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Influence analysis of the characteristic coefficients of solar domestic water systems tested according to the Standard ISO 9459-2 regarding its long term prediction

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The Solar Thermal Testing Laboratory shared by CENER and GTER in Seville performs outdoor efficiency tests for factory-made solar systems according to the international standard ISO 9459-2.This method (CSTG acronym for “Collector and System Testing Group”, also called the input-output method) consists of three different parts: one part for determining mixing in the storage tank during draw-off, another part for determining daily system performance, and a part for the determination of storage tank heat losses. From the so-called CSTG test, the following coefficients are obtained: the characteristic coefficients of the solar system in the daily performance (a_1, a_2, a_3), the normalized draw-off temperature profile (f(V)), the normalized mixing draw-off temperature profile (g(V)) and the storage tank heat loss coefficient (Us).After having tested some solar systems according to the CSTG method, the long term prediction of the system output is performed using a simulation program. Using the obtained test results as a starting point, we vary the parameters stepwise and observe how this influences the solar fraction f_{sol}. Therefore, the purpose of the present paper is to analyze the influence of those parameter variations on the solar fraction f_{sol} obtained from the long-term prediction in different reference locations (Stockholm, Würzburg, Davos and Athens) and for various solar systems with a different volume/area ratio.

Keywords

solar system
testing
certification

Ključne riječi

Solarnisustav
testiranje
potvrda

Analiza utjecaja karakterističnih koeficijenata solarnih toplinskih sustava ispitanih prema normi ISO 9459-2 s **obzirom na dugoročno predviđanje njihove iskoristivosti**

Izvorni znanstveni rad

Laboratorij za istraživanje solarnih toplinskih sustava u Sevilli kojega koriste CENER i GTER vrši ispitivanja iskoristivosti komercijalnih solarnih sustava prema standardu ISO 9459-2. Ova metoda (zvana CSTG – Collector and System Testing Group) se sastoji od tri dijela: određivanje miješanja u spremniku topline tokom ispusta, određivanje dnevnih performansi sustava, i određivanje toplinskih gubitaka u spremniku topline. Iz CSTG testa, dobiveni su sljedeći koeficijenti: karakteristični koeficijenti solarnog sustava za procjenu dnevne performanse (a_1, a_2, a_3), normalizirani profil temperatura u spremniku topline tokom ispusta (f(V)), normalizirani profil temperatura miješanja tokom ispusta u spremniku topline (g(V)) i koeficijent toplinskih gubitaka toplinskog spremnika (Us). Nakon testiranja solarnih sustava CSTG metodom, dugoročno predviđanje njihove iskoristivosti je izvršeno računalnom simulacijom. Koristeći rezultate ispitivanja kao početnu točku, mijenjani su radni parametri te je promatran utjecaj tih parametara na solarni udio energetskog učina sustava f_{sol}. Ovaj rad analizira utjecaj tih parametara na promjenu solarnog udjela u energetskoj bilanci sustava, što je dobiveno dugoročnim predviđanjem performansi sustava na različitim loacijama (Stockholm, Würzburg, Davos i Atena) za različite solarne sustave sa različitim omjerima volumena toplinskog spremnika i površine kolektora.

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1. Introduction

According to the Spanish Technical Building Code (CTE) and Ministerial Order ITC/71/2007, all solar thermal systems on the Spanish market must be homologated by the Ministry of Industry to be eligible for government subsidies, and for this they have to pass all the UNE-EN 12976-2 European Standard tests. This

Standard stipulates durability and efficiency tests, and user and installer documents to be checked.

The CENER and GTER Accredited Solar System Testing Laboratory in Seville have been performing all the tests for factory-made solar thermal systems according to the European Standard since 2008. Solar systems had been tested in this laboratory for 25 years before that. The European Standard efficiency test refers to two ISO Standards: ISO 9459-2 (CSTG method) and ISO 9495-5 (DST method). The CSTG method, named after the group which originally developed it, "Complete System Testing Group", makes use of an input-output ratio, while the DST method, called the "Dynamic System Test", makes use of dynamic software for parameter identification.

From the so-called CSTG test, the following coefficients are obtained: the characteristic coefficients of the solar system in the daily performance (a_1, a_2, a_3), the normalized draw-off temperature profile (f(V)), the normalized mixing draw-off temperature profile (g(V)) and the storage tank heat loss coefficient (U_s).

Taking the previous into account, the purpose of this paper is to analyze the influence of those parameter variations on the solar fraction f_{sol}. Manufacturers could make use of the results in order to study the potential improvements of their systems. Some of these enhancements could be the increasing of the collector performance through improved a_1, improving the tank stratification through improved f(V) and g(V) factors, and the decreasing of the storage tank heat losses through improved $U_{s.}$

Symbols

A	- Collectors aperture area, m^2 - Površina kolektora, m^2	Q_L	- Energy supplied by the solar part, MJ - Solarni udio ukupne energije, MJ
a_1, a_2, a_3	- Daily characteristic coefficients of the solar system - Dnevni karakteristični koeficijenti solarnog sustava	$t_{a(day)}$	- Ambient temperature, ºC - Temperatura okoliša, °C
f_{SOL}	- Solar fraction - Udio solarne energije	t_{main}	- Cold water supply temperature, ºC - Temperatura hladne vode, °C
$f(V)$	- Normalized draw-off temperature profile - Normalizirani temperaturni profil tokom pražnjenja	t_n	- Average ambient air temperature during the night, ºC - Prosječna temperatura okoliša tokom noći, °C
$g(V)$	- Normalized mixing draw-off temperature profile - Normalizirani temperaturni profil miješanja tokom pražnjenja	Us	- Storage tank heat loss coefficient, W k^{-1} - Koeficijent gubitaka topline spremnika topline, W k^{-1}
H	- Daily solar irradiation in the collector aperture, MJ m^2 - Dnevna dozračena Sunčeva energija na kolektorsku površinu, MJ m^2	V_c	- Volume of daily hot water consumption, l - Volumen dnevne potrošnje tople vode, l
Q	- Output energy production of the solar system, MJ - Proizvedena energija solarnog sustava, MJ	η	- System performance - Iskoristivost sustava
Q_D	- Heat demand, MJ - Potreba za toplinom, MJ		

2. Description of testing method (ISO 9459-2)

This method (CSTG for "Collector and System Testing Group", also called the input-output method) is a "black box" procedure. It is applicable to solar-only and solar-preheat systems. It consists of three different parts: one part for determining daily system performance, another part for determining mixing in the storage tank during draw-off, and the last part for the determination of storage tank heat losses.

2.1. Determination of daily system performance

The daily system performance test consists in conditioning the system at least six hours before solar noon, circulating water in the tank until it is sufficiently uniform. Then, the solar system operates normally for 12 hours. Finally, six hours after solar noon, the tank water is drawn off until outlet and inlet temperatures are equalized, while the inlet water temperature is maintained constant. The same test procedure is repeated until a set of one-day points is obtained with a sufficient range of daily solar radiation H and temperature difference [$t_{a(day)}$ - t_{main}]. According to the Standard, the set should contain at least four different days with approximately the same values of [$t_{a(day)}$ - t_{main}] and the daily solar irradiation values H evenly spread over the range between 8 MJ/m^2 to 25 MJ/m^2, and it should also contain at least two additional days with values of [$t_{a(day)}$ - t_{main}] at least 9 K above or below the values of [$t_{a(day)}$ - t_{main}] obtained for the first four days. The value of [$t_{a(day)}$ - t_{main}] shall be in the range - 5 K to + 20 K for each test day.

The mathematical model for the output energy production of the solar system Q depends on daily solar irradiation H and the temperature difference between mean ambient temperature $t_{a(day)}$ and inlet water temperature t_{main} as follows:

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

The results consist of the coefficients a_1, a_2 and a_3 obtained by a multiple linear regression using the least-squares fitting method.

During each of the testing days, the draw-off profiles are also recorded and normalized for low and for high daily solar radiation days f(V).

2.2. Determination of the degree of mixing in the storage vessel during draw-off

The test consists in conditioning the system, circulating water at a temperature above 60 ºC in the tank at a rate of at least five times the tank volume per hour until it is sufficiently uniform, while the collector is shaded from the sun. The water in the store is assumed to be uniform when the outlet temperature and the inlet temperature vary by less than 1 K for a period of 15 min. Afterwards, the storage tank is drawn off at a constant flow rate of 600 l/h, while the inlet water introduced in the storage tank is maintained at a constant temperature of less than 30 ºC. The draw off volume should be at least three times the tank volume and until that the temperature difference between inlet and outlet water temperature is less than 1 K. The procedure aims to determine the mixing draw-off profile g(V).

2.3. Determination of storage tank heat losses

The test consists in conditioning the system, by circulating water at a temperature above 60 ºC in the same way as the mixing draw-off test. Afterwards, the tank is left for cooling for a time period between 12 h and 24 h at night or without any incident solar radiation. During the cooling period, the air circulates freely over the collector's plane with a mean wind speed between 3 m/s and 5 m/s. After this cooling period, the water is again circulated in the same way in order to measure the drop of temperature suffered by the tank over the night. The test is carried out with the collector loop disconnected, eliminating the possibility of reverse flow during the night. The procedure aims to determine the heat loss coefficient U_s of the storage tank.

2.4. Prediction of long-term performance

With the total energy output, characteristics of the system [a_1, a_2 and a_3], the normalized draw-off temperature profile [f(V)], the normalized mixing draw-off temperature profile [g(V)], the storage tank heat loss coefficient [Us], the daily meteorological data [daily solar irradiation H, the daily mean ambient temperature $t_{a(day)}$, the night mean temperature [t_n] of the reference locations and the system characteristics [V_c], the performance of the system is calculated day-by-day for different reference locations and differing load demand.

The solar fraction (f_{Sol}) is defined as the energy supplied by the solar part (Q_L) divided by the total system load (Q_D = heat demand).

3. Description of sensitivity analysis of the parameters a1, f(V), g(V) and Us

In this section, it will carry out the sensitivity analysis of the parameters a_1, f(V), g(V) and U_s independently.

3.1. Sensitivity analysis of a_1

When analyzing equation 1, we observe that the output energy production of the solar system Q depends on the a_1, a_2 and a_3 parameters. The sensitivity analysis was conducted on the a_1 parameter. This factor represents the system performance when $t_{a(day)} = t_{main}$, assuming that the a_3 parameter is close to zero. So, the performance equation is:

$$\eta = a_1 / A \qquad (2)$$

Where η is the system performance and A is collectors aperture area.

The sensitivity analysis on this factor consists in increasing the values of the a_1 parameter and observes such influence on the prediction of long-term performance (f_{Sol})

3.2. Sensitivity analysis of f(V)

In this section, we have proceeded to analyze the influence in the solar fraction f_{sol} as if f(V) were the ideal, that is, as if the useful energy extracted from the system were constantly approaching zero from a certain value. For both cases, we will make the prediction of long-term performance and we will compare both results.

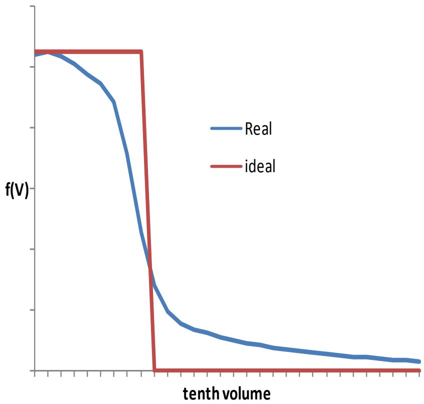

Figure 1. f(V) graph
Slika 1. Funkcija f(V), idealno-ideal, i stvarno-real.

3.3. Sensitivity analysis of g(V)

In this section, we have proceeded to analyze the influence on the solar fraction f_{sol} as if g(V) were the ideal, that is, as if the useful energy extracted from the system were constantly reaching zero at a certain value. For both cases, we will make the prediction of long-term performance and we will compare both results.

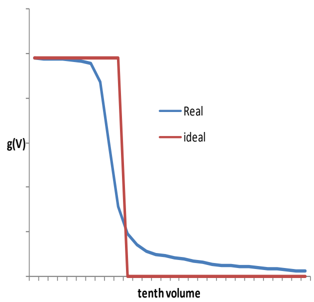

Figure 2. g(V) graph
Slika 2. Funkcija g(V), idealno-ideal, i stvarno-real.

3.4. Sensitivity analysis of Us

In this section we have proceeded to analyze the influence in the solar fraction f_{sol} if we change the storage tank heat loss coefficient U_s. We will improve such a coefficient, increasing its values to 30, 60 and 90% and will observe the influences that this factor has on the prediction of long-term performance.

4. Sensitivity analysis

4.1. Testing samples

In order to carry out the sensitivity analysis we use two only-solar systems. One is a thermosyphon system with a storage tank of a volume of 280 l and 2 flat-plate collectors with an aperture area of 3.60 m^2. The second system is of the thermosyphon type as well, with a storage tank of 200 l volume, and 1 flat-plate collector with an aperture area of 1.92 m^2.

The results of these systems parameters are indicated in Table 1 and figures 3, 4, 5 and 6.

Table 1. CSTG parameter identification
Tablica 1. Prikaz CSTG parametara.

Parameter	System 1	System 2	Unit
a_1	1,70	1,01	m^2
a_2	0,61	0,36	MJ.K^{-1}
a_3	-2,00	-1,75	MJ
U_s	3,90	4,17	W/k

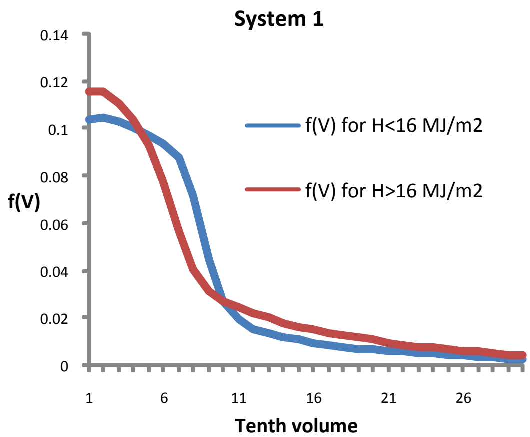

Figure 3. f(V) Results of System 1.
Slika 3. Rezultati f(V) za sustav 1.

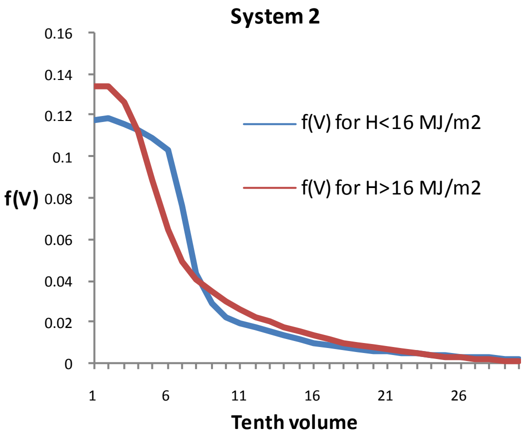

Figure 4. f(V) results of system 2
Slika 4. Rezultati f(V) za sustav 2.

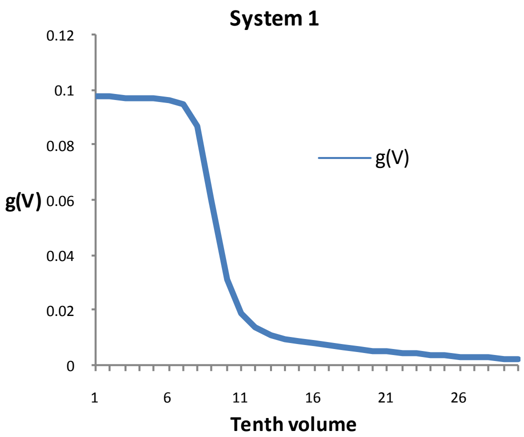

Figure 5. g(V) results of system 1
Slika 5. Rezultati g(V) za sustav 1.

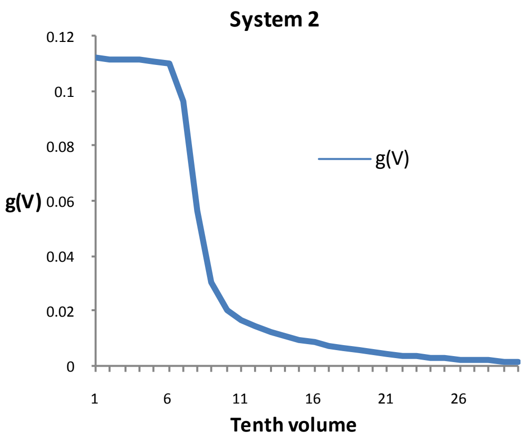

Figure 6. g(V) results of system 2
Slika 6. Rezultati g(V) za sustav 2.

4.2. Comparative analysis

Thanks to the sensitivity analysis of the characteristic parameters in the different locations, the following can be observed:

- For all daily load volumes, the parameter that improves the solar fraction the most is the a_1 coefficient.
- For low daily load volumes (under 140 l/day in system one and under 90 l/day in system two) the second most effective measure to improve the solar fraction would be the U_s coefficient. It can be observed that there is no improvement in the behavior of the system, even if the g(V) curve were ideal.
- For medium daily load volumes (approximately system volume) the second most effective measure to improve the solar fraction would be to make the normalized draw-off temperature profile f(V) ideal. The third most effective measure would be to reduce the U_s parameter. The idealization of the g(V) curve has a very small influence on the solar fraction. It is very similar to an improvement of 30% on the U_s factor.
- For high daily load volumes (greater than system volume), the second most effective measure to improve the solar fraction would be to make the normalized draw-off temperature profile f(V) ideal. For these daily load volumes there would not be a significant increase on the solar fraction to improve the U_s parameter or g(V) curve.

The results obtained for both systems are presented in the following graphs:

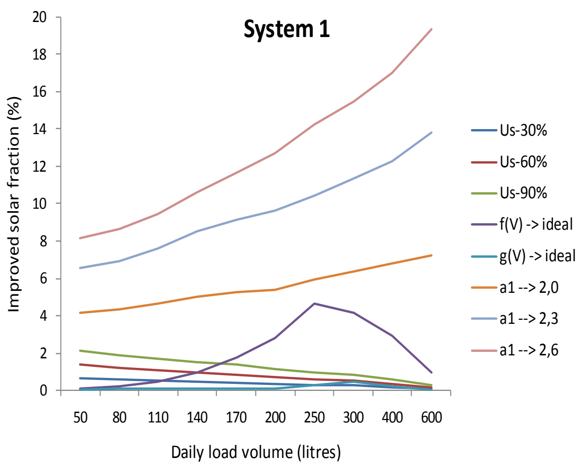

Figure 7. Athens results of system 1
Slika 7. Rezultati za sustav 1 – Atena.

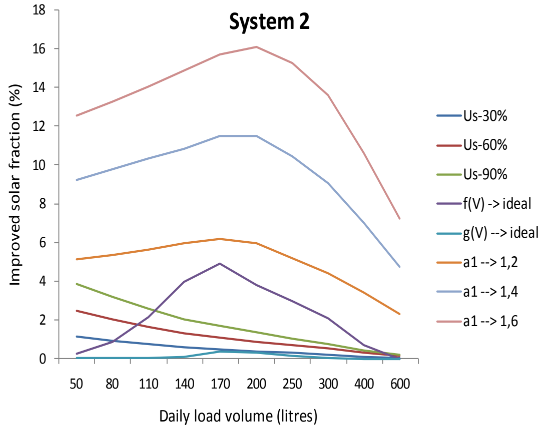

Figure 8. Athens results of system 2
Slika 8. Rezultati za sustav 2 – Atena.

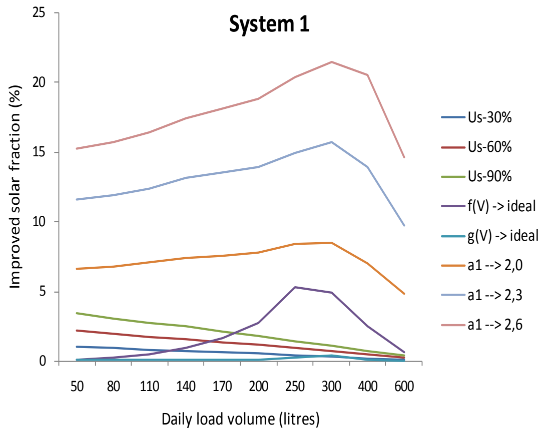

Figure 9. Davos results of system 1
Slika 9. Rezultati za sustav 1 – Davos.

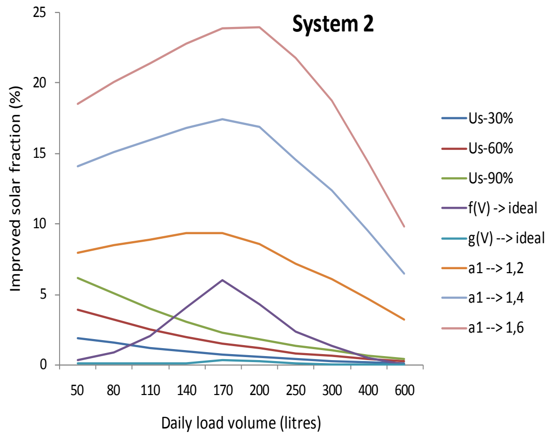

Figure 10. Davos results of system 2
Slika 10. Rezultati za sustav 2 – Davos.

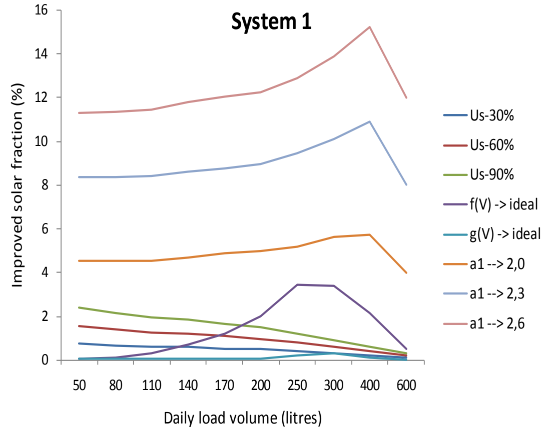

Figure 11. Wurzburg results of system 1
Slika 11. Rezultati za sustav 1 – Würzburg.

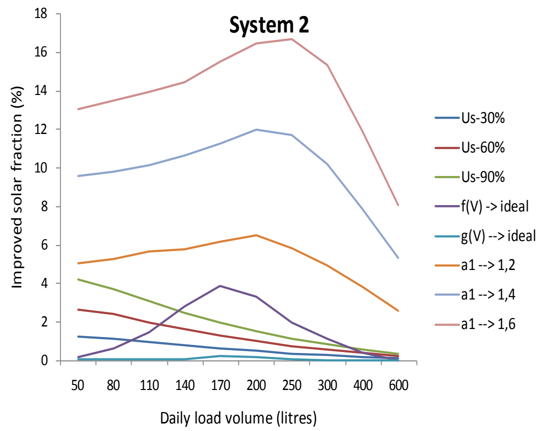

Figure 12. Wurzburg results of system 2
Slika 12. Rezultati za sustav 2 – Würzburg.

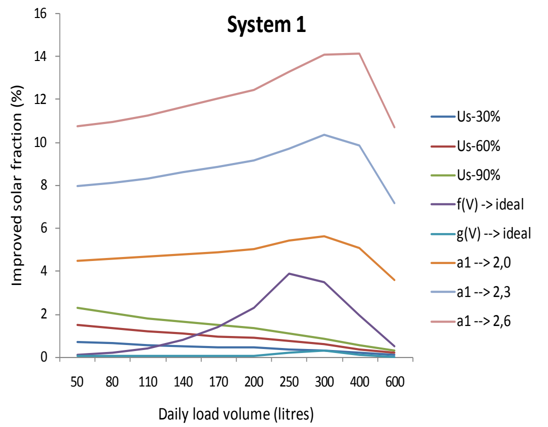

Figure 13. Stockholm results of system 1
Slika 13. Rezultati za sustav 1 – Stockholm.

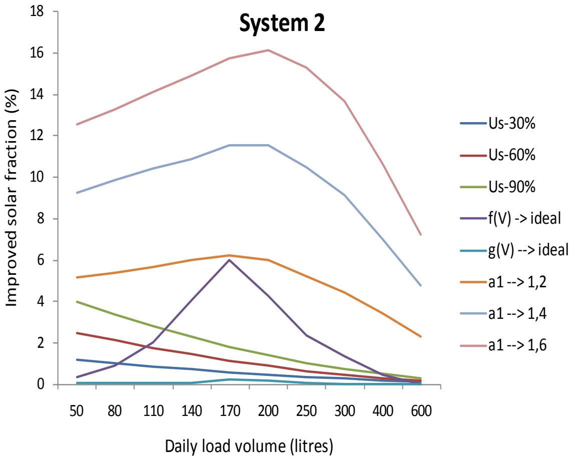

Figure 14. Stockholm results of system 2
Slika 14. Rezultati za sustav 2 – Stockholm.

5. Conclusion

The main conclusions that can be drawn from the study presented here are:

- Improvements in U_s. The range of improvement with this factor in the annual solar fraction is between 0 and 3.5% for system one and between 0 and 6.2% for system two. The higher values are obtained for the solar fraction with improvements of 90% in the U_s factor and low daily load volumes. Also, it can be observed that in Davos, the maximum value is 3.5% for system one and 6.2% for system two, while in the other reference locations improvements in the annual solar fraction are between 2% and 4% respectively.
- Improvements in f(V). With this factor the range to the annual solar fraction is improved between 0 and 5.4% for system number one and between 0 and 6.0% for system number two. It can be observed that in all reference locations the maximum values reached are for daily load volumes near to tank volume. There is no improvement for lower and higher daily load volumes. In Davos and Athens the maximum improved values are 5.3 - 6 %, while in Wurzburg and Stockholm the improvements are approximately 4%.
- Improvements in g(V). This is the parameter with less influence on the annual solar fraction. The improvements in the annual solar fraction ranges from 0% to 0.4%. It can be perceived that in all reference locations the maximum values reached correspond to daily load volumes near to tank volume.
- Improvements in the Q-H curve. For system one, the range of improvements when going from a_1=1.7 m^2 to 2.0, 2.3 and 2.6 m^2, respectively, reaches typical values of 8-14-20% in Wurzburg and Stockholm and values of 5-10-15% in Athens and Davos. Concerning system two, its range of improvement when going from a_1=1.0 m^2 to 1.2, 1.4 and 1.6 m^2 respectively reaches typical values of 8-16-22% in Wurzburg and Stockholm and values of 6-11-16% in Athens and Davos. The greater influence in these locations is related to the higher levels of radiation in these places.

The a_1 factor is the parameter that would most improve the annual solar fraction of the four parameters and enhancing it would be the first step of action the manufacturer should take.

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