Minimum hot water temperature: T_m

–Necessary peak temperature: T_p

•No seasonal dependence of cold water tempeteration: T_{cw} = 10°C constant

2.4 Energy Labelling within QAIST

Work will be done to adapt the solar thermal EN standards to the requirements in the ANNEX IV – and give advice how to use existing EN standards for solar systems in ANNEX IV. Work will focus on a flexible procedure which can use separate tests of solar thermal systems/components and back-up boilers for determination of energy efficiency of the whole system – this is to avoid immense testing of all possible configurations of solar thermal systems and boilers. Furthermore the solar standards will be adapted to the "EU Tapping Profile" as defined in CEN Mandate M/324 concerning Energy labelling.

Procedure that will allow based on the present EN standards for Factory Made Systems, to determine the Energy label according to the objective of European Union to have labels for water heater systems.

2.5 Performance test methods under the EN 12976 standard

The EN12976 is dedicated to the definition of general requirements and test methods for factory made systems. Factory made systems are defined as "solar systems sold as products in large quantities as complete, packaged and ready to install kits with one trade name".

The outdoor test methods considered to determine the thermal performance of these systems are ISO 9459-2 (named also as CSTG method or Input-Output method) for preheat and solar-only systems, and ISO 9459-5 (named also as DST method) for solar-plus-supplementary systems.

Figure 3 Factory made system outdoor test benches

2.6 The CSTG test procedure

2.6.1 Performance testing procedure

A procedure for testing the performance of solar water heaters was developed during the 1980s by the Collector and System Testing Group (CSTG) coordinated by the Ispra Joint Research Centre[5], which treats a solar water heater as a black box with input-output parameters that are determined by all-day tests. This work included round robin tests of different systems for validation of the test method.

The basis of the CSTG test procedure is the linear input-output model for the daily performance of solar water heaters. The performance of a domestic solar-only water heater system can be represented by the equation:

$$Q = a_1 H + a_2 \left(t_{a(day)} - t_{main}\right) + a_3$$

Q = net solar energy gained by the storage tank during the day [MJ]

H = daily total solar irradiation on collector aperture [MJ/m^2]

$T_{a(day)}$ = daytime average ambient temperature [ºC]

T_{main} = cold water supply temperature [ºC]

The coefficients a_1, a_2 and a_3 for the system are determined from the outdoor test results using a least-squares fitting method.

The performance test involves a series of one-day outdoor tests on the complete system (at least six one-day tests), together with a short test to determine the degree of mixing in the storage tank during draw-off (f(V) and g(V)), and an overnight heat loss test to determine the heat loss coefficient of the storage tank (U_s).

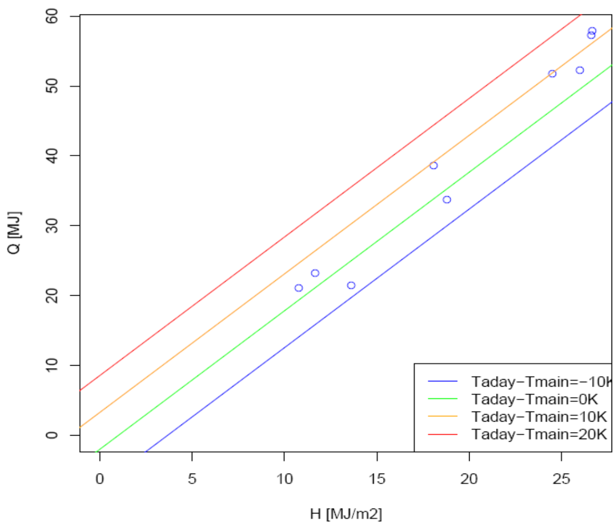

Figure 4 System output results during several performance test days

[5] Recommendations for Performance and Durability Tests of Solar Collectors and Water Heating Systems (Part A), Aranovitch E., Gilliaer D., Gillett W. B. and Bates J. E. (Eds.), (1989).

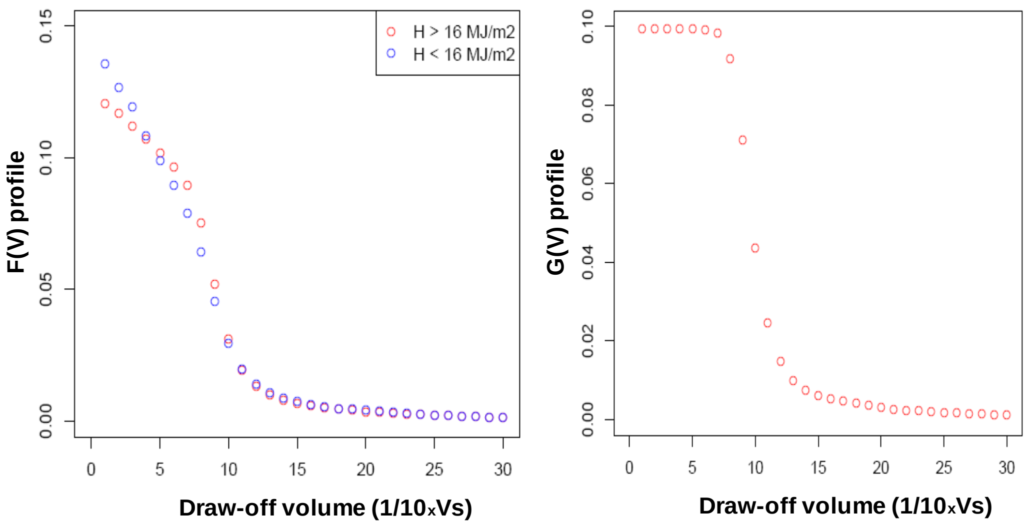

Figure 5 System output results for draw-off and mixing profile tests

The test procedure consists of a number of one-day tests which are independent of each other. On each day of the test, the system is allowed to operate outdoors and a single draw-off is applied at the end of day. At the start of each day of the test, the system is preconditioned by flushing it with water at a known temperature. The input, (i.e. the irradiation incident on the system), and the output, (i.e. the energy contained in the hot water draw-off), are measured for each test day and plotted on an input/output diagram. The test days shall cover a range of irradiation values and values of ($t_{a(day)}$ - t_{main}) so that the dependence of the system performance on these parameters can be established.

2.6.2 Long term performance prediction (LTPP)

The performance of the system is calculated for each day of the year based on climatic data for the day and volume of hot water consumption for the day, taking into account energy in the storage tank carried over from the previous day.

The system output for any given period is the sum of the daily energy calculated outputs:

Eq. 1 $Q = Q_{c(1)} + Q_{c(2)} + ... + Q_{c(n)}$

2.6.2.1 Required data for the system performance calculation

Data from the solar thermal system test results:

- The performance equation of the solar thermal system:

Eq. 2 $Q = a_1 H + a_2 \left(t_{a(day)} - t_{main}\right) + a_3$

- The draw-off temperature profile, expressed as a function of the storage tank extracted volume, f(V), and normalized so the area under the draw-off profile is equal to 1:

Eq. 3 $\int_0^\infty f(V)dV = 1$

The f(V) value is known at least each tenth of the storage tank volume. The draw-off temperature shall be determined for the following the daily irradiance ranges: from 8 MJ/m^2 to 16 MJ/m^2 and from 16 MJ/m^2 to 25 MJ/m^2.

- The mixing draw-off profile, expressed as a function of the storage tank extracted volume, f(V), and normalized so the area under the draw-off profile is equal to 1:

Eq. 4 $\int_0^\infty g(V)dV = 1$

The g(V) value is known at least each tenth of the storage tank volume.

- The heat loss coefficient of the storage tank (U_S), in W/K.

Location, climate and usage data:

- Daily solar irradiation on the collector plane H, in MJ/m^2
- Day average ambient temperature for each day: $t_{a(day)}$ in ºC
- Night average ambient temperature for each night, $t_{a(night)}$ in ºC
- The reference conditions for performance prediction are described in EN 12976-2 Annex B
- Cold water temperature according to the following equation and parameters from EN 12976-2 table B.4:

Eq. 5 $t_{main}=t_{ave}+\Delta\, t_{amplit} \sin(2\Pi\, ([Day]-D_s)/365)$

(Following the EN 12976-2 Annex B)

please note that for the DST method with the Insitu program the previous equation changes to: $t_{cw} - \Delta\, t_{amplit} \cos((N - N_o) * 2\Pi /365))$ with t_{cw}=10ºC.

- the volume of daily hot water consumption, V_c, or the minimum useful temperature limit for the hot water consumption

2.6.2.2 Calculation steps for day 1

System conditions for day 1:

- Irradiance = H (1)
- Day ambient temperature = $t_{a(day)}(1)$
- Cold water temperature = $t_{main}(1)$
- Extracted volume $V_C(1)$ or draw-off temperature limit = $t_h(1)$

The system starts the day with the storage tank at the cold water temperature $t_{main}(1)$. 6 hours after solar noon, the volume $V_C(1)$ is drawn-off.

Step 1: The total energy contained in the system at 6 hours after solar noon, Q(1), is calculated using Eq. 6 with $t_{main} = t_{main}(1)$, $t_{a(day)} = t_{a(day)}(1)$ and H = H(1)

Eq. 6 $$Q(1) = a_1 H(1) + a_2\left(t_{a(day)}(1) - t_{main}(1)\right) + a_3$$

Step 2: Volume drawn-off to reach the minimum temperature limit. This step is required only if the hot water demand is temperature-limited. For a hot water demand which is volume-limited, omit step 2 and continue with step 3. The hot water drawn-off temperature profile, as function of the volume, is calculated with Eq. 7:

Eq. 7 $$t_d(V) = t_{main}(1) + \frac{Q(1) f(V)}{0.1 V_S \rho_w c_{pw}}$$

The consumed volume $V_c(1)$ is calculated by determining the maximum volume at which t_d, as calculated in Eq. 8, remains higher than $t_h(1)$.

V_S, storage tank volume in litres.

Step 3: Energy drawn off. The energy $Q_C(1)$, contained in the draw-off volumen $V_C(1)$ is calculated with the f(V) function integrated from V=0 to V=V'.

Eq. 8 $$Q_C(1) = Q\ (1)\int_0^{V'} f(V)dV = Q\ (1).\sum f(V)$$

Where V' is determined by two conditions:

Eq. 9 $Q_C(1) \leq V_{load}\rho_w c_{pw}(t_{load} - t_{main})$ and Eq. 10 $V' \leq V_{load}$

For V_{load} and t_{load} reference conditions see EN12976-2 table B.1.

Step 4: The energy remaining in the storage tank Q_R is calculated:

Eq. 11 $$Q_R(1) = Q(1) - Q_C(1)$$

Step 5: The energy lost during night Q_{LOS} is calculated using the storage tank loss coefficient (U_s) and considering that the storage tank is completely mixed next morning at a uniform temperature t_S.

Eq. 12 $$t_S(2) = t_{main}(1) + \frac{Q_R(1) - Q_{LOS}}{"Storage\_capacity"})$$

Storage_ capacity = $V_S.\rho_w c_{pw}$

Eq. 13 $$Q_{LOS} = V_S.\rho_w c_{pw}\left[t_i - t_{a(night)}\right]\left[1 - \exp\left(-\frac{U_S \Delta t}{V_S \rho_w c_{pw}}\right)\right]$$

t_i is the temperature of the storage at the beginning of the night and it is calculated using Q_R from Eq. 14:

Eq. 14 $$t_i = \frac{Q_R(1)}{V_S \rho_w c_{pw}} + t_{main}(1)$$

Step 6: The daily hot water demand is calculated as follows:

Eq. 15 $$Q_d = V_{load} \cdot \rho_w c_{pw} \cdot (t_{load} - t_{main})$$

2.6.2.3 Calculation steps for day 2 and following days

System conditions for day 2:

- Irradiance = H (2)
- Day ambient temperature = $t_{a(day)}(2)$
- Cold water temperature = $t_{main}(2)$
- Extracted volume $V_C(2)$ or draw-off temperature limit = $t_h(2)$

The system starts the day with the storage tank at the $t_S(2) > t_{main}(2)$. 6 hours after solar noon, the volume $V_C(2)$ is drawn-off.

Step 1: The energy available 6 h after solar noon comes one part from the energy gained by the system if it was refilled with water at the initial temperature of $t_s(2)$. Q(2:part1), is calculated using Eq. 16 with $t_{main} = t_s(2)$, $t_{a(day)} = t_{a(day)}(2)$ and H = H(2):

Eq. 16 $$Q(2:part1) = a_1 H(2) + a_2 \left(t_{a(day)}(2) - t_s(2)\right) + a_3$$

The other part of energy gained comes from the fact that the storage tank was filled with water at $t_{main}(2) < t_S(2)$. Q(2:part 2), is calculated using Eq. 17:

Eq. 17 $$Q(2:part2) = V_S \rho_w c_{pw} \left(t_s(2) - t_{main}(2)\right)$$

The total energy available is:

Eq. 18 $$Q(2) = Q(2:part1) + Q(2:part2)$$

Step 2: Volume drawn-off to reach the minimum temperature limit. This step is required only if the hot water demand is temperature-limited. For a hot water demand which is volume-limited, omit step 2 and continue with step 3. The hot water drawn-off temperature profile, as function of the volume is calculated in Eq. 19. In calculating the temperature profile, it is necessary to consider the two energy contributions Q(2:part 1) and Q (2:part 2):

Eq. 19 $$t_d(V) = t_{main}(2) + \frac{Q(2:part1) f(V)}{0.1 V_S \rho_w c_{pw}} + \frac{Q(2:part2) g(V)}{0.1 V_S \rho_w c_{pw}}$$

The consumed volume $V_c(2)$ is calculated by determining the maximum volume at which t_d, as calculated in Eq. 19, remains higher than $t_h(2)$.

Step 3: Energy drawn off. One part of the energy Q(2:part1) is the energy considering that the system is refilled with water at the initial temperature of

$t_s(2)$. It is based on the energy determined in Eq. 16 and calculated with the f(V) function integrated from V=0 to V=V'.

$$Q_C(2:part1) = Q(2:part1)\int_0^{V'} f(V)dV$$

Eq. 20

The other part of energy is due to the ratio of draw-off volume $V_C(2)$ and is calculated using the mixing profile g (V):

$$Q_C(2:part2) = Q(2:part2)\int_0^{V'} g(V)dV$$

Eq. 21

Where V' is determined by two conditions:

Eq. 22 $Q_C(2) = Q_C(2:part1) + Q_C(2:part2) \le V_{load}\rho_w c_{pw}\left(t_{load} - t_{main}\right)$

Eq. 23 $V' \le V_{load}$

Step 4: The energy remaining in the storage tank Q_R is calculated:

Eq. 24 $Q_R(2) = Q(2) - Q_C(2)$

Step 5: The energy lost during night Q_{LOS} is calculated using the storage tank loss coefficient (U_s) and considering that the storage tank is completely mixed next morning at a uniform temperature t_S.

Eq. 25 $t_S(3) = t_{main}(2) + \dfrac{Q_R(2) - Q_{LOS}}{\text{"}Storage\_capacity\text{"}}$

Storage_ capacity = $V_S.\rho_w c_{pw}$

$$Q_{LOS} = V_S.\rho_w c_{pw}\left[t_i - t_{a(night)}\right]\left[1 - \exp\left(-\frac{U_S \Delta t}{V_S \rho_w c_{pw}}\right)\right]$$

Eq. 26

t_i is the temperature of the storage at the beginning of the night and it is calculated using Q_R from Eq. 11:

$$t_i = \frac{Q_R(2)}{V_S \rho_w c_{pw}} + t_{main}(2)$$

Eq. 27

Step 6: The daily hot water demand is calculated as follows:

Eq. 28 $Qd = V_{load}.\rho_w c_{pw}.(t_{load} - t_{main})$

Step 7: Sum Q_d value at the Q_d value of the day before.

Step 8: For the following days repeat the calculation procedure of day 2 starting at step 1. The equations are the same but changing the day index (i).

2.6.2.4 *Presentation of LTPP results*

The long term prediction results are presented for the reference locations, load volumes and conditions specified in EN 12976-2 Annex B.

Table 1. Example of LTPP for a solar thermal thermosiphon system with 4,17 m^2 collector area and 300 litre storage tank

Performance indicators for solar-only and solar preheat Systems on annual base for a demand volume of :				**300 l/day**
Location (latitude)	**Q_d [MJ]**	**Q_L [MJ]**	**f_{sol} [%]**	**Q_{par} [MJ]**
Stockholm (59.6°N)	16706	6482	38,8	--
Würzburg (49.5°N)	16020	7237	45,2	--
Davos (46.8°N)	18125	10245	56,5	--
Athens (38.0°N)	12450	9210	74,0	--

Q_d Hot water energy demand (load)
Q_L Enery delivered by the solar thermal system

$$Q_L = Q_{c(1)} + Q_{c(2)} + ... + Q_{c(n)}$$

Q_{par} Parasitic energy (electricity) for pump and controls
f_{sol} Solar fraction, $f_{sol}=Q_L/Q_d$

2.7 The DST test procedure

2.7.1 Test procedure

The dynamic system test (DST) procedure defined in ISO 9459-5 subjects the complete solar thermal system to a set of defined sequences under real outdoor test conditions. The test conditions and the systems answer to sequence specific load profiles are recorded during the test and evaluated after all sequences are finished.

During the evaluation the InSitu Scientific (ISS) Software is used to fit parameters of a numerical model representing a generic solar thermal system to the data collected during the test. Ideally the fitted numerical model generates the same system answer as the real solar thermal system if the recorded test conditions and draw-off profiles are used as input data. Once a parameter set has been determined, the input data may be changed to calculate a system answer during the long term performance prediction (LTPP) with standardised input data.

Since the numeric model determined with the DST method is independent of the used tapping cycles and climatic data during the test, there is no need to retest the product when evaluating it for different tapping cycles. However, the LTPP must be recalculated using the changed boundary conditions. The procedure for calculation and presentation of the performance indicators will be explained in the following.

2.7.2 Calculation procedure for LTPP acc. to EN 12976-2:2006

An important part of the evaluation of the system performance of a SDHW system according to EN 12976-2 consists of the calculation of the LTPP for all combinations of boundary conditions. These are mainly the reference locations and the reference load profiles. The reference locations for which the evaluation has to be performed are:

- Athens
- Davos
- Stockholm
- Wuerzburg

For each location a data set is provided containing the weather data of a reference year. Additionally the EN 12976-2 Annex B.3 defines a season dependent profile for the cold water temperature for each location.

The reference load profiles are given in the EN 12976-2 Annex B.1. The standard load profile allows only one draw-off with the whole daily load volume at 6 hours after solar noon. The daily load volume in litres per day must be chosen from the following series: 50 l/d, 80 l/d, 110 l/d, 140 l/d, 170 l/d, 200 l/d, 250 l/d, 300 l/d, 400 l/d and 600 l/d. Four load volumes must be chosen from this series, which lie between 0.5 and 1.5 times the design load stated by the manufacturer. The draw-off flow rate is defined as minimum of 10 l/min or the value stated by the manufacturer.

The main performance indicator for the LTPP is the solar fraction (f_{sol}) defined as follows in EN ISO 9488:

$$f_{sol} = \frac{Q_L}{Q_D}$$

Q_L: thermal energy delivered by the solar part of the system
Q_D: thermal energy demand

The solar fraction has to be extracted for each daily load volume and all locations. The results are presented as charts in the test report.

2.7.3 Application of the EU reference tapping cycles to the procedure of LTPP

Since the approach of the definition of the EU reference tapping cycles is different than the approach of the defined load profiles in the EN 12976, it is not possible to implement the EU reference tapping cycles into the described evaluation procedure. There are several differences that must be considered:

	EN 12976	EU reference tapping cycles
load profile definition	**one draw-off** per day	**distributed draw-offs** over a day, distribution differs between profiles

	daily load **volume**	daily withdrawn **energy** (Q_{ref} = sum(Q_{tap}))
hot water temperature	**constant** demand temperature (T_d = 45 °C)	**Combination** of min. hot water temp. (**T_m**) and peak temp. (**T_p**) **for each draw-off**
cold water temperature	**function** of season and location	**constant** (T_{cw} = 10 °C)
volume flow rate	**constant** (10 l/h)	minimal flow rate given **for each draw-off**

Since the evaluation is always performed with the InSitu Scientific Software (ISS), which is designed to be used with draw-off profiles defined according to the EN 12976, there are some issues that can't be resolved when implementing the EU reference tapping profiles. The limitations are:

- Only one value for the hot water temperature can be defined
- The total daily draw-off volume V_L must be specified
- Set point temperature and power for the auxiliary heating must be provided for solar plus supplementary systems
- Each draw-off is defined as f(t_{start}, d, f_v) with:
  - t_{start}: start time in hour of the day (e.g. 7.25 for 07:15)
  - d: duration of the draw-off in hours
  - f_v: volume fraction of the daily draw-off volume
- The volume fraction f_v must not be smaller than 0.01. Smaller draw-off volumes are considered as zero by the program ISS.

Due to the listed limitations the following procedure was developed within the QAiST project to apply the EU reference tapping cycles for SDHW systems.

1. T_{cw} is defined to be always constant: T_{cw} = 10°C
2. T_d is to be set to the highest value of peak temperature T_p and the minimum temperature T_m of the profile
3. V_L (daily load volume) shall be calculated with the total daily energy demand Q_{ref} given in each profile definition and the two temperatures T_{cw} and T_d (with constant heat capacity c_p = 4.19 kJ/kg/K acc. to ISS manual (DFM.pdf) and density ρ = 0.998 kg/m^3)

$$V_L = \frac{Q_{ref}}{c_p \cdot \rho \cdot (T_D - T_{cw})}$$

4. t_{start} (start time of a tapping) is calculated as fraction of the day in [h] (07:30 -> 7.5)
5. f_v (fractional volume function) is set to the fractional energy demand of each tapping:

$$f_v = \frac{Q_{tab}}{Q_{ref}}$$

6. d (duration of the tapping) is calculated with the minimal flow rate f (see tapping cycle profile) and the fractional volume f_v*V_L

$$d = \frac{f_V \cdot V_L}{f \cdot 60\left[\frac{\min}{h}\right]}$$

7. Set the operating conditions of the auxiliary heating to $T_{aux,set} = T_d +$ 2.5 K and the power of the auxiliary heater to P_{aux} = 15 kW (or acc. to manufacturer).

With the described methodology in the steps 1-7 the following sequencer files were created:

Profile	Implementation within the ISS sequencer file

XXS	`DailyLoadVol,120.527`
	`DemandTemp,25`
	`MainsTemp,10`
	`Aux,27.5,15E+03`
	`DrawOff,7,0.05,0.05`
	`DrawOff,7.5,0.05,0.05`
	`DrawOff,8.5,0.05,0.05`
	`DrawOff,9.5,0.05,0.05`
	`DrawOff,11.5,0.05,0.05`
	`DrawOff,11.75,0.05,0.05`
	`DrawOff,12,0.05,0.05`
	`DrawOff,12.5,0.05,0.05`
	`DrawOff,12.75,0.05,0.05`
	`DrawOff,18,0.05,0.05`
	`DrawOff,18.25,0.05,0.05`
	`DrawOff,18.5,0.05,0.05`
	`DrawOff,19,0.05,0.05`
	`DrawOff,19.5,0.05,0.05`
	`DrawOff,20,0.05,0.05`
	`DrawOff,20.75,0.05,0.05`
	`DrawOff,21,0.05,0.05`
	`DrawOff,21.25,0.05,0.05`
	`DrawOff,21.5,0.05,0.05`
	`DrawOff,21.75,0.05,0.05`

XS	`DailyLoadVol,72.316`
	`DemandTemp,35`
	`MainsTemp,10`
	`Aux,37.5,15E+03`
	`DrawOff,7.5,0.075,0.25`
	`DrawOff,12.75,0.075,0.25`
	`DrawOff,20.5,0.151,0.5`

S	`DailyLoadVol,40.176`
	`DemandTemp,55`
	`MainsTemp,10`
	`Aux,57.5,15E+03`
	`DrawOff,7,0.011,0.05`
	`DrawOff,7.5,0.011,0.05`
	`DrawOff,8.5,0.011,0.05`
	`DrawOff,9.5,0.011,0.05`
	`DrawOff,11.5,0.011,0.05`
	`DrawOff,11.75,0.011,0.05`
	`DrawOff,12.75,0.025,0.15`
	`DrawOff,18,0.011,0.05`
	`DrawOff,18.25,0.011,0.05`
	`DrawOff,20.5,0.033,0.2`
	`DrawOff,21.5,0.033,0.25`

M	`DailyLoadVol,111.823`
	`DemandTemp,55`
	`MainsTemp,10`
	`Aux,57.5,15E+03`

	DrawOff,7,0.011,0.018 DrawOff,7.083,0.075,0.24 DrawOff,7.5,0.011,0.018 DrawOff,8.017,0.011,0.018 DrawOff,8.25,0.011,0.018 DrawOff,8.5,0.011,0.018 DrawOff,8.75,0.011,0.018 DrawOff,9,0.011,0.018 DrawOff,9.5,0.011,0.018 DrawOff,10.5,0.011,0.018 DrawOff,11.5,0.011,0.018 DrawOff,11.75,0.011,0.018 DrawOff,12.75,0.025,0.054 DrawOff,14.5,0.011,0.018 DrawOff,15.5,0.011,0.018 DrawOff,16.5,0.011,0.018 DrawOff,18,0.011,0.018 DrawOff,18.25,0.011,0.018 DrawOff,18.5,0.011,0.018 DrawOff,19,0.011,0.018 DrawOff,20.5,0.059,0.126 DrawOff,21.25,0.011,0.018 DrawOff,21.5,0.074,0.238
L	DailyLoadVol,222.976 DemandTemp,55 MainsTemp,10 Aux,57.5,15E+03 DrawOff,7.5,0.011,0.009 DrawOff,7.083,0.074,0.12 DrawOff,7.5,0.011,0.009 DrawOff,7.75,0.011,0.009 DrawOff,8.083,0.115,0.309 DrawOff,8.417,0.011,0.009 DrawOff,8.5,0.011,0.009 DrawOff,8.75,0.011,0.009 DrawOff,9,0.011,0.009 DrawOff,9.5,0.011,0.009 DrawOff,10.5,0.011,0.009 DrawOff,11.5,0.011,0.009 DrawOff,11.75,0.011,0.009 DrawOff,12.75,0.025,0.027 DrawOff,14.5,0.011,0.009 DrawOff,15.5,0.011,0.009 DrawOff,16.5,0.011,0.009 DrawOff,18,0.011,0.009 DrawOff,18.25,0.011,0.009 DrawOff,18.5,0.011,0.009 DrawOff,19,0.011,0.009 DrawOff,20.5,0.059,0.063 DrawOff,21,0.115,0.309 DrawOff,21.5,0.012,0.01
XL2*	DailyLoadVol,364.835 DemandTemp,55 MainsTemp,10 Aux,57.5,15E+03 DrawOff,7,0.022,0.011 DrawOff,7.25,0.096,0.095 DrawOff,7.75,0.141,0.232 DrawOff,8.017,0.022,0.011 DrawOff,8.5,0.022,0.011 DrawOff,9,0.022,0.011 DrawOff,10,0.022,0.011 DrawOff,11,0.022,0.011 DrawOff,11.75,0.022,0.011 DrawOff,12.75,0.059,0.039 DrawOff,15,0.022,0.011 DrawOff,16,0.022,0.011 DrawOff,17,0.022,0.011 DrawOff,18.25,0.022,0.011 DrawOff,19,0.022,0.011

	DrawOff,20.5,0.059,0.039 DrawOff,20.767,0.141,0.232 DrawOff,21.5,0.133,0.219
XXL2*	DailyLoadVol,469.292 DemandTemp,55 MainsTemp,10 Aux,57.5,15E+03 DrawOff,7,0.026,0.01 DrawOff,7.25,0.096,0.074 DrawOff,7.75,0.124,0.254 DrawOff,8.017,0.026,0.01 DrawOff,8.5,0.026,0.01 DrawOff,9,0.026,0.01 DrawOff,10,0.026,0.01 DrawOff,10.5,0.026,0.01 DrawOff,11.5,0.026,0.01 DrawOff,12.75,0.059,0.03 DrawOff,14.5,0.026,0.01 DrawOff,15.5,0.026,0.01 DrawOff,16.5,0.026,0.01 DrawOff,18,0.026,0.01 DrawOff,18.5,0.026,0.01 DrawOff,20.5,0.059,0.03 DrawOff,20.767,0.121,0.247 DrawOff,21.5,0.199,0.255
3XL	DailyLoadVol,894.582 DemandTemp,55 MainsTemp,10 Aux,57.5,15E+03 DrawOff,7,0.075,0.24 DrawOff,8.017,0.067,0.108 DrawOff,9,0.022,0.036 DrawOff,10.5,0.011,0.018 DrawOff,11.75,0.022,0.036 DrawOff,12.75,0.034,0.054 DrawOff,15.5,0.025,0.054 DrawOff,18.5,0.045,0.072 DrawOff,20.5,0.059,0.126 DrawOff,21.5,0.08,0.256
4XL	DailyLoadVol,1789.163 DemandTemp,55 MainsTemp,10 Aux,57.5,15E+03 DrawOff,7,0.075,0.24 DrawOff,8.017,0.067,0.108 DrawOff,9,0.022,0.036 DrawOff,10.5,0.011,0.018 DrawOff,11.75,0.022,0.036 DrawOff,12.75,0.025,0.054 DrawOff,15.5,0.034,0.054 DrawOff,18.5,0.045,0.072 DrawOff,20.5,0.059,0.126 DrawOff,21.5,0.08,0.256

NOTE: The profiles marked with (*) are changed and not conform to the actual EU reference tapping profiles. The implementation of these profiles was not possible due to too small draw-off volume fractions. The problem was solved by merging two adjacent draw-offs into one with doubled volume fraction.

The listed sequencer files should be used as input for the LTPP and combined with the standard weather data for the reference locations. These profiles have been applied for a SDHW system tested before at ITW. The results will be presented in the Chapter 0.

2.7.4 Calculation of the energy efficiency of a solar thermal water heater tested acc. to EN 12976-2

The energy efficiency shown on the energy label has to be calculated according to the Annex VIII chapter 4 of the [working document on energy labelling]. Since the results of the simulation are given in different form, some changes to the suggested formula must be applied:

- Annual values are used for the calculation instead of daily values
- Distribution heat losses within the solar thermal system are already accounted in the solar fraction f_{sol} and are therefore set to 0.
- Since a generic backup heater is used for the calculation, it is assumed, that it has an efficiency of 1.

Under these changes the formula given in Annex VIII 4(a) changes to:

$$\eta_{wh} = \frac{E_{d,a}}{(1 - f_{sol})E_{d,a} + prim \cdot E_{aux,a}}$$

with:

$E_{d,a}$	Annual demand thermal energy in kWh
$E_{aux,a}$	Annual electric energy used for driving auxiliary components (mainly solar loop pump and controller) in kWh
prim	Primary energy conversion factor prim = 2.5 according to Annex VIII (3).

According to existing evaluation methods the annual auxiliary energy consumption is calculated with the following formula:

$$E_{ctrl,a} = 8760 \cdot P_{ctrl,mean,measured}$$

$$E_{pump,a} = 8760 \cdot P_{pump,mean,measured}$$

with:

$E_{ctrl,a}$	Annual electric energy consumption of the controller in kWh
$E_{pump,a}$	Annual electric energy consumption of the solar loop pump in kWh
$P_{ctrl,mean,measured}$	Mean measured power for controller operation in kW
$P_{pump,mean,measured}$	Mean measured power for pump operation in kW

Note: A more accurate procedure for the determination of the auxiliary energy consumption will be suggested as part of the work in the QAiST WP 3.2.

The annual primary energy used for driving auxiliary components shall be calculated as follows:

$$E_{aux,a} = E_{ctrl,a} + E_{pump,a}$$

The factors AFC and AEC shall be given as:

AFC $= (1 - f_{sol}) E_{d,a}$

AEC = $E_{aux,a}$

3 CSTG EU tapping cycles validation process

3.1 Solar system performance testing and conversion to energy labelling conditions

The solar thermal system test method CSTG (ISO 9459-2) is not mentioned as a testing procedure to be applied to solar only or preheat systems in the ecodesign/energy labelling directive, only the DST test method (ISO 9459-5) is mentioned. The CSTG test method is less used by European test labs due to its dependency on the weather conditions. For this reason the CSTG is more popular on south Europe or the Mediterranean area, where the weather conditions are more favourable. The DST method is less affected by the weather conditions and faster to obtain the number of required performance test days.

One of the QAIST project goals is to find a calculation approach to integrate the CSTG method as a valid procedure for the performance testing of solar preheat systems according to the EU energy labelling conditions and requirements. The first approach is to modify the CSTG LTPP calculation procedure in order integrating the EU reference tapping cycles and the reference input data with the obtained CSTG performance test results.

3.2 CSTG LTPP integration approach

The Long Term Performance Prediction (LTPP) is a day by day calculation procedure (chapter 2.6.2) that will be modified in order to integrate the EU reference load profiles (tapping cycles of the Ecodesign/Energy Labelling) to calculate the daily and annual energy sums. The new approach is basically the same CSTG LTPP calculation procedure but dividing the day in as many fractions as the number of tappings (water draw-offs) of a certain EU reference load profile instead of having a single draw-off of 100% of the load volume at 18h.

To get an overview of the principle for the LTPP modified procedure the following M profile day example is described.

For every tapping (j) of a day (i) the following values are computed:

- Temperature of the mixed storage tank $t_s(i,j+1)$
- Available energy fraction Q(i,j) and withdrawn energy fraction $Q_c(i,j)$
- For each day (i) the sums of Q(i,j) and $Q_c(i,j)$ are computed
- The solar radiation (H) is divided to be applied between draw-offs
- Meteo data in hourly values and interpolation for the values applied at each tapping

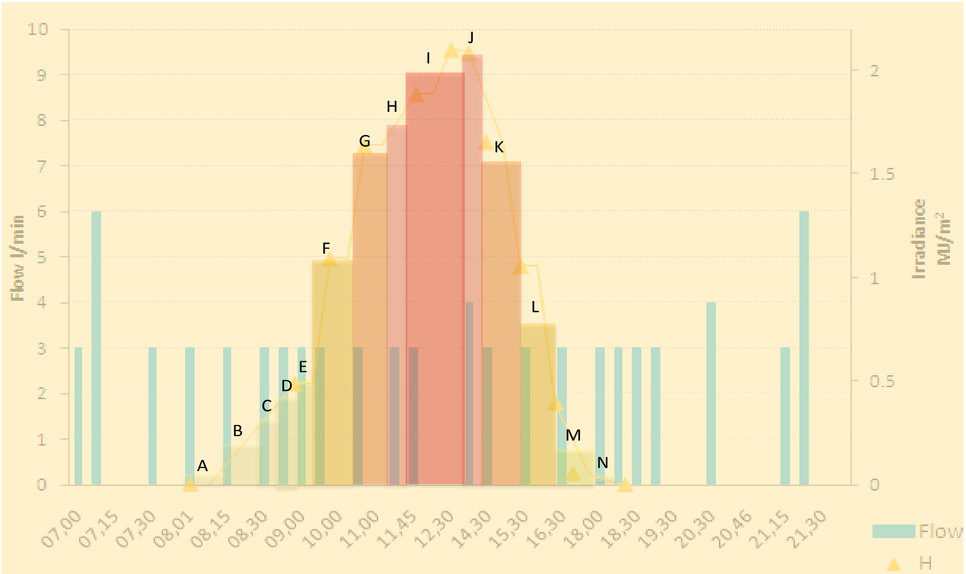

Figure 6 M profile day example for the LTPP calculation

Table 2 M profile day example for the LTPP calculation

	Tapping	Irradiance	Withdrawn volumes	Available daily energy	Daily energy withdrawn
Time	j	H	Vload_j	Q(i,j)	Qc(i,j)
07,00	1,2,3	0,0,0	F1*t1, F2*t2, F3*t3	Q(i,1:p2)+Q(i,2:p2)+Q(i,3:p2)	Qc(i,1:p2)+Qc(i,2:p2)+Qc(i,3:p2)
08,00	4,5,6,7	0,A,B,C	F4*t4, F5*t5, F6*t6,F7*t7	Q(i,4:p2)+Q(i,5:p1_A+p2)+Q(i,6:p1_B+p2)+Q(i,7:p1_C+p2)	Qc(i,4:p2)+Qc(i,5:p1+p2)+Qc(i,6:p1+p2)+Qc(i,7:p1+p2)
09,00	8,9	D,E	F8*t8, F9*t9	Q(i,8:p1_D+p2)+Q(i,9:p1_E+p2)	Qc(i,8:p1+p2)+Qc(i,9:p1+p2)
10,00	10	F	F10*t10	Q(i,10:p1_F+p2)	Qc(i,10:p1+p2)
11,00	11,12	G,H	F11*t11, F12*t12	Q(i,11:p1_G+p2)+Q(i,12:p1_H+p2)	Qc(i,11:p1+p2)+Qc(i,12:p1+p2)
12,00	13	I	F13*t13	Q(i,13:p1_I+p2)	Qc(i,13:p1+p2)
14,00	14	J	F14*t14	Q(i,14:p1_J+p2)	Qc(i,14:p1+p2)
15,00	15	K	F15*t15	Q(i,15:p1_K+p2)	Qc(i,15:p1+p2)
16,00	16	L	F16*t16	Q(i,16:p1_L+p2)	Qc(i,16:p1+p2)
18,00	17,18,19	M,N,0	F17*t17, F18*t18, F19*t19	Q(i,17:p1_M+p2)+Q(i,18:p1_N+p2)+Q(i,19:p2)	Qc(i,17:p1+p2)+Qc(i,18:p1+p2)+Qc(i,19:p2)
19,00	20	0	F20*t20	Q(i,20:p2)	Qc(i,20:p2)
20,00	21	0	F21*t21	Q(i,21:p2)	Qc(i,21:p2)
21,00	22,23	0,0	F22*t22, F23*t23	Q(i,22:p2)+Q(i,23:p2)	Qc(i,22:p2)+Qc(i,23:p2)

Table notes:

- Fj: are the tapping flows,
- tj: tapping time intervals
- Q(i,11:p1_G+p2): Available energy during tapping 11, p1_G= is part1 equation where the irradiance sum (G) is applied, p2 = is part2 equation computing the energy left from the previous tapping
- Qc(i,5:p1+p2): Energy withdrawn during tapping 5, p1 is part1 equation and p2 is part2
- After the last tapping of the day(i) the Q_R and Q_{LOS} are calculated and also the mixed storage temperature for next day $t_s(i+1,j)$

3.3 Implementation process of CSTG LTPP approach

To set up the CSTG LTPP new approach which is compatible with the EU reference load profiles for Energy Labelling an implementation process has been developed.

This process was divided two phases; the first phase mainly includes:

- The development of a new CSTG LTPP algorithm (in R[6]) which adds a new calculation loop for computing the fraction of energy available Q(i,j) and the fraction of energy withdrawn Q_c(i,j) for every tapping and its daily sums
- The generation of hourly meteorological data files for the reference ambient conditions, climates: Average (A), Cold (C), Warm (W)
- Check the consistency of the CSTG LTPP input data and demand parameters like T_m and T_p with the new calculation algorithm

The second phase was dedicated to the analysis and validation of the CSTG LTPP approach results and includes:

- Check the accuracy of this calculation method, specially the influence of small values of H applied at the system performance equation Q obtained from the CSTG performance test:

$$Q(i,j:part1) = a_1 H(i,j) + a_2 \left(t_{a(day)}(i,j) - t_s(i,j)\right) + a_3$$

- Validation of the LTPP – R algorithm results with the TRNSYS simulation results for a thermosiphon system

- Validation of the LTPP – R algorithm results with the In-situ DST-LTPP results integrating the EU reference load profiles for the same thermosiphon system

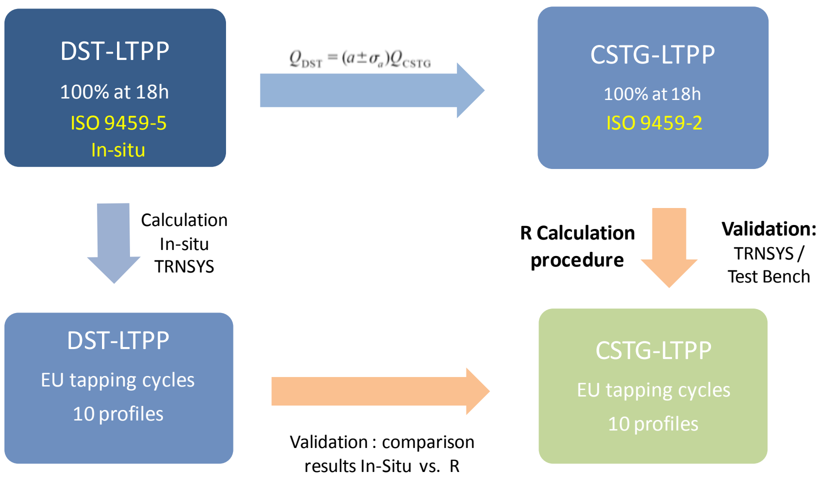

Figure 7 Implementation process of the CSTG LTPP approach[7]

[6] R is a free software environment for statistical computing and graphics. http://www.r-project.org/

[7] COMPARISON OF TEST METHODS FOR EVALUATION OF THERMAL PERFORMANCE OF PREHEAT AND SOLAR-ONLY FACTORY MADE SYSTEMS, M.J.CARVALHO, D.J.NARON

3.4 CSTG LTPP - R implementation

A detailed description of the CSTG LTPP approach implementation to integrate the EU tapping cycles is provided. As previously mentioned the daily and annual energy gained by the solar thermal system can be described as follows:

$Q_1 = Q_{tap1} + Q_{tap2} + \ldots + Q_{tapn}$ → The daily energy gained by the system is the result of adding the energy from each tapping (tap_1 to tap_n) within a day.

$Q = Q_1 + Q_2 + \ldots + Q_{365}$ → The annual energy gained is the sum of the previous calculated daily energy values for every day of the year.

3.4.1 Input data and hypothesis

3.4.1.1 CSTG test results and system technical features

The following test results are necessary as inputs:

- The thermal performance equation of the solar system (Eq.2)
- f(V): the normalized draw-off temperature profile (Eq. 3) The f (V) values are known each tenth of the storage tank volume (V_s) and interpolated among them every V_s centh. The f (V) values are given for the daily irradiance ranges: from 8 MJ/m^2 to 16 MJ/m^2 and from 16 MJ/m^2 to 25 MJ/m^2.
- g(V): the normalized mixing draw-off profile, (Eq. 4) expressed as a function of the storage tank extracted volume, The g(V) values are known each V_s tenth and interpolated among them every V_s centh.
- The heat loss coefficient of the storage tank (U_S), in W/K.
- The technical features of SolaHart 180J thermosiphon system (TS), same TS system used for the QAIST Round Robin performance test

3.4.1.2 Climate data

The climate data used is grouped in two different sets. The first set uses Meteonorm data for the reference locations stated in the EN 12976-2 Annex B, plus the locations of Seville and Lisbon.

The second set of climate data is the generation of the artificial climate data using as a base the daily hour distribution for the global solar irradiance and the average temperatures according to the Annex VII Tables 3 and 4 of the energy labelling document[8].

[8] Working Document COMMISSION DELEGATED REGULATION (EU) No …/.. of […] implementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of water heaters and hot water storage tanks. 23 June 2010.

The annual data is generated for the Average, Colder and Warmer climate conditions taking into account the daily solar radiation distribution from the real climate data for the Cold (Helsinki), Average (Strasbourg) and Warm (Athens) climates and adjusting the monthly mean values to the previous Annex VII tables.

Once the climate data sets are obtained, the following values must be calculated within the R-algorithm:

- "$t_{a(tap)}$", average ambient temperature between two tappings, calculated from the hourly ambient temperatures read from the climate data file for each day. This value can be rounded down and is the result of averaging the mean temperatures of two consecutive tappings
- H (H_{first}, H_{ini}, H_{mid}, H_{end} and also H_1, H_2, H_3, H_4 y H_5), is the sum of the hourly global solar radiation on the collector plane (H in MJ/m^2) for the time of the day considered.
  - H_{first}, is the accumulated solar radiation till the beginning of the calculation process.
  - H_{ini} is the accumulated solar radiation till 11:45h of the calculation day considered.
  - H_{mid} is the accumulated solar radiation till 12:45h of the calculation day considered.
  - H_{end}, is the accumulated solar radiation at the end of the calculation day considered.
  - H_1, is the accumulated solar radiation from the beginning of the calculation till 11h.
  - H_2, is the accumulated solar radiation from 11h till 12h.
  - H_3, is the accumulated solar radiation from 12h till 12:45h.
  - H_4, is the accumulated solar radiation from 12:45h till 13:45h
  - H_5, is the accumulated solar radiation from 13:45h till the end of the day
- Cold water temperature (t_{main}) constant for the whole year at 10ºC.
- t_m, "useful water temperature" means the water temperature for which hot water is contributing to the reference heat.
- t_p, "peak temperature", means the minimum water temperature to be achieved during water draw-off
- t_h, draw-off limit water temperature, maximum value between t_m and t_p.
- $T_{a(tapn+1)}$, is the ambient temperature at the beginning of the next tapping.
- t_i, storage tank average temperature at the end of the tapping under consideration.
- t_s, is the water temperature at the beginning of the next tapping.

- t_d, is the water temperature of the storage tank after draw-off a certain water volume.

3.4.1.3 *Reference load profiles used*

The reference load profiles used are according to the Annex VII Table 1of the energy labelling document[9]

The reference load profiles are defined by the following set of parameters:

- 10 different profiles: 3XS, XXS, XS, S, M, L, XL, XXL, 3XL y 4XL.
- Draw-off initial time: 0:00h.
- Q_{tap}, "useful energy content", energy content of water provided at temperature equal to, or above, the useful temperature, and at flow rates equal to, or above, the useful water flow rate.
- f, minimum water flow rate (l/min).
- t_m and t_p.
- Q_{ref}, "reference energy", is the sum of the energy content of water draw offs in a specific load profile.

3.4.2 Calculation procedure

3.4.2.1 *First tapping calculation steps and hypothesis*

First tapping input data and related conditions:

- Accumulated solar radiation till the beginning of the calculation process (H_{first});
- Average ambient temperature the beginning of the tapping ($t_{a(tap)}$).
- Cold water temperature (t_{main}=10ºC).
- Useful water temperature (t_m).
- Peak temperature (t_p).
- Tapping useful energy content (Q_d=Q_{tap}).
- Load water volume for each tapping (V_{demand}). It is variable because is related with t_{main}, t_m, t_p and t_d and Q_d.

Step1: Energy available at the beginning of the first tapping

The total energy available at the system at the beginning of the tapping it is calculated as follows:

$$Q_i = a_1 H_{first} + a_2 \left(t_{a(tap)} - t_{main}\right)$$

(The parameter a_3 from Eq. 2 is only considered at the last tapping of the day)

Step 2: Draw-off volume to reach the minimum temperature limit

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[9] Working Document COMMISSION DELEGATED REGULATION (EU) No …/.. of […] implementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of water heaters and hot water storage tanks. 23 June 2010.

Due to the temperature limit for extracting hot water from the storage tank, the maximum volume draw-off has to be calculated using f(V) which gives the instantaneous energy as a function of the hot water volume drawn off:

$$t_d(V) = t_{main} + \frac{Q_i \cdot f(V)}{0.1 \cdot V_S \cdot \rho_w \cdot c_{pw}}$$

The volume that can be consumed at the tapping (V_p), is calculated determining the maximum volume where the resulting $t_d > t_h$ (maximum value between tm and t_p)

"0,1·V_s" is referring to a tenth of the storage tank volume and $V_p = \Sigma 0{,}1 * Vs$ (is the sum of storage volume tenths till $t_d > t_h$).

Step 3: Energy drawn off in the tapping

The energy Q_c contained in the extracted volume V_{ext} is calculated with the f(V) profile integrated from V=0 till V=volume to be extracted.

The volume to be extracted is determined according to the following conditions:

1- If $V_p > V_{demand} \rightarrow V_c = V_{demand}$
2- If $V_p \leq V_{demand} \rightarrow V_c = V_p$

where:

$$V_{demand} = \frac{Q_d}{c_w \cdot \rho_{pw} \cdot (t_m - t_{main})}$$

According to this the energy contained in the extracted volume of the tapping is calculated as follows:

$$Q_c = Q_i * \int_0^{V_c} f(V) \cdot dV = Q_i * \sum f(V)$$

Step 4: Energy remaining in the storage tank

Remaining energy in the storage tank once V_c is drawn off:

$$Q_R = Q_i - Q_c$$

Step 5: Energy loss between tappings

The energy lost between tappings is calculated using the thermal loss coefficient of the storage tank (U_s), doing this it is possible to know the energy at the beginning of next tapping. It is considered that for next tapping the storage tank is completely mixed at uniform temperature t_s (calculated with Eq. 12). The energy lost between tappings Ql_{os} is based on Eq. 13,

$$Q_{los} = \frac{V_s}{10^6} * \rho_w * c_{pw} * [t_i - t_{fol}] * \left[1 - \exp\left(-\frac{U_S * \Delta t}{V_S * \rho_w * c_{pw}}\right)\right]$$

where:

ΔT, time period between tappings

t_i, the storage tank average temperature at the end of the tapping, calculated with Eq. 14

t_{fol}, average ambient temperature between two consecutive tapping.

If during the first tapping no water has been drawn off, the t_i and t_S temperature values are the same and the thermal losses between the first and second tapping are almost zero.

$$\text{If} \quad V_{ext} = 0 \rightarrow t_i = t_s \quad \text{y} \quad Q_{los} \approx 0$$

3.4.2.2 Second and following tapping calculation steps and hypothesis

The initial conditions for the second tapping are:

- Average ambient temperature between tappings ($t_{a(tap)}$).
- Cold water temperature (t_{main}=10ºC).
- Useful water temperature (t_m).
- Peak temperature (t_p).
- Tapping useful energy content (Q_d=Q_{tap}).
- Load water volume for each tapping (V_{demand}). It is variable because is related with t_{main}, t_m, t_p and t_d and Q_d.
- Accumulated solar radiation till the moment of the tapping under calculation (H_{ini}, H_{mid} y H_{fin}) (or H_1, H_2, H_3, H_4 y H_5) according to the the following hypothesis:

    - Hypothesis 1: For the calculation process it is considered that the whole daily solar radiation is applied at the end of the day (H_{fin}). The purpose of this hypothesis is to have a calculation process as similar as the CSTG LTPP without the influence of low radiation values for the system performance equation (Eq.2).

    - Hypothesis 2: For the calculation process it is considered that the whole daily solar radiation is divided in two parts. The first part is applied around midday (H_{mid}) and the other at the end of the day (H_{fin}). In this case H_{mid} is the solar radiation accumulated till 12:45h H_{fin} is the solar radiation accumulated from 12:45h to the end of the day. The purpose of this hypothesis is to check the influence of low radiation values for the system performance equation (Eq.2).

    - Hypothesis 3: For the calculation process it is considered that the whole daily solar radiation is divided in three parts

(H_{ini}, H_{mid} and H_{fin}). Hypothesis to check further the influence of low radiation values for the system performance equation (Eq.2).

- Hypothesis 4: For the calculation process it is considered that the whole daily solar radiation is divided in five parts. H_1, is the accumulated solar radiation from the beginning of the calculation till 11h. H_2, is the accumulated solar radiation from 11h till 12h. H_3, is the accumulated solar radiation from 12h till 12:45h. H_4, is the accumulated solar radiation from 12:45h till 13:45h.H_5, is the accumulated solar radiation from 13:45h till the end of the day. The purpose of this hypothesis is to check the influence of very low radiation values for the system performance equation (Eq.2).

The system will start the second tapping at t_s temperature, as it was calculated in the first tapping with $t_s > t_{main}$.

Step1: Energy available at the beginning of the second tapping

In this step two calculation variants can be considered depending if in the previous tapping some water volume has been extracted or not.

<u>Variant 1 – Hot water volume extracted</u>:

One part of the energy gained by the system will be due to the refilling with water at the initial temperature of t_s.

$$Q_{ip1} = a_1 H + a_2 \left(t_{a(day)} - t_s\right)$$

In this case H is determined according to the divisions previously explained in the hypothesis from the initial conditions. For example, if the accumulated radiation is applied in two parts, 12:45h and the end of the day, and assuming that the second tapping is at 12:45h, $H=H_{mid}$ and the previous equation results in:

$$Q_{ip1} = a_1 H_{mid} + a_2 \left(t_{a(day)} - t_s\right)$$

A part from that, for calculating the total energy gained is necessary to calculate add the part of energy gained at the end of the day (H_{fin}) and adding the "a_3" coefficient at the system equation, as follows:

$$Q_{ip1} = a_1 H_{fin} + a_2 \left(t_{a(day)} - t_s\right) + a_3$$

The other part of system energy gained (part 2) is due to the fact that the system is filled with cold water at $t_{main} < t_s$. This energy is obtained by applying Eq. 17:

$$Q_{ip2} = \frac{V_s}{10^6} * \rho_w * c_{pw} * (t_s - t_{main})$$

The total energy gain by the systems is:

$$Q_i = Q_{ip1} + Q_{ip2}$$

The same procedure can be applied at the rest of the tappings of a reference load profile whenever in the previous tapping water has been extracted from the storage tank.

Variant 2 – Hot water volume not extracted:

In the case that no water volume has been drawn off in the previous tapping the system energy gained is calculated slightly different.

The first part of the equation (Q_{ip1}) is calculated in the same way as variant 1. The second part of the equation (Q_{ip2}) calculated in a different way because the system has not been filled with cold water, it will be calculated based on the energy available at the previous tapping (Q_R) and deducting the thermal losses between tappings, resulting in:

$$Q_i = Q_{ip1} + Q_{ip2} = Q_{ip1} + Q_R - Q_{los}$$

If no radiation has to be considered in the calculation tapping ($H \neq H_{ini}$, H_{mid} o H_{fin}), the total energy gained by the system in the tapping will be:

$$Q_i = Q_{ip1} + Q_{ip2} = Q_R - Q_{los}$$

Once again the same procedure can be applied at the rest of the tappings whenever in the previous tapping no water has been extracted from the storage tank.

Step 2: Draw-off volume to reach the minimum temperature limit

In this step, again two calculation variants can be considered depending if in the previous tapping some water volume has been extracted or not.

Variant 1 – Hot water volume extracted:

The equation to calculate the maximum volume to be drawn off as function of the temperature limit will have two parts, resulting in:

$$t_d = t_{main} + \frac{Q_{ip1} * f(V)}{0.1 * V_s * \rho_w * c_{pw}} + \frac{Q_{ip2} * g(V)}{0.1 * V_s * \rho_w * c_{pw}}$$

As previously explained, the volume that can be consumed at the tapping (V_p), is calculated determining the maximum volume where the resulting t_d > t_h (maximum value between t_m and t_p).

Variant 2 – Hot water volume not extracted:

t_d and V_p will be determined in the same way as the first tapping.

This procedure will be the same for the following tappings after the second.

Step 3: Energy drawn off in the tapping

As in the previous step, two calculation variants can be considered depending if in the previous tapping some water volume has been extracted or not.

Variant 1 – Hot water volume extracted:

The volume to be extracted is determined according to the following conditions:

1- If $V_p > V_{demand} \rightarrow V_c = V_{demand}$
2- If $V_p \leq V_{demand} \rightarrow V_c = V_p$

where: $$V_{demand} = \frac{Q_d}{c_w \cdot \rho_{pw} \cdot (t_m - t_{main})}$$

Because part of the energy contained in the extracted volume is Q_{ip1}, such energy related with Q_c is calculated with the f(V) profile integrated from V=0 to V= V_c.

$$Q_{cp1} = Q_{ip1} * \int_0^{V_c} f(V) dV = Q_{ip1} * \sum f(V)$$

The part of the extracted energy from V_c (energy Q_c related to Q_{ip2}) is calculated using the mixing profile g(V).

$$Q_{cp2} = Q_{ip2} * \int_0^{V_c} g(V) dV = Q_{ip2} * \sum g(V)$$

Finally, the total energy gained/extracted is:

$$Q_c = Q_{cp1} + Q_{cp2}$$

This procedure will be the same for the following tappings after the second.

Variant 2 – Hot water volume not extracted:

The calculation procedure will be the same as the first tapping

Step 4: Energy remaining in the storage tank

Remaining energy in the storage tank once V_c is extracted:

$$Q_R = Q_i + Q_c$$

This procedure will be the same for the following tappings after the second.

Step 5: Energy loss between tappings

Variant 1 – Hot water volume extracted:

The energy lost between tappings is calculated in the same way as first tapping.

Variant 2 – Hot water volume not extracted:

If during the first tapping no water has been drawn off, the t_i and t_S temperature values are the same and the thermal losses between the second and third tapping are almost zero.

This procedure will be the same for the following tappings after the second.

3.4.2.3 Rest of LTPP calculation days

For the rest of the LTPP calculation days the same calculation procedure is repeated starting from tapping 1- Step 1

3.4.3 Results

3.4.3.1 Meteonorm climate data set

Hypothesis 1: Whole solar radiation applied at the end of the day

The long term prediction results are presented for the reference locations Seville and Lisbon, and the 10 reference load profiles: 3XS, 2XS, XS, S, M, L, XL, 2XL, 3XL and 4XL. The whole solar radiation is applied at the last tapping of the day. The following annual magnitudes are calculated as LTPP - R results:

Q_d Hot water energy demand (load)

Q_L Enery delivered by the solar thermal system

f_{sol} Solar fraction, $f_{sol}=Q_L/Q_d$

The following table and figure show the solar fraction results of the LTPP-R calculation procedure for the whole daily radiation (All Radiation) applied at the end of the day.

Table 3 Solar fraction LTPP- R results for All Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Stockholm	47,16	36,04	28,93	23,33	18,21	7,56	6,00	4,54	2,58	1,29
Würzburg	56,36	43,41	34,48	28,05	21,92	9,01	7,22	5,47	3,09	1,55
Davos	59,19	42,40	34,91	29,14	21,15	8,51	6,73	5,16	2,88	1,44
Athens	86,39	71,59	62,71	47,47	40,48	17,69	13,97	10,52	6,12	3,06
Seville	94,96	84,93	76,04	55,86	48,37	21,48	16,87	12,72	7,40	3,70
Lisbon	91,51	80,25	70,22	52,29	44,77	19,43	15,36	11,55	6,67	3,33

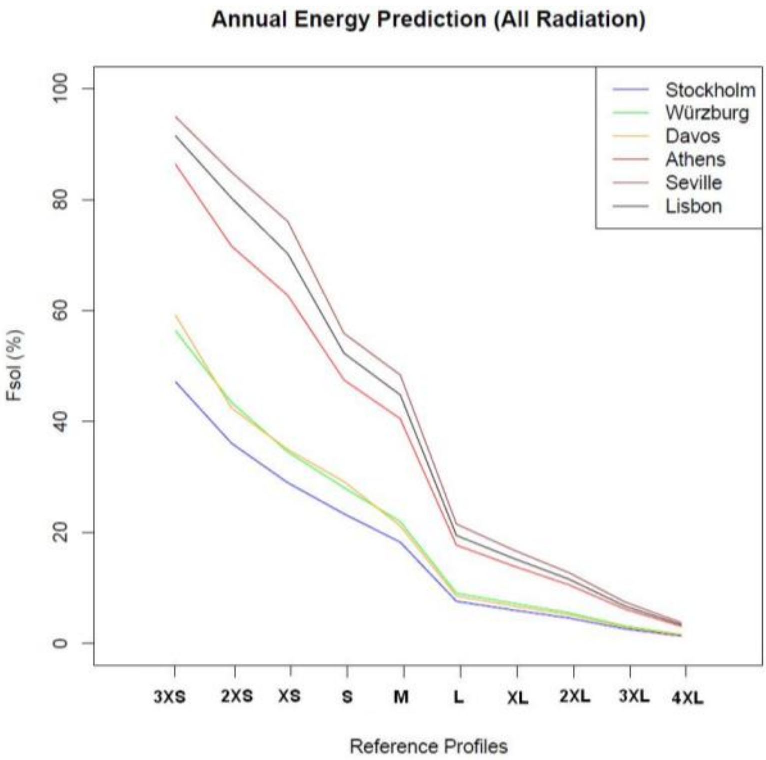


Figure 8 Solar fraction results for LTPP-R calculation (All Radiation)

<u>Hypothesis 2: Whole solar radiation divided in two parts</u>

It is considered that the whole daily solar radiation is divided in two parts. The first part is applied around midday (H_{mid}) and the other at the end of the day (H_{fin}). In this case H_{mid} is the solar radiation accumulated till 12:45h H_{fin} is the solar radiation accumulated from 12:45h to the end of the day.

The long term prediction results are presented for the reference locations Seville and Lisbon, and the 10 reference load profiles. The following table and figure show the solar fraction results of the LTPP-R calculation procedure of the whole daily radiation divided and applied in two parts (Half Radiation).

Table 4 Solar fraction LTPP- R results for Half Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Stockholm	34,32	29,05	11,59	10,16	8,47	4,80	3,50	2,54	1,76	0,88
Würzburg	44,26	36,73	15,50	14,97	11,66	6,18	4,56	3,34	2,29	1,15
Davos	37,65	30,33	10,62	8,97	8,32	4,51	3,41	2,39	1,75	0,87
Athens	71,89	65,79	40,22	34,25	25,77	13,84	10,23	7,80	5,24	2,62
Seville	87,11	78,70	52,04	44,12	34,21	16,76	12,79	9,68	6,33	3,17
Lisbon	81,37	73,60	46,13	38,15	29,88	13,72	10,72	8,02	5,26	2,63

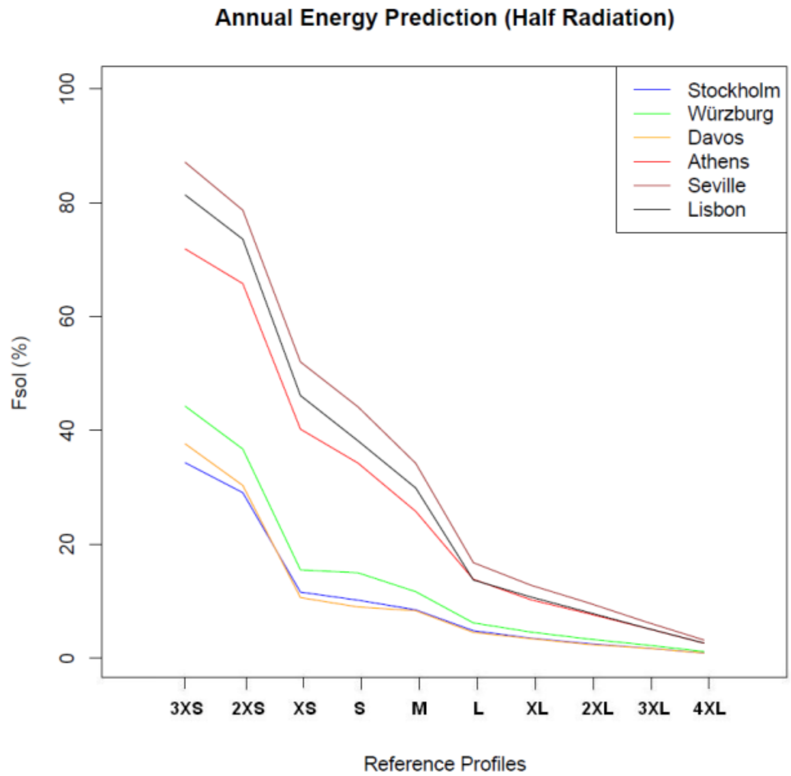


Figure 9 Solar fraction results for LTPP-R calculation (Half Radiation)

Hypothesis 3: Whole solar radiation divided in three parts

It is considered that the whole daily solar radiation is divided in three parts (H_{ini}, H_{mid} and H_{fin}). The long term prediction results are presented for the reference locations Seville and Lisbon, and the 10 reference load profiles. The following table and figure show the solar fraction results of the LTPP-R calculation procedure of the whole daily radiation divided and applied in three parts(1/3 Radiation).

Table 5 Solar fraction LTPP- R results for 1/3 Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Stockholm	24,83	19,10	0,29	6,38	6,16	2,32	1,75	1,24	1,21	0,60
Würzburg	33,96	27,03	1,94	9,88	8,97	3,60	2,73	1,94	1,67	0,84
Davos	21,30	15,56	0,00	5,34	5,38	1,88	1,38	0,99	0,97	0,49
Athens	61,88	56,99	15,66	23,01	20,43	8,95	6,82	5,01	4,35	2,18
Seville	75,87	67,26	27,00	33,01	27,89	11,71	9,22	6,83	5,21	2,61
Lisbon	70,64	61,22	19,07	27,88	24,17	9,70	7,90	5,78	4,13	2,06

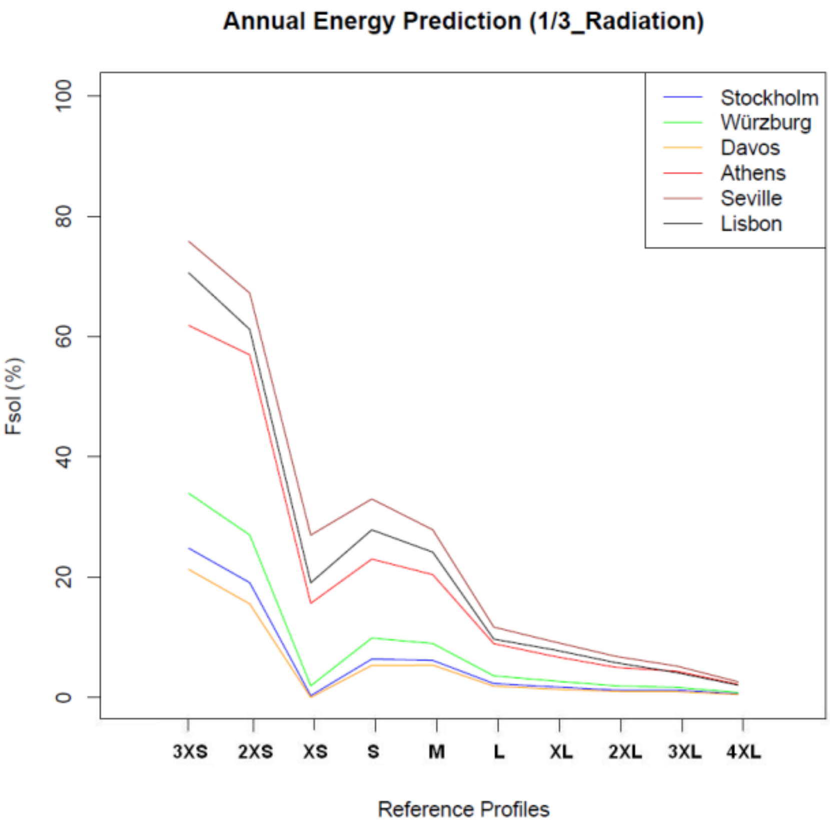


Figure 10 Solar fraction results for LTPP-R calculation (1/3 Radiation)

Hypothesis 4: Whole solar radiation divided in five parts

It is considered that the whole daily solar radiation is divided in five parts. H_1= is the accumulated solar radiation from the beginning of the calculation till 11h. H_2, is the accumulated solar radiation from 11h till 12h. H_3, is the accumulated solar radiation from 12h till 12:45h. H_4, is the accumulated solar radiation from 12:45h till 13:45h. H_5, is the accumulated solar radiation from 13:45h till the end of the day. The long term prediction results are presented for the reference locations Seville and Lisbon, and the 10 reference load profiles. The following table and figure show the solar fraction results of the LTPP-R calculation procedure of the whole daily radiation divided and applied in five parts (1/5 Radiation).

Table 6 Solar fraction LTPP- R results for 1/5 Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Stockholm	12,96	10,18	0,00	4,21	3,18	1,21	0,95	0,72	0,50	0,25
Würzburg	23,35	18,78	0,28	7,34	5,86	2,39	1,89	1,39	0,90	0,45
Davos	9,63	7,85	0,00	3,01	2,19	0,85	0,74	0,56	0,28	0,14
Athens	53,90	49,51	5,90	18,04	16,28	7,14	5,44	3,89	3,08	1,54
Seville	64,83	59,26	10,98	24,63	21,16	8,87	7,23	5,28	3,70	1,85
Lisbon	58,48	51,52	6,55	21,05	17,40	7,48	5,97	4,33	2,60	1,30

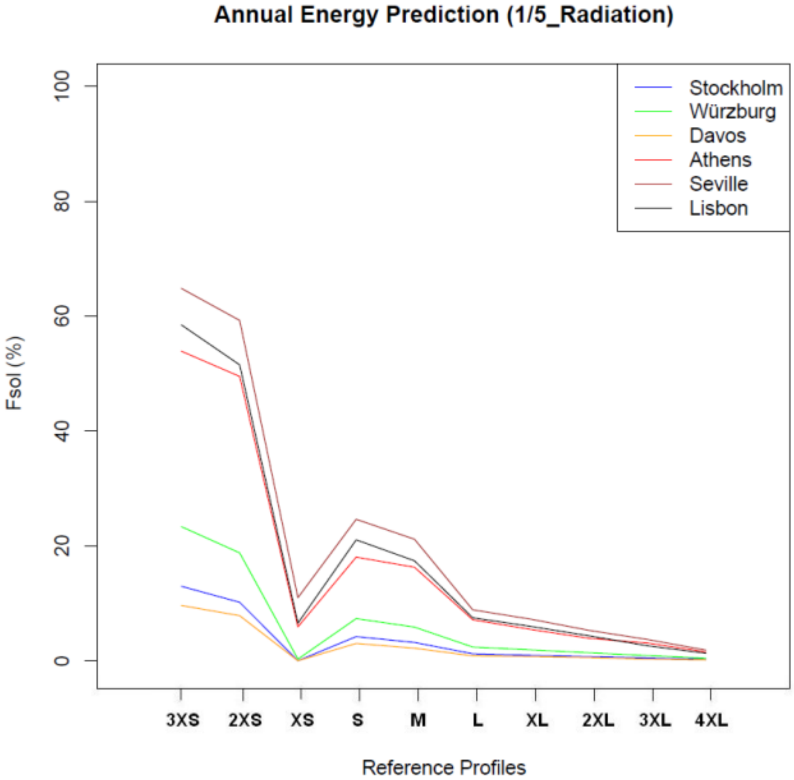


Figure 11 Solar fraction results for LTPP-R calculation (1/5 Radiation)

3.4.3.2 Ecodesign climate data set (Average, Cold and Warm)

<u>Hypothesis 1: Whole solar radiation applied at the end of the day</u>

The long term prediction results are presented for the reference Average, Cold and Warm climates and the 10 reference load profiles. The whole solar radiation is applied at the last tapping of the day. The following table and figure show the solar fraction results of the LTPP-R calculation procedure for the whole daily radiation (All Radiation) applied at the end of the day.

Table 7 Solar fraction LTPP- R results for All Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Average climate	60,26	50,07	41,74	32,40	26,59	11,40	9,05	6,82	3,93	1,96
Cold climate	45,43	37,01	30,53	23,78	19,17	8,10	6,42	4,85	2,77	1,39
Warm climate	84,72	70,90	62,36	48,70	41,99	18,84	14,68	11,04	6,51	3,25

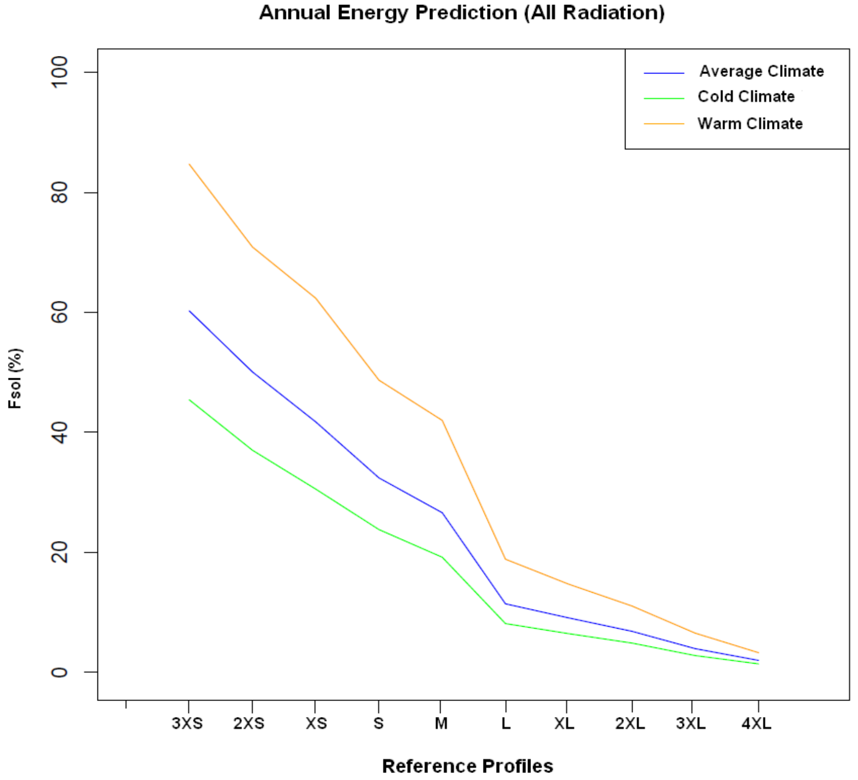


Figure 12 Solar fraction results for LTPP-R calculation (All Radiation)

<u>Hypothesis 2: Whole solar radiation divided in two parts</u>

The long term prediction results are presented for the reference Average, Cold and Warm climates and the 10 reference load profiles.

The following table and figure show the solar fraction results of the LTPP-R calculation procedure of the whole daily radiation divided and applied in two parts(Half Radiation).

Table 8 Solar fraction LTPP- R results for Half Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Average climate	51,36	44,59	23,98	21,63	16,31	8,38	6,36	4,73	3,19	1,59
Cold climate	36,79	31,82	14,69	12,62	9,89	5,75	4,13	3,05	2,16	1,08
Warm climate	71,00	65,74	43,17	38,38	28,17	15,02	11,18	8,55	5,75	2,87

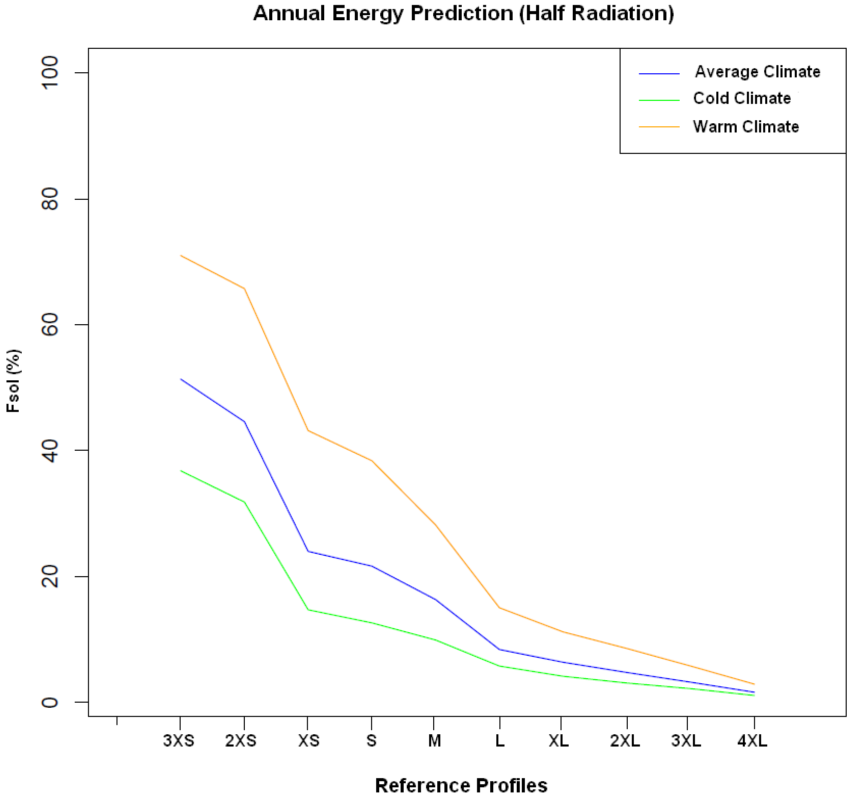


Figure 13 Solar fraction results for LTPP-R calculation (Half Radiation)

Hypothesis 3: Whole solar radiation divided in three parts

It is considered that the whole daily solar radiation is divided in three parts (H_{ini}, H_{mid} and H_{fin}).

The long term prediction results are presented for the reference Average, Cold and Warm climates and the 10 reference load profiles. The following table and figure show the solar fraction results of the LTPP-R calculation procedure of the whole daily radiation divided and applied in three parts(1/3 Radiation).

Table 9 Solar fraction LTPP- R results for 1/3 Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Average climate	43,20	36,40	7,09	15,16	13,17	5,41	4,24	3,10	2,48	1,24
Cold climate	29,84	25,05	0,79	8,32	7,84	3,17	2,42	1,69	1,61	0,80
Warm climate	62,05	57,79	21,92	26,62	22,77	10,01	7,73	5,77	4,80	2,41

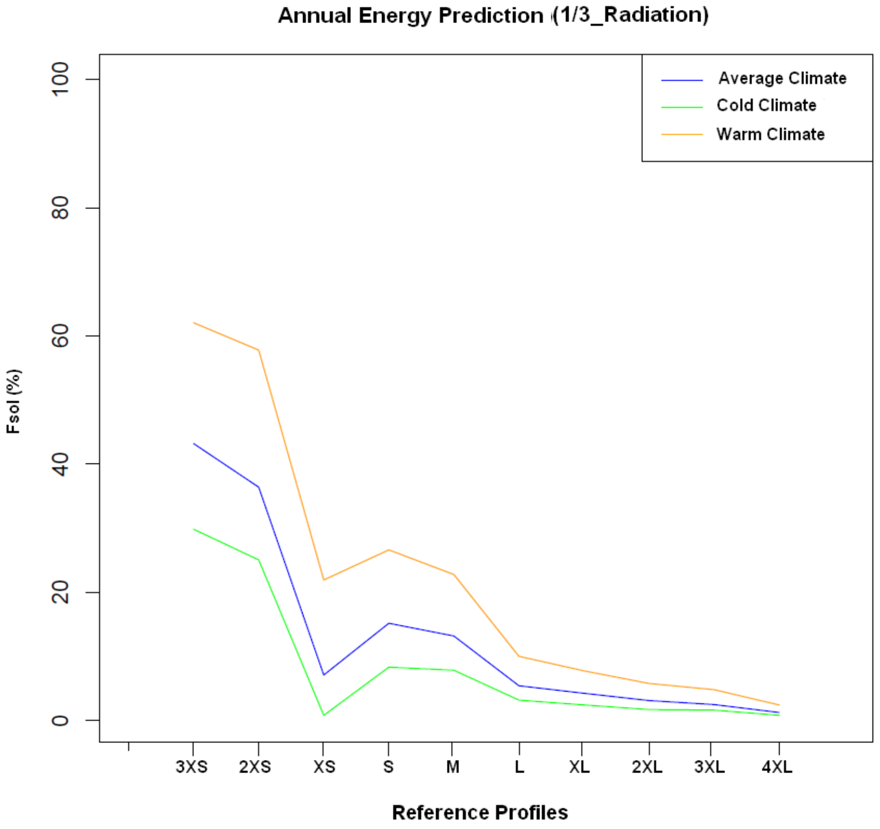


Figure 14 Solar fraction results for LTPP-R calculation (1/3 Radiation)

<u>Hypothesis 4: Whole solar radiation divided in five parts</u>

it is considered that the whole daily solar radiation is divided in five parts. H_1= is the accumulated solar radiation from the beginning of the calculation till 11h. H_2, is the accumulated solar radiation from 11h till 12h. H_3, is the accumulated solar radiation from 12h till 12:45h. H_4, is the accumulated solar radiation from 12:45h till 13:45h. H_5, is the accumulated solar radiation from 13:45h till the end of the day.

The long term prediction results are presented for the reference Average, Cold and Warm climates and the 10 reference load profiles. The following table and figure show the solar fraction results of the LTPP-R calculation procedure of the whole daily radiation divided and applied in five parts(1/5 Radiation).

Table 10 Solar fraction LTPP- R results for 1/5 Radiation

fsol	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Average climate	34,36	29,51	2,36	11,07	9,53	4,07	3,17	2,29	1,60	0,80
Cold climate	20,98	17,08	0,00	6,18	5,30	2,13	1,66	1,20	0,92	0,46
Warm climate	54,96	51,44	9,55	19,68	17,69	7,79	5,95	4,28	3,56	1,78

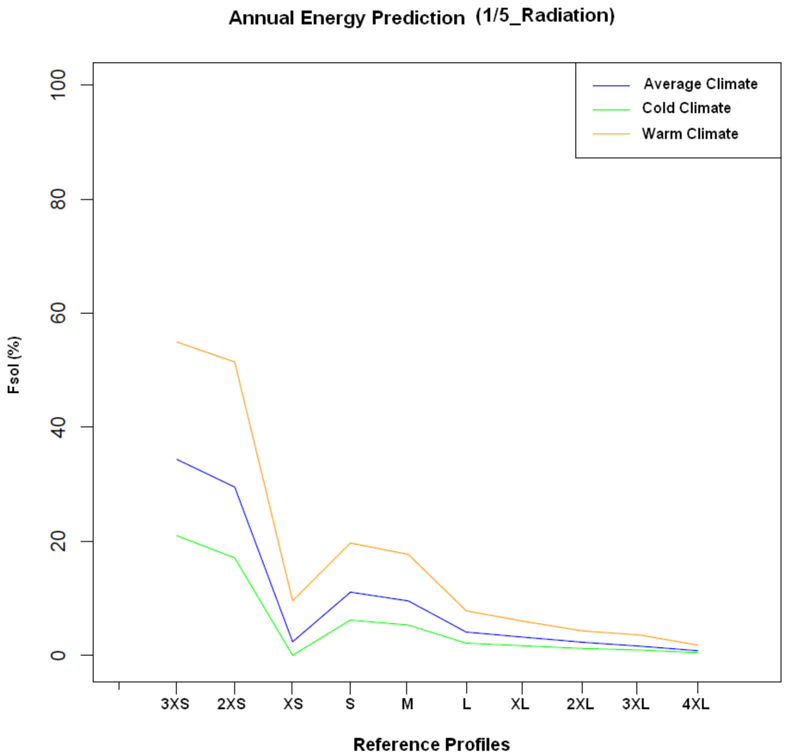


Figure 15 Solar fraction results for LTPP-R calculation (1/5 Radiation)

3.4.3.3 Conclusion

Arising from the LTPP – R calculation results it can be concluded that the solar thermal system CSTG equation (Eq. 2) is no longer valid when dividing the solar daily radiation in several parts. The results show that the annual solar fraction is decreasing according to the increasing number of solar radiation divisions, and this effect happens in both climate data sets.

In the LTPP – R calculation results when dividing the solar radiation, the XS profile shows a lower solar fraction due to two main reasons. In spite of the profiles XS, S and M demand the same energy (same Q_{ref}), the required draw-off volume in each tapping is bigger in XS than in the others, additionally, the chosen times of the divisions of the solar radiation are not the best for this profile.

3.5 EU tapping cycles LTPP - TRNSYS simulation

In order to validate the LTPP – R calculation procedure the same calculations have been performed with the dynamic simulation software TRNSYS. TRNSYS is the suitable tool to apply the reference load profiles and climate date sets to a simulation model of the thermosiphon system (TS) Solahart 180J used in the LTPP-R calculation procedure.

3.5.1 TRNSYS

TRNSYS[10] is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modular nature of TRNSYS gives the program high flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of any system whose behaviour is dependent on the passage of time. TRNSYS has become reference software for researchers and engineers around the world. Main applications include: solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells.

3.5.2 Input data

3.5.2.1 Climate data

In this case the Meteonorm climate data set for the following locations, Stockholm, Würzburg, Davos, Athens, Seville and Lisbon, has been used. The climate data used is in TMY2 format and the (TRNSYS Type 109). The solar daily radiation is applied every simulation time step (5 to 15min.).

3.5.2.2 Load profiles

For the implementation of the EU reference tapping cycles the time forcing function (Type 14b) has been used. It allows defining day, week, an annual load profiles. All the EU reference tapping profiles have been implemented in the thermosiphon system model.

[10] TRNSYS: A TRaNsient SYstems Simulation Program. http://sel.me.wisc.edu/trnsys/index.html

3.5.2.3 *Thermosiphon system (TS) model and parameters*

The TS system model consist of a flat plate collector, an horizontal integrated storage tank base on Type 45, a reverse flow valve and water as working fluid. The system is divided in several segments which the Bernoulli equation is applied. The flow rate results from the previous equations and the temperature stratification in the water storage tank can be modelled using Type38.

The TS system model parameters must be adjusted to the SolaHart 180J technical features. The main parameters to be adjusted are: area, performance equation coefficients and tilt of the solar thermal collector, heat insulation of collector and storage tank and material thermal conductivity, etc). See Annex 2: Solahart 180 J technical data.

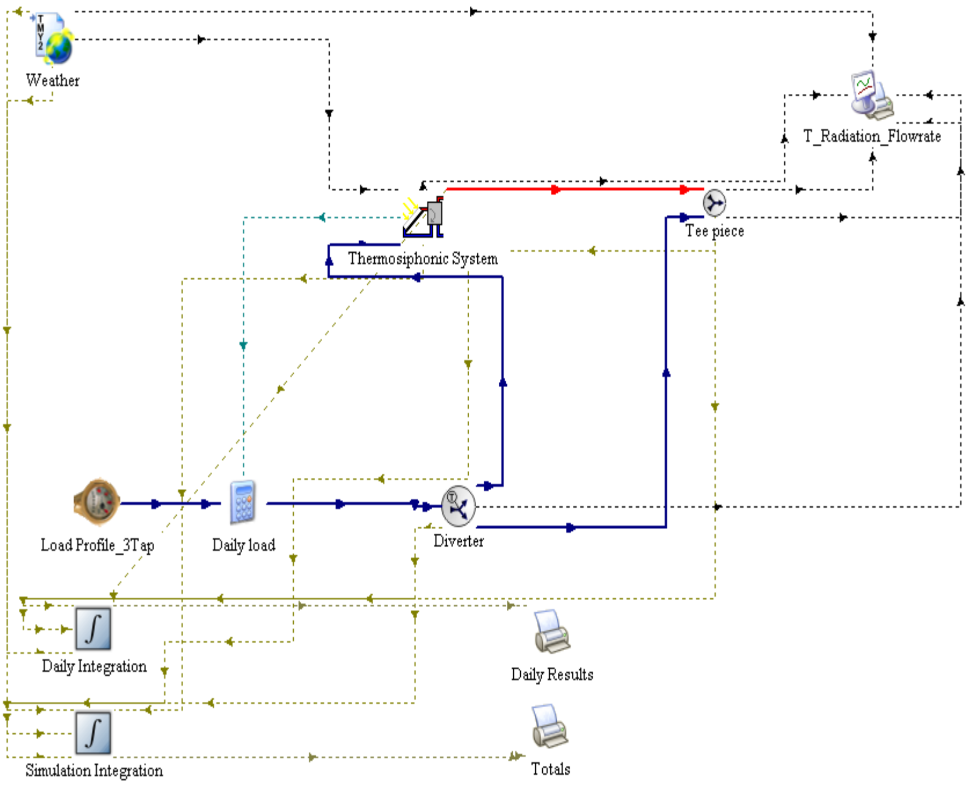


Figure 16 TRNSYS model of the thermosiphon system

3.5.3 Annual performance simulation

TRNSYS allows solving the thermal behaviour equations of the TS system model in small time steps (<1minute) for the whole year. The annual performance of solar thermal system can be calculated and also smaller time periods (from hours, days, weeks or months).

3.5.1 Results

A graphic example of the TRNSYS simulation results of the Solahart 180J system during the first week of July at Würzburg location and climate for the XS profile are show in the next figure. Most of the simulation results are presented in Chapter 3.6 when comparing R and TRNSYS results.

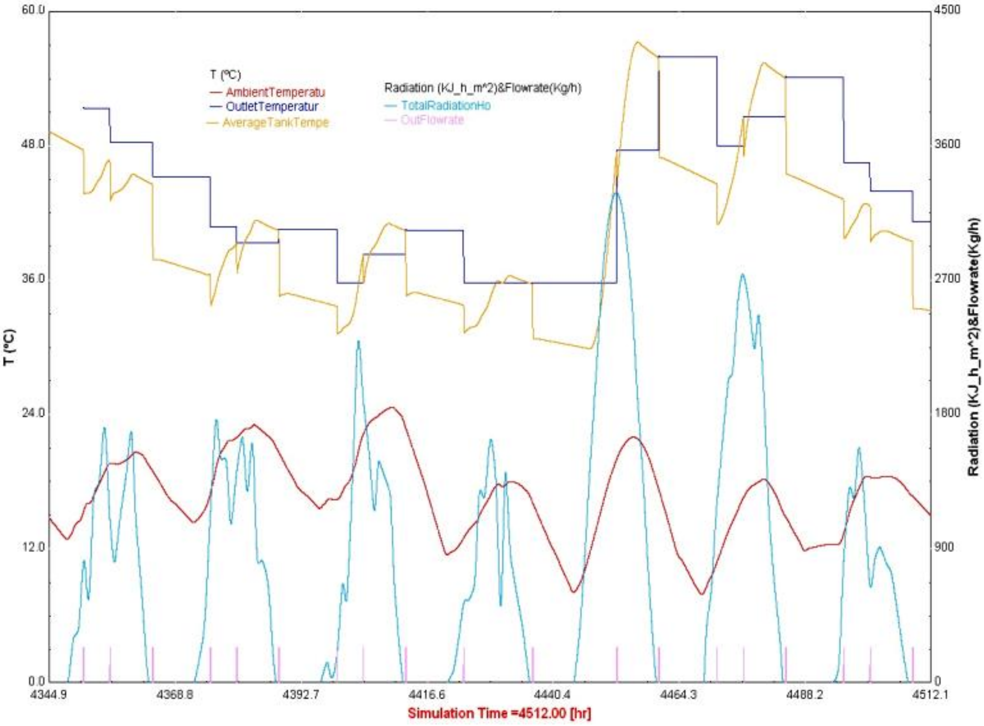


Figure 17 Simulation results for TS Solahart 180J
(1st week of July - Würzburg - XS profile)

3.6 LTPP result validation: comparison R vs. TRNSYS

In this chapter the results of LTPP – R calculation procedure and the TRNSYS annual simulation results are compared for the same TS system and using the following input data.

3.6.1 Input data

- TS system model adjusted to the Solahart 180J features
- Climate data from Meteonorm
  - Locations: Stockholm, Würzburg, Davos, Athens, Seville and Lisbon
- Solar daily radiation applied
  - R: All_Radiation: Whole solar daily radiation applied at the end of the day (like CSTG method)
  - R: 1/2_Radiation: Solar daily radiation divided in two parts
  - R: 1/3_Radiation: Solar daily radiation divided in two parts

- R: 1/5_Radiation: Solar daily radiation divided in 5 parts
- TRNSYS: Radiation applied every simulation time step (5 to15 min.)

- Cold water temperature, T_{cw}=10ºC constant during the whole year
- Reference load profile - Profile XS

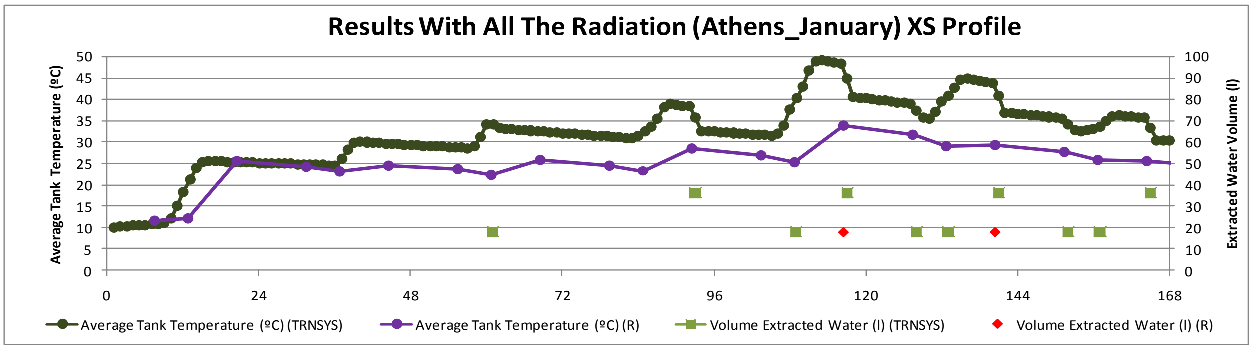
3.6.2 Result comparison

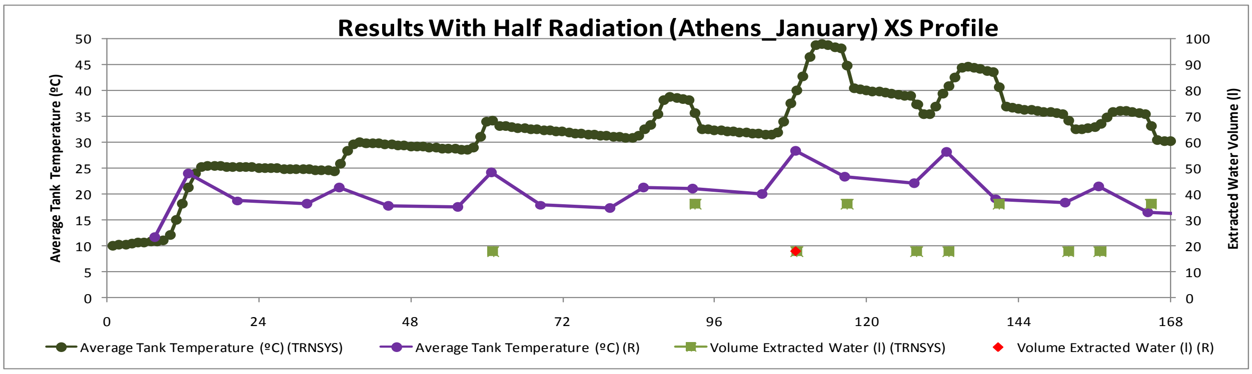
To compare the thermal behaviour of the TS system with both LTPP calculation methods (R and TRNSYS), the following parameters have been analysed:

- Storage tank average temperature: temperature of the middle node of the water stored in the tank
- Extracted volume: amount of liters drawn off from the TS system if the water from the storage tank is higher than t_m or t_p for the XS profile.
- Solar fraction: energy delivered by the solar thermal system/hot water energy demand ($f_{sol}=Q_L/Q_d$).

As an example the comparison results for Athens are presented in the following figures. The results of the rest of locations studied are in the Annex 1 - CSTG LTPP result validation: comparison R vs. TRNSYS

3.6.2.1 Athens, January 1st week

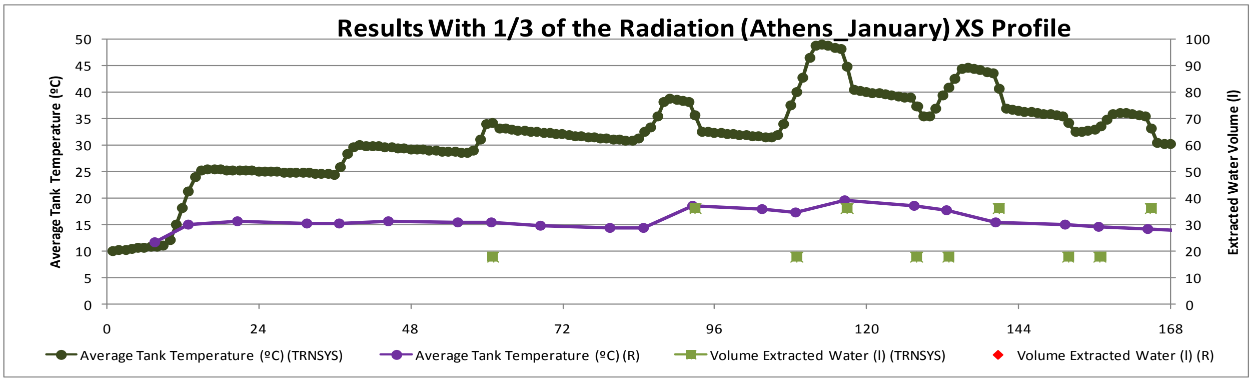


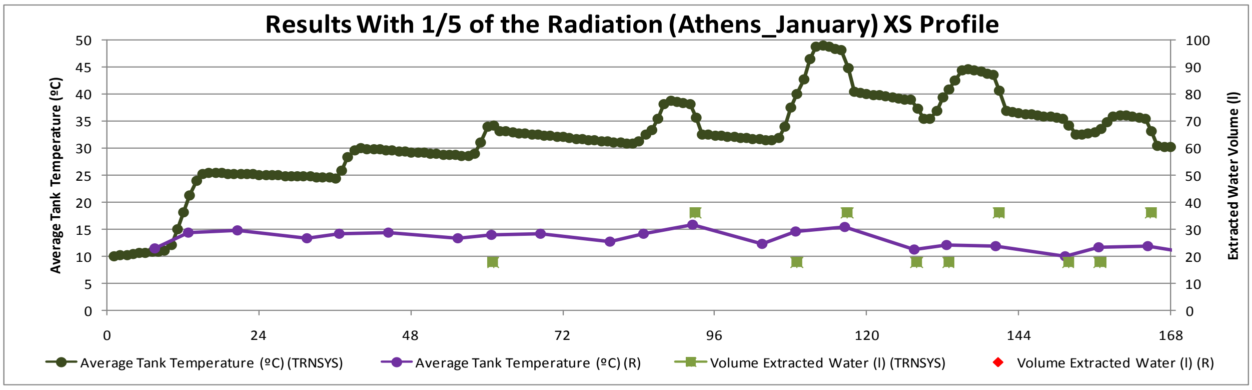


It can be noticed that the storage tank average temperature for the R calculation procedure with All_Radiation is almost around 5 ºC below TRNSYS values. The tank average temperature increase from R calculation procedure is always shifted because the daily solar radiation is applied at the end of the day (or in few parts) instead of each simulation time step like TRNSYS. Apart from that the average tank temperature increase, due to solar radiation on the TS system, from R calculation is almost the same as the one in TRNSYS, when All-Radiation is applied.

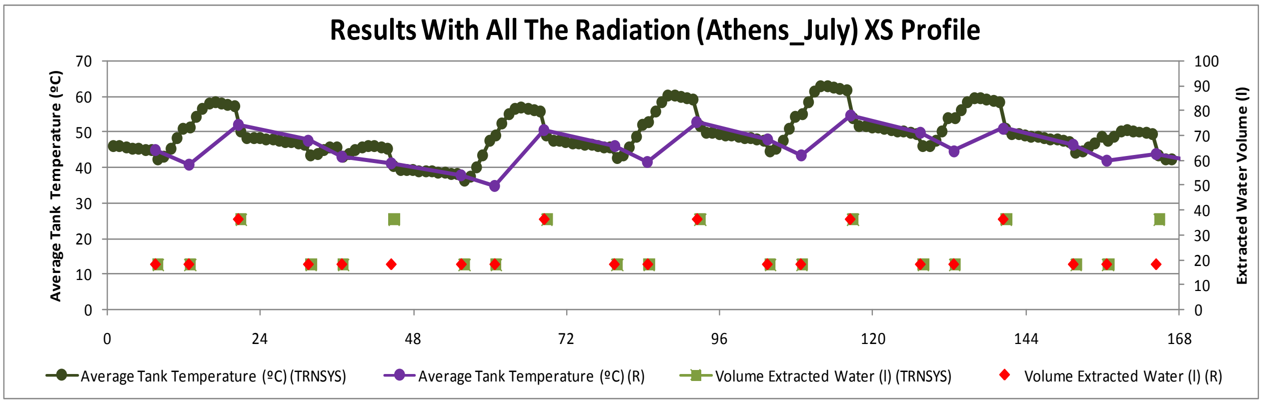
It can be also noticed that the amount of volume extracted in the R calculation procedure is lower than in TRNSYS even in the All_Radiation case. When dividing the solar radiation in 3 or 5 parts the volume extracted is zero, as it can be seen in the following figures.

Also when dividing the solar radiation in 2, 3 or 5 parts the tank average temperature decreases a lot for the R calculation procedure compared to the TRNSYS that always maintains the same value (as expected). This effect shows that the CSTG performance equation used in the R calculation procedure is only valid when applied with the daily solar radiation as a whole.

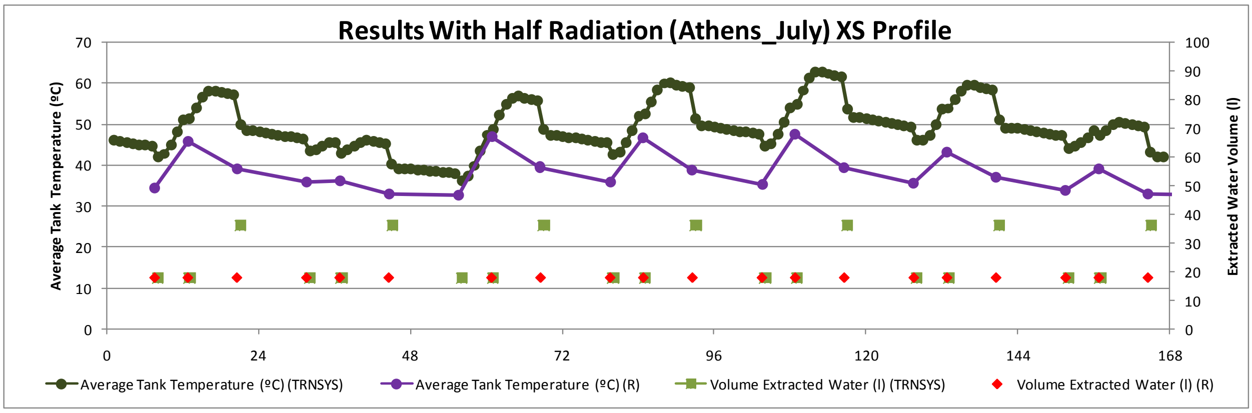


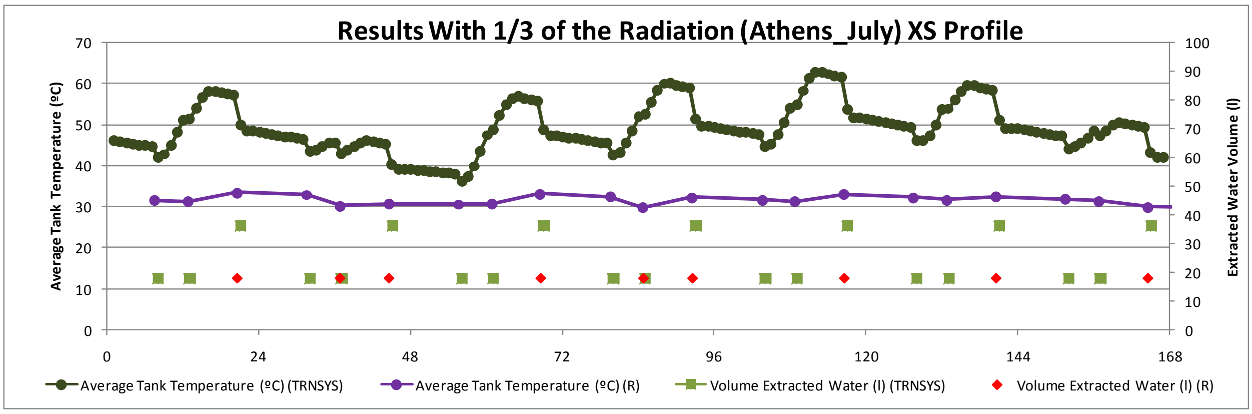


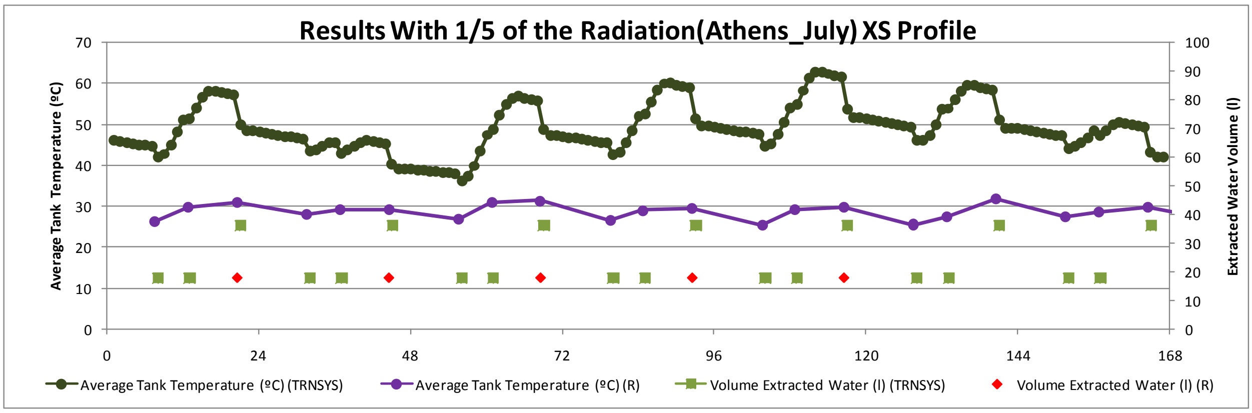
3.6.2.2 Athens, July 1st week



It can be noticed that the tank average temperature for All_Radiation is almost the same for R and TRNSYS, the only difference is when the daily solar radiation is applied (shift). The extracted volume is almost the same but lower in the R calculation procedure (two draw offs are not matching).







Like January results: when dividing the solar radiation in 2, 3 or 5 parts the tank average temperature and the extracted volume decrease a lot for the R calculation procedure compared to TRNSYS.

3.6.3 Comparison results with all the reference profiles

The LTPP results with the R calculation method (All_Radiation) and TRNSYS have been obtained for all the EU reference tapping cycles using as a climate data the reference climates defined in the EN12976. The Figure 18 and Table 11 show the LTPP solar fraction (fsol) results for both methods.

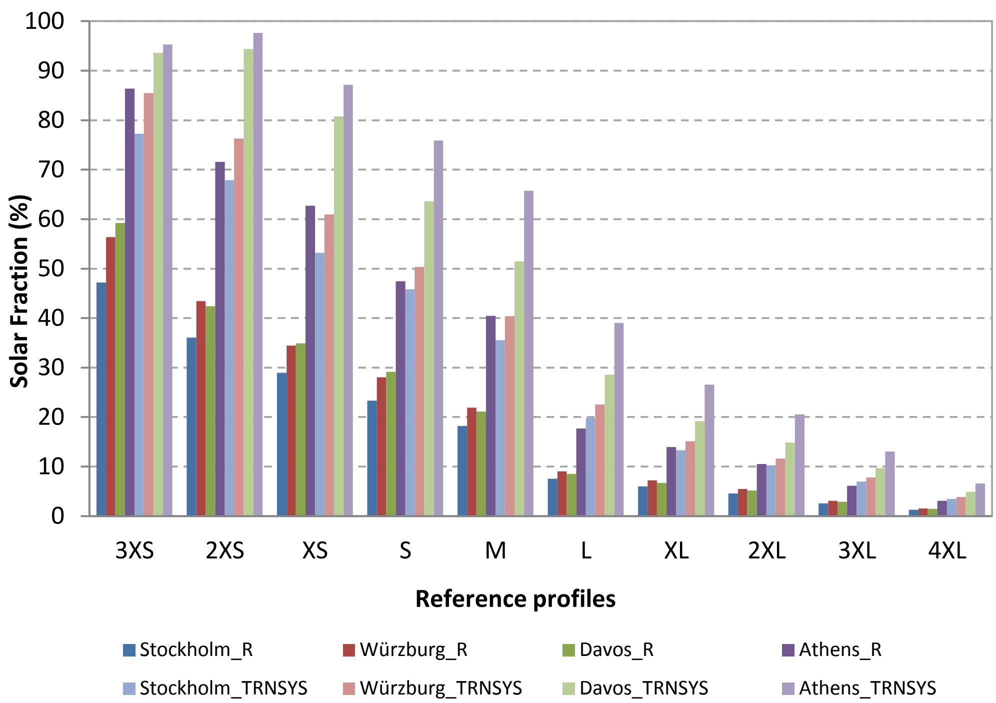


Figure 18 LTPP-R (All_Radiation) and TRNSYS results for all reference profiles with EN12976 reference climates

Table 11 Solar fraction LTPP- R (All_Radiation) and TRNSYS results

fsol (%)	3XS	2XS	XS	S	M	L	XL	2XL	3XL	4XL
Stockholm_R	47,16	36,04	28,93	23,33	18,21	7,56	6,00	4,54	2,58	1,29
Stockholm_TRNSYS	77,28	67,91	53,21	45,83	35,58	19,86	13,31	10,24	6,94	3,46
fsol difference (%)	30,12	31,87	24,28	22,50	17,37	12,30	7,31	5,70	4,36	2,17
Würzburg_R	56,36	43,41	34,48	28,05	21,92	9,01	7,22	5,47	3,09	1,55
Würzburg_TRNSYS	85,46	76,32	60,95	50,38	40,40	22,52	15,11	11,62	7,78	3,89
fsol difference (%)	29,10	32,91	26,47	22,33	18,48	13,51	7,89	6,15	4,69	2,34
Davos_R	59,19	42,40	34,91	29,14	21,15	8,51	6,73	5,16	2,88	1,44
Davos_TRNSYS	93,64	94,37	80,74	63,61	51,47	28,57	19,18	14,84	9,65	4,91
fsol difference (%)	34,45	51,97	45,83	34,47	30,32	20,06	12,45	9,68	6,77	3,47
Athens_R	86,39	71,59	62,71	47,47	40,48	17,69	13,97	10,52	6,12	3,06
Athens_TRNSYS	95,30	97,61	87,18	75,90	65,76	39,03	26,55	20,52	13,06	6,56
fsol difference (%)	8,91	26,02	24,47	28,43	25,28	21,34	12,58	10,00	6,94	3,50

It can be noticed that even with the LTPP-R All-Radiation the annual solar fraction is underestimated in R compared to TRNSYS. The solar fraction difference can be up to 51,97% in the most unfavorable climate (Davos) and tapping profile (2XS). The solar fraction difference is lower for the most favorable climate (Athens) due to the higher daily solar radiation which has a better performance when applying the CSTG performance equation.

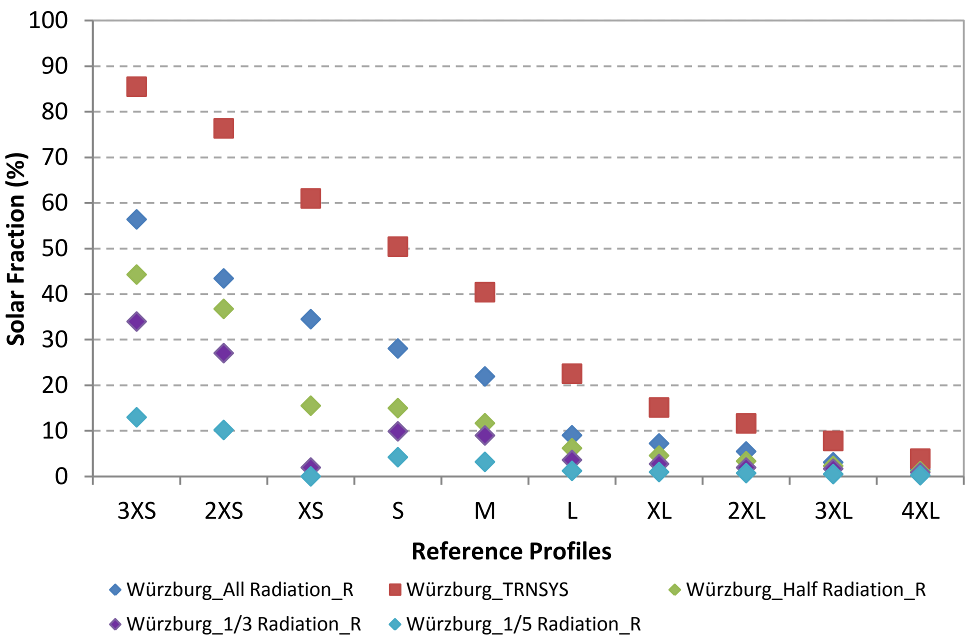


Figure 19 LTPP-R and TRNSYS results for different radiation parts and all reference profiles for Würzburg

3.6.4 Conclusions

- Results for All_Radiation
  - If the TRNSYS model is well adjusted the results should be the same, but the average storage tank temperature is lower (around 5ºC) and also the extracted volumes. To be checked:
    - The influence of not applying solar radiation among tappings in the R calculation procedure
    - The TRNSYS TS model
  - Shows higher differences for the extracted volume and the average storage tank temperature due to low radiation values applied to the CSTG equation used in the R calculation procedure
  - Athens XS profile LTPP shows a solar fraction (f_{sol}) difference of 25%.
    - TRNSYS: Q_D=2759 MJ, Q_L=2300 MJ, f_{sol}=0,87
    - R: Q_D=2759 MJ, Q_L=1730 MJ, f_{sol}=0,63
- For all reference tapping cycles applying the daily radiation divided by 2, 3 and 5 parts shows an increasing system performance difference between TRNSYS and R. Meaning that the CSTG system performance equation (Eq. 2) is no longer valid when applying it with the daily solar radiation divided in several parts, see Figure 19.

3.7 Comparison LTPP results for DST and CSTG

In order to validate the CSTG LTPP – R calculation procedure results a comparison exercise has been performed. The CENER LTPP- R results are compared with the ITW DST In Situ results for the same Solahart 180J thermosiphon system. The comparison between the two test methods has been done for Würzburg and for the reference load profiles: 2XS, XS and S.

In this case, the annual energy delivered by the solar thermal system was compared as well as the solar fraction ($f_{sol}=Q_L/Q_d$). Q_d is the load energy demand. The LTPP results and the graphical comparisons between are presented in the following table and figures.

Table 12 LTPP result comparison for CSTG and DST – Würzburg

	Sequence	**Profile**	**Q_d** MJ/year	**Q_L** MJ/year	**f_{sol}**
ITW - DST In Situ adapted for reference profiles	ECO0_XXS	2XS	2759	2015	73,02
	ECO1_XS	XS	2759	1933	70,05
	ECO2_S	S	2759	1703	61,71
CENER- CSTG R calculation procedure	R0_XXS	2XS	2759	1198	43,41
	R1_XS	XS	2759	951	34,48
	R2_S	S	2759	774	28,05

Figure 20: Annual energy delivered Q_L comparison - Würzburg

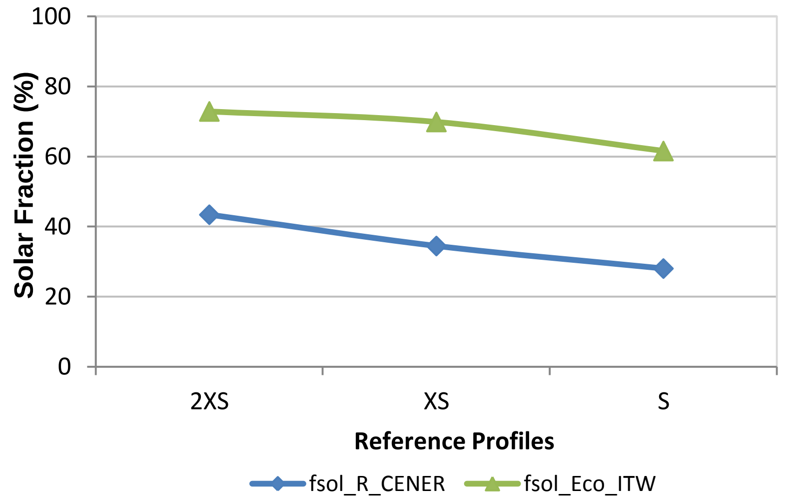


Figure 21: Annual solar fraction comparison – Würzburg

Arising from the results of both methodologies LTPP for DST and CSTG the DST LTPP method using the InSitu program gives higher and more trustable results for the solar thermal system performance applying the load reference profiles. The CSTG LTPP – R calculation procedure gives low system performance results, as expected, because in the previous comparison with TRNSYS also showed low LTTP results.

It can be concluded that the CSTG LTPP - R calculation procedure is not valid because it is based on the CSTG system equation (Eq. 2) which is not applicable for low solar radiation values.

4 DST EU tapping cycles validation process

For the validation of the method suggested in chapter 2.7.3 simulation results based on standard reference conditions acc. to EN 12976-2 will be compared with results from simulations implementing the EU reference tapping cycles. These results will be discussed in the following chapters.

4.1 Reference condition for the validation of the proposed method

For reasons of comparability some adjustments to the reference conditions had to be done. To keep the load profile as close to the profile given in EN 12976, only one draw-off per day was implemented. The following list contains all settings needed to implement the reference profile:

- 100 % evening draw-off at 18:00
- Demand temperature: T_d = 45 °C
- Cold water temperature: **constant** T_{cw} = 10 °C
- Draw-off flow rate: 10 l/min
- Auxiliary Heating
  - P_{aux} = 15 kW
  - $T_{aux,set}$ = 55 °C
- Daily draw-off Volume acc. to energy content of the corresponding EU reference tapping pattern

There are two major changes compared to the standard: The cold water temperature is not a function of the location and season anymore and the daily draw-off volumes are not members of the series given in EN 12976. The cold water must be set to a constant temperature, because it is used for the calculation of the daily draw-off volume. In the case of season dependent value, the delivered energy will be a season dependent function as well. The results will be barely comparable and the ISS does not provide a feature to implement season dependent draw-off volumes.

To ensure that comparable loads are applied to the SDHW system, the daily draw-off volumes are calculated according to the amount of energy withdrawn each day from the system. The same formula is used as defined in the methodology for applying the EU reference tapping cycles in chapter 2.7.3.

The series of daily load volumes used as reference is shown in the following table:

Pattern No.	Pattern	Qref [kWh]	V_d [l]
3	S	2.100	51
4	M	5.845	143
5	L	11.655	287
6	XL	19.070	469
7	XXL	24.530	603
8	3XL	46.700	1150
9	4XL	93.520	2300

4.2 SDHW System used for Simulations

The methodology defined in chapter 2.7.3 has been applied to a SDHW system already tested and very well known at ITW. The system has been evaluated with the ISS program as well as by using TRNSYS simulations before. It consists of a heat store with a nominal volume of 300 l and a collector aperture area of 4.75 m².

4.3 Evaluation of simulation results for applied EU reference tapping cycles

It is expected, that the simulations with the reference load profiles and corresponding EU reference tapping patterns will lead to similar results. Since distributed draw-offs will lead to lower temperature of the store but may disturb stratification, it's difficult to estimate its impact before the calculation. Nevertheless significant deviations between two simulations with corresponding draw-off profiles are an indicator for an error in the implementation of the EU reference tapping cycles.

Figure 22 shows the annual energy demand Q_{ref} and the annual load energy Q_L for evaluations with the reference profile (see 4.1) called "REF" and the EU reference tapping cycles acc. to the eco-design directive called "ECO".

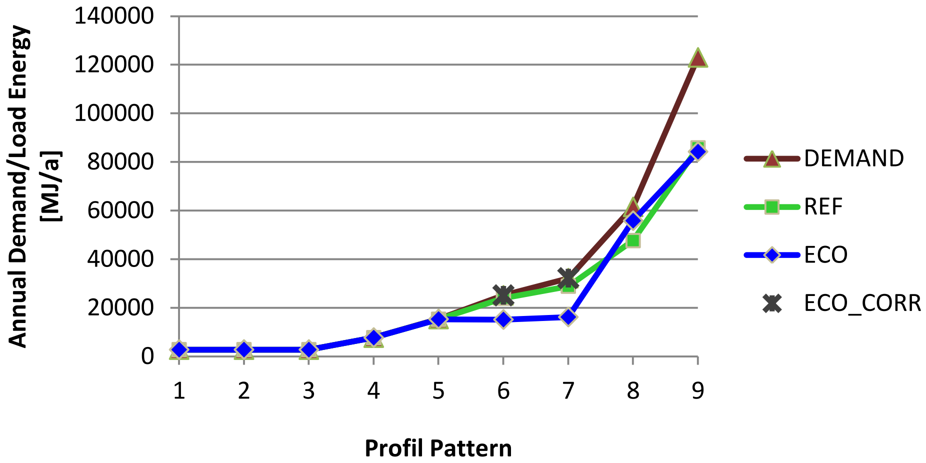


Figure 22: Annual energy demand and the annual load energy for the different reference profiles studied

For the profiles 1-5 (XXS-L) the simulation shows, that the SDHW system is able to cover the load. Both applied draw-off profiles show similar results. Beginning with the profile XL the draw-off volume is greater than the nominal store volume. This leads to a deviation of the Q_L from Q_{ref}. This is expected for the REF profile, since the store is used as a auxiliary heater when an amount of 1.5 times the nominal store volume is withdrawn. The deviation shown in the ECO profile is not probable. Since the same amount of energy is withdrawn, but not all of it at the same time, the Q_L should meet the Q_{ref}. The fact that this is not the case indicates, that not all draw-offs are performed and hence the amount of tapped energy is less.

This error have been corrected by merging adjacent draw-offs, which were supposed to withdraw a draw-off volume fraction smaller than 0.01, into one draw-off. The effect of the correction is shown by the ECO_CORR plot. The ECO_CORR profile covers the energy demand much better than the REF profile. This leads to a plausible behaviour.

4.4 Application of the eco design tapping profiles in TRNSYS simulations as reference for validation

The EU reference tapping cycles have been implemented with the simulation program TRNSYS. In this simulation program detailed daily profiles for nearly all boundary conditions may be defined. But since the program divides the whole simulated time span into fixed time steps, the defined values must be constant within each time step.

In TRNSYS time dependent mass flow rates and time dependent tapping profiles have been defined using the Type 14 (time dependent forcing function). The Figures 23 and 24 are showing the mass flow rate and the temperatures profile of the eco design pattern “M”.

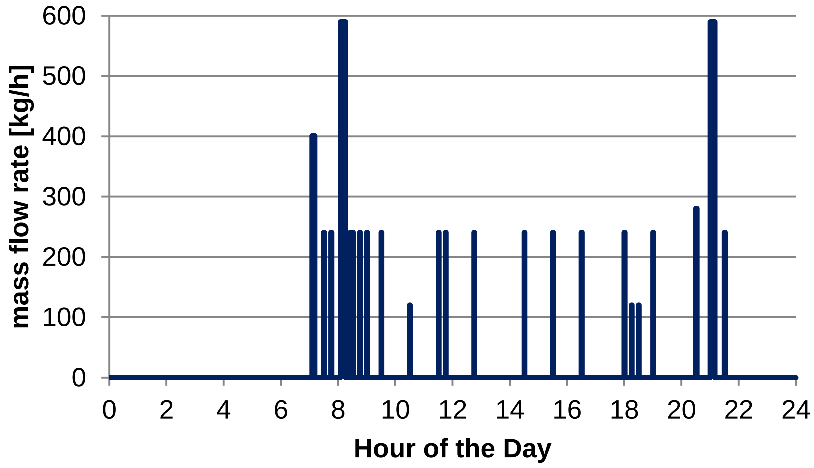


Figure 23: Profile of the draw-off mass flow rate for the pattern “M”

The mass flow is set to a value slightly higher than the minimum mass flow rate defined in the pattern. The exact value has been chosen to match the desired withdrawn energy amount in an integer multiple of the used time steps. Since smaller time steps increase the simulation time, a compromise between the accuracy and duration has been found by using time steps of 90s.

The temperature profile applied matches quite well the tapping pattern using the maximum value of the peak temperature T_p and the minimum required temperature T_m.

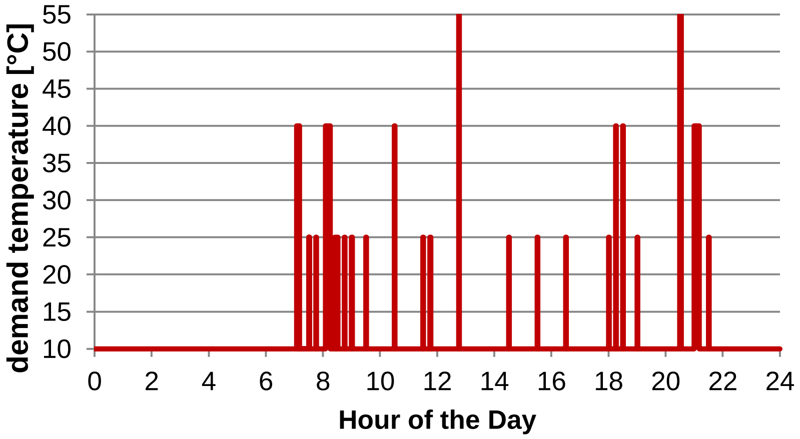


Figure 24: Temperature profile of demanded hot water temperature for the pattern “M”

The auxiliary heating parameters are in equivalence to the parameters of the ISS. The set point temperature is set to 2.5 K above the maximal demand temperature ($T_{d,max}$ + 2.5 K), the power of the auxiliary heater is 15 kW, and the hysteresis temperature difference is 5 K.

The simulation results are plotted in Figure 25 as annual load energy for each eco design pattern in comparison with the annual demand energy and the reference simulation with the 100% evening draw-off profile from ISO 9459.

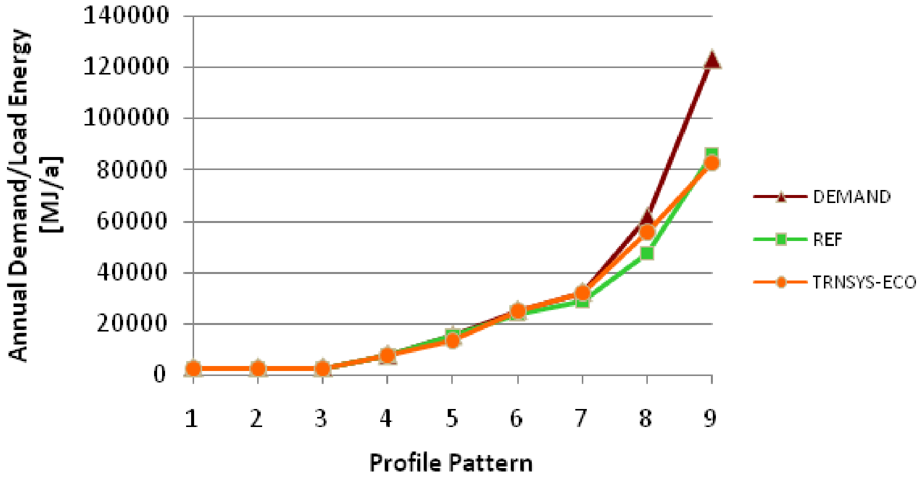


Figure 25: Comparison of the annual load energy yielded while applying the reference tapping cycles and the eco design directive patterns in TRNSYS

The results meet all expectations as described in section 4.3. For draw-off volumes greater than the nominal store size, the system is covering the load better when using distributed draw-offs over the whole day than with the 100% evening draw-off profile.

The main performance indicator for system performance is the solar fraction F_{sol}. The Figure 26 shows plots of the solar fraction for all applied tapping profiles.

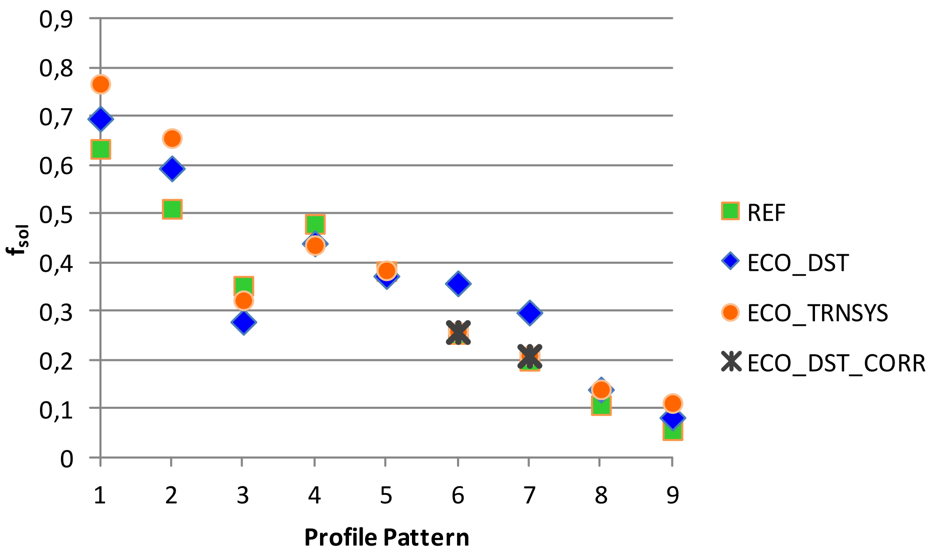


Figure 26: Solar fraction for eco design patterns applied in ISS software and in TRNSYS compared to reference patterns acc. to the reference profile

The Figure 26 shows that the EU reference tapping cycles are applicable to the DST method. The solar fraction of the system evaluated with the ISS program is slightly lower than the solar fraction gained from TRNSYS simulation for the same system. This is not surprising, because the demand temperature for all draw-offs is higher than required in the profile. The correction discussed in section 2.7.3 is also necessary to gain reasonable results for the profiles 6 and 7.

The profile 3 shows a significant deviation in the Fsol value. This is a system model specific phenomenon, where the solar fraction gets lower with small daily draw-off volumes. This behaviour is less distinct for warmer climates. This issue is not related to the application of the tapping profiles.

4.5 Summary

To sum up the work it can be said, that the EU reference tapping cycles which are the main part of the implementation of the eco design directive have been successfully implemented in the ISS program for evaluation of one system according to the DST method. Furthermore a calculation procedure for all important figures shown on an energy label has been suggested based on the simulation results gained by applying the EU reference tapping cycles.

After the completion of the QAiST WP4 round robin test for solar thermal systems the proposed evaluation procedure will be applied to the two systems investigated. Since there is a broad data basis the application of the described procedure will be done by more than one test institute.

5 Recommendations for standard revision

The conclusions of this study, where several options for integrating the performance test results of factory made systems with the reference load profiles for energy labelling purposes, show that new LTPP procedures are needed to integrate the reference load profiles with the system test results.

This new LTPP procedures have been outlined as a result of all the CSTG/DST LTPP procedures studied. But this new procedures need to be further elaborated due to the limitations found within the QAIST project, before including them in solar thermal system standards revision.