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INFLUENCE OF THE INPUT PARAMETERS ACCURACY DEFINED IN THE STANDARD ISO 9459-5 FOR A DOMESTIC WATER HEATING THERMOSIPHON

Jonathan Vera[1]*, Isidoro Lillo[2], Laima Reina[2] and Sara Moreno[2]

[1] Solar Thermal Energy Department, National Renewable Energy Centre (CENER), Sarriguren, Spain

[2] Group of Thermodynamic and Renewable Energies (GTER), University of Seville, Seville, Spain

*Corresponding Author, jvera@cener.com

Abstract

The International Standard ISO 9459-5 describes the characterization of thermal performance for domestic water heating systems. The objective of this paper is to analyze the influence of measurement accuracy of some input parameters (inlet water temperature, outlet water temperature and solar radiation) during the test sequences on resulting solar fraction of a domestic water heating system, type thermosiphon, on the different European reference locations (Athens, Davos, Würzburg and Stockholm). A study of the measurement accuracy according to Standard ISO 9459-5 and other values has been carried out. The long-term prediction (solar fraction) for each of the input measurements was determined, and according to these results, a less restrictive measurement accuracy could be propose for a future revision of Standard ISO 9459-5.

Keywords: *solar system, dynamic testing, certification*

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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. For this reason, they must pass the EN 12976-1 and -2 (2006) European Standard tests. This Standard stipulates durability, safety and efficiency tests and user and installer documents checking.

The CENER (National Renewable Energy Centre) and GTER (Group of Thermodynamic and Renewable Energies) Accredited Solar System Testing Laboratory in Seville has been performed all the tests for factory-made solar thermal systems according to the European Standard since 2008. Before that, solar systems had been tested in this laboratory for 25 years. The European Standard efficiency test refers to two ISO Standards, ISO 9459-2 (2008) (CSTG method) and ISO 9495-5 (2007) (DST method). The CSTG method "Complete System Testing Group" makes use of an input-output method, while the DST method, called the "Dynamic System Test", makes use of dynamic software for parameter identification of the system characterization.

These International Standards provide information about measurement accuracies for each experimental measure (ambient temperature, inlet water temperature, outlet water temperature, flow-meter and solar radiation). The objective of this paper is to analyze the influence of measurement accuracy of some input parameters (inlet water temperature, outlet water temperature and solar radiation) on solar fraction in four different locations (Athens, Davos, Würzburg and Stockholm) for a factory made solar heating system, type thermosiphon, testing according to Standard ISO 9459-5.

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2. Description of testing method (ISO 9459-5)

The efficiency test of the DST method (also called dynamic method) consists in several test sequences with different system behaviors: S-Sol for characterizing the collector array performance at high efficiencies and acquire information about store heat losses and collector array performance at low efficiencies, S-Store for characterizing store heat losses and S-Aux for determining the heat losses and the volume fraction of the auxiliary heated portion of the storage tank. All the significant parameters (solar radiation, inlet and outlet water temperature, ambient temperature and flow-meter) are recorded. The mathematical model of the system energy output is based on a partial differential equation.

2.1. S-Sol Sequence

The aims of these sequences are to characterize the collector array performance at high efficiencies and acquire information about store heat losses and collector array performance at low efficiencies. The tests consists in conditioning the system and then letting the solar system operates normally for several days and finally the system is conditioned again to make uniform the tank temperature. Those sequence types are the called Test A and Test B. During those sequences, a series of 5 (Test A) or 7 (Test B) draw-offs are executed with different durations according to the system characteristics and at different times of the day. The Test A is supposed to let the system work at high efficiencies with enough closed draw-offs to not let the collectors heat too much. The Test B is supposed to let the system work at low efficiency leaving the tank as warm as possible.

Within those sequences, there should be a minimum of valid days with enough daily solar radiation and outlet temperature higher than a minimum for Test B.

2.2. S-Store Sequence

This sequence aims to characterize the store heat losses parameter of the system. It consists of a Test B sequence for at least 2 days and a cooling period of between 36 and 48 h.

2.3. S-Aux Sequence

This sequence aims to characterize the volume fraction of the auxiliary heated portion of the store. But it is not used in the tests of solar-only system.

2.4. Identification of system parameters and prediction of long-term performance

The identification of the characteristics parameters of the system is done using all the measured data recorded during the whole testing sequences. It is made by the validated commercial software InSitu (version 2.7) referred in the Standard ISO 9459-5. Figure 1 shows the flow chart of InSitu program

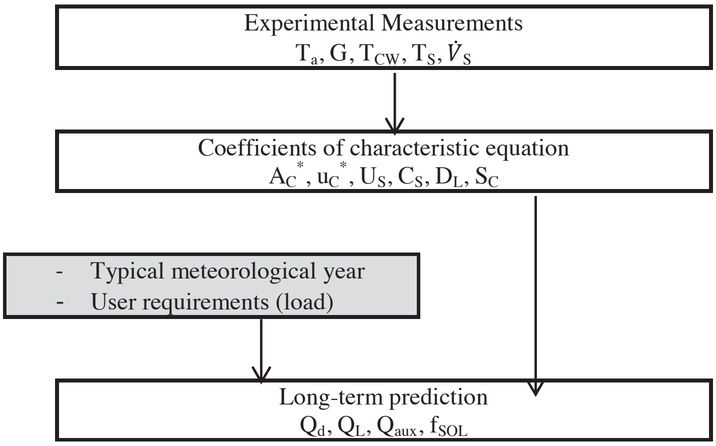


Fig. 1: Flow chart, InSitu program

The results consist in the coefficients A_c* (effective collector area), u_c* (effective collector loss coefficient), U_s (total store heat loss coefficient), C_s (total store heat capacity), D_L (mixing constant), Sc (store stratification). Each of those parameters is a coefficient of the terms in the physical model used for the thermosiphon.

The same software is used to calculate the yearly performance of the system for different reference locations and load demand using hourly meteorological data [H, T_a].

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 influence of the input parameters measurement accuracy

This section analyzes the influence of measurement accuracy of some the input parameters (inlet water temperature, outlet water temperature and solar radiation) on solar fraction in four different locations (Athens, Davos, Würzburg and Stockholm) for a factory made thermosiphon solar system. Table 1 shows the measurement accuracies according to Standard ISO 9459-5, as well as the accuracies proposed for this analysis. A prediction of long-term performance for each of the measurement accuracies has been carried out.

Tab. 1: Measurement accuracies

Parameter	**Measurement accuracy according to Standard ISO 9459-5**	**Measurement accuracy analysed in this study**
Inlet temperature	± 0.1 ºC	± 0.2 ºC, ± 0.5 ºC
Outlet temperature	± 0.1 ºC	± 0.2 ºC, ± 0.5 ºC
Solar radiation	± 1.0 %	± 1.5 %, ± 3.0 %

4. Influence of the input parameters measurement accuracies

4.1 Testing sample

A thermosiphon system with a storage tank of a volume of 300 l. and 2 flat-plate collectors with an aperture area of 4.46 m^2 is selected for analyzing the influence of input parameters measurement accuracies.

The results of these system parameters obtained according to Standard ISO 9459-5 are shown in Table 2

Tab. 2: System parameters

Parameter	**Value**	**Unit**
A_C*	2.619	m^2
u_C*	8.191	$Wm^{-1}\ K^{-1}$
U_S	2.504	$W\ K^{-1}$
C_S	1.114	$MJ\ K^{-1}$
D_L	0.125	--
S_C	0.515	--

The results of the long-term performance are presented in the following graphs

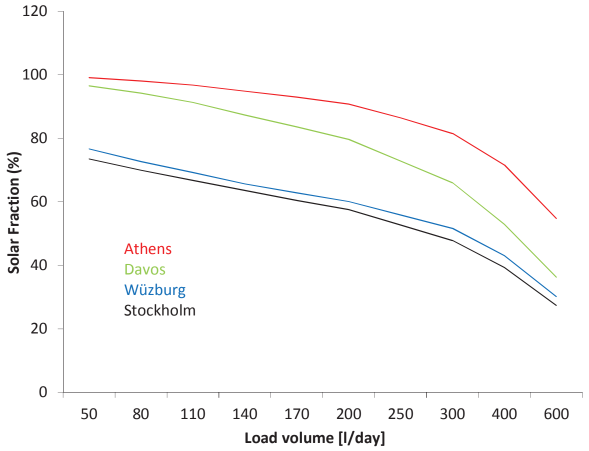


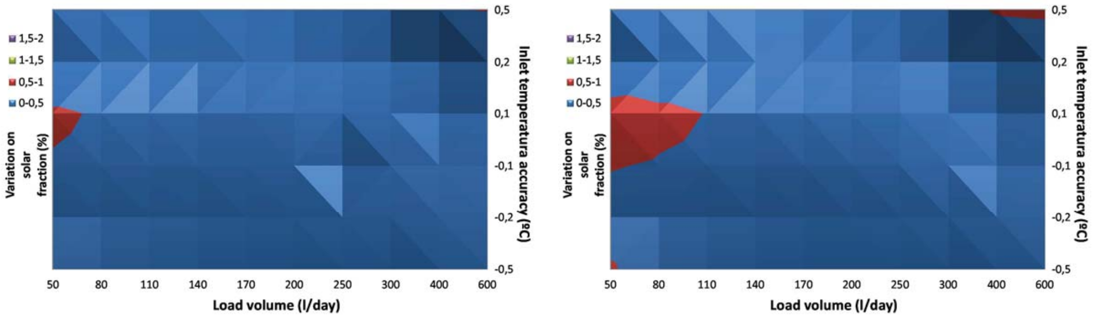
Fig. 2: f_{SOL} results

4.2 Comparative analysis

This section describes the variation on the solar fraction as a function of the load volume for every reference locations in order to modify the measurement accuracy of each parameter proposed in Table 1. Similarly, the average relative error of the solar fraction in every input parameter will be represented.

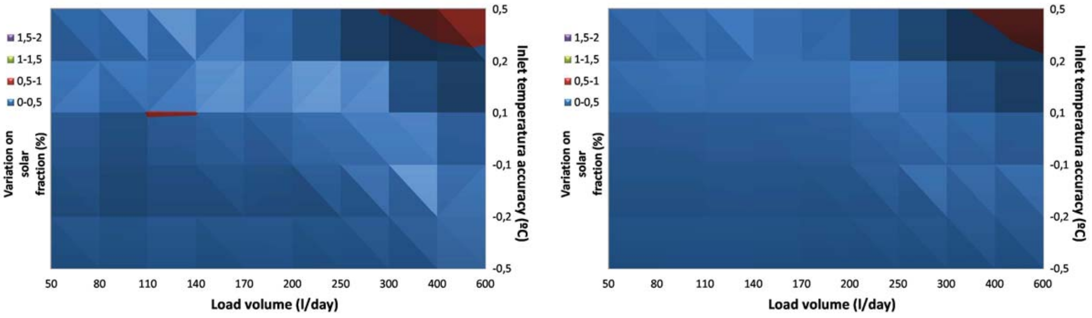
a. Inlet temperature

As shown in Figure 3, the maximum difference of the solar fraction obtained between the results to testing sample and the results in all intlet temperature measurement accuracies (table 1) is lower than 0.9 % in different reference locations. The maximum difference in variation on solar fraction is lower than 0.7 % to measurement accuracies according to Standard ISO 9459-5 (± 0.1 ºC) and 0.9 % to other measurement accuracies proposed (± 0.2 ºC, ± 0.5 ºC).



(a)

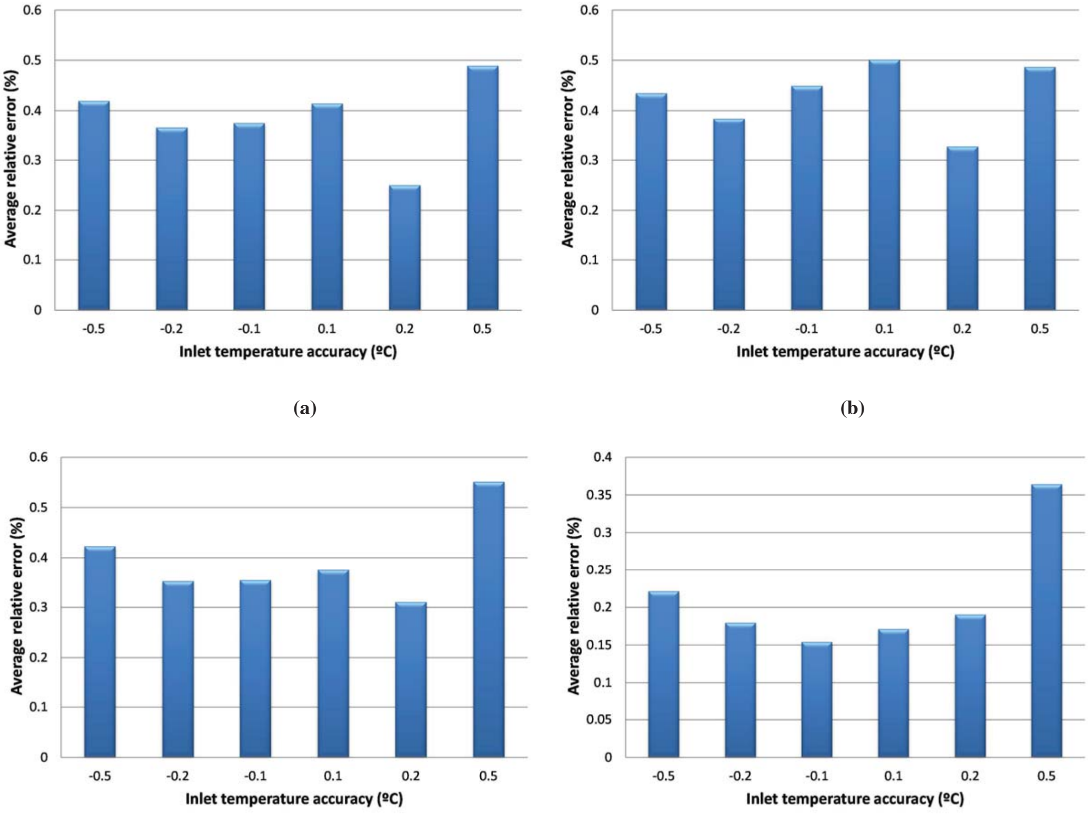
(b)



(c) (d)

Fig. 3: Variation on f_{SOL} to modify inlet temperature measurement accuracy in Stockholm (a) Würzburg (b) Davos (c) and Athens (d)

Figure 4 shows the average relative error of solar fraction with respect to inlet temperature accuracy in all reference locations. The maximum average relative error on solar fraction is lower than 0.6 % for all measurement accuracies studied (table 1). The minimun values of average relative error on solar fraction occurs on Athens location.



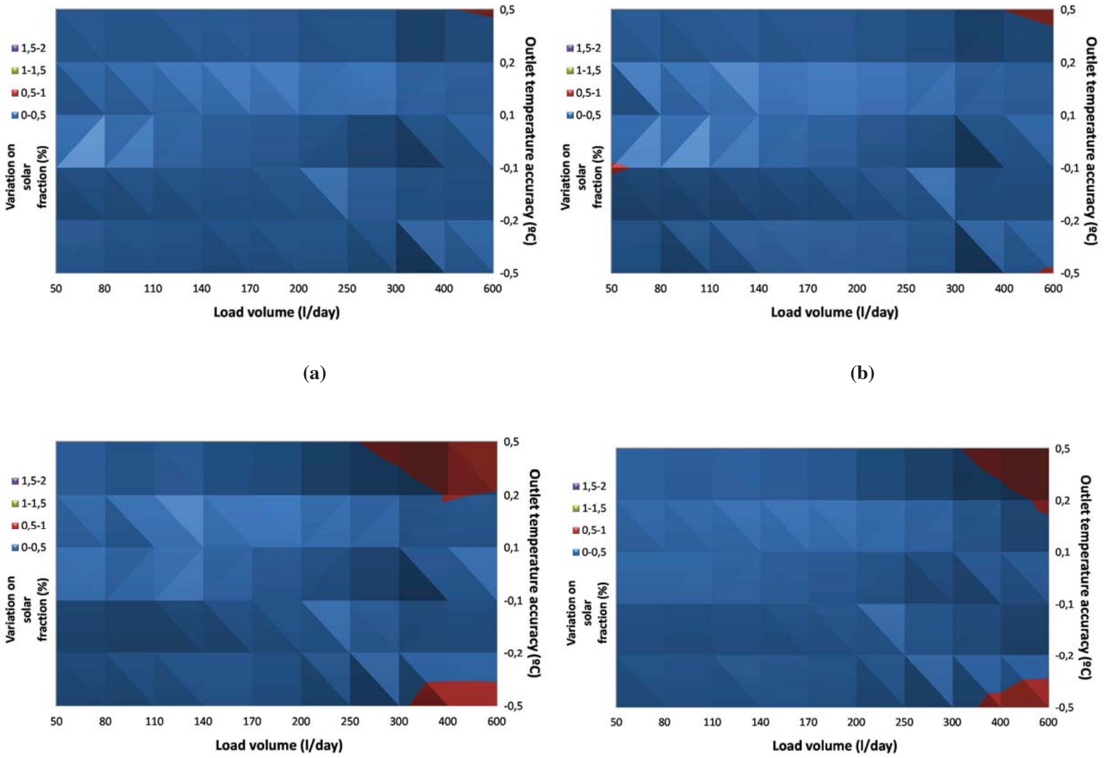
(a) (b)

(c) (d)

Fig. 4: Average relative error on solar fraction to modify inlet temperature measurement accuracy in Stockholm (a) Würzburg (b) Davos (c) and Athens (d)

b. Outlet temperature

As shown in Figure 5, the maximum difference of the solar fraction obtained between the results to testing sample and the results in all outlet temperature measurement accuracies (table 1) is lower than 1% in different reference locations. The maximum difference in variation on solar fraction is lower than 0.4% to measurement accuracies according to Standard ISO 9459-5 (± 0.1 ºC) and 1% to other measurement accuracies proposed (± 0.2 ºC, ± 0.5 ºC).



(a)

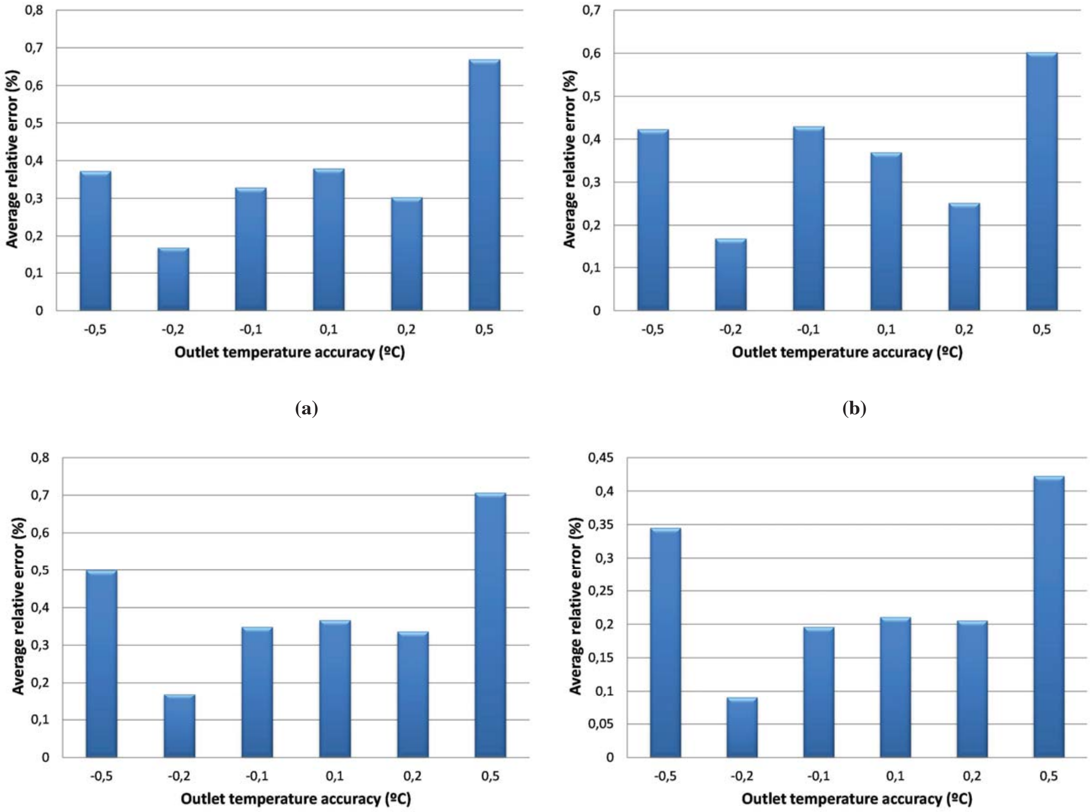
(b)

(c)

(d)

Fig. 5: Variation on f_{SOL} to modify outlet temperature measurement accuracy in Stockholm (a) Würzburg (b) Davos (c) and Athens (d)

Figure 6 shows the average relative error of solar fraction with respect of outlet temperature accuracy in all reference locations. The maximum average relative error on solar fraction is lower than 0.4% for the measurement accuracies according to Standard ISO 9459-5 (± 0.1 ºC) and 0.7% for other measurement accuracies analized (± 0.2 ºC, ± 0.5 ºC). The minimun values of average relative error on solar fraction occurs on Athens location.



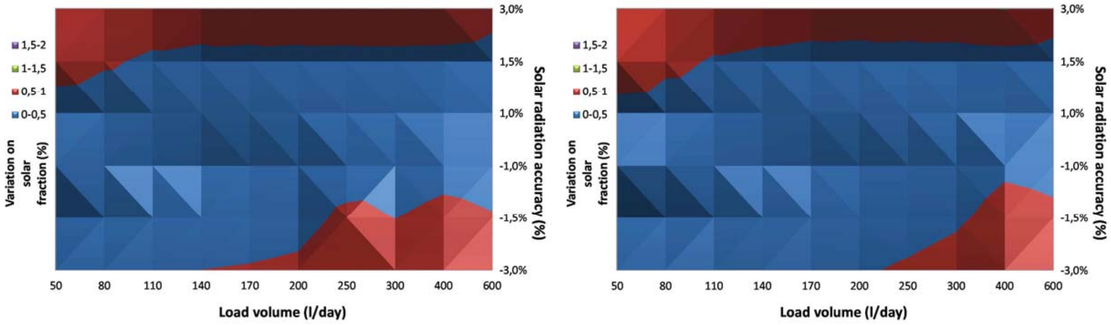
(a) **(b)**

(c) **(d)**

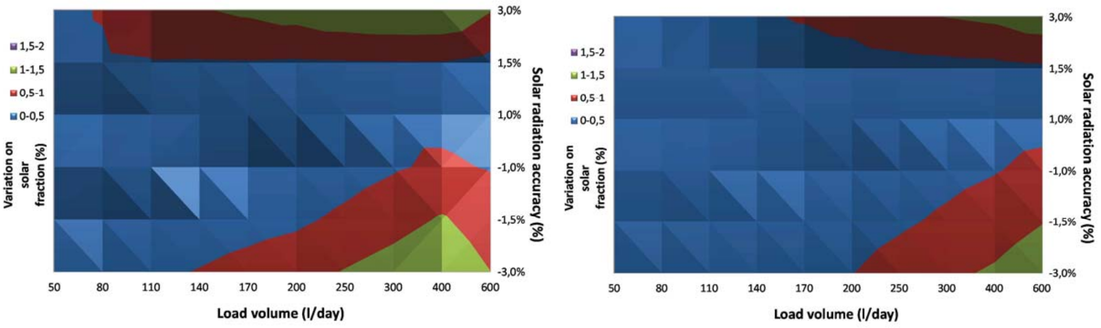
Fig. 6: Average relative error on solar fraction to modify outlet temperature measurement accuracy in Stockholm (a) Würzburg (b) Davos (c) and Athens (d)

c. Solar radiation

As shown in Figure 7, the maximum difference of the solar fraction obtained between the results to testing sample and the results in all solar radiation measurement accuracies (table 1) is lower than 1.3% in different reference locations. The maximum difference in variation on solar fraction is lower than 0.7% to measurement accuracies according to Standard ISO 9459-5 (± 1.0 %) and 1.3% to other measurement accuracies proposed (± 1.5 %, ± 3.0 %).



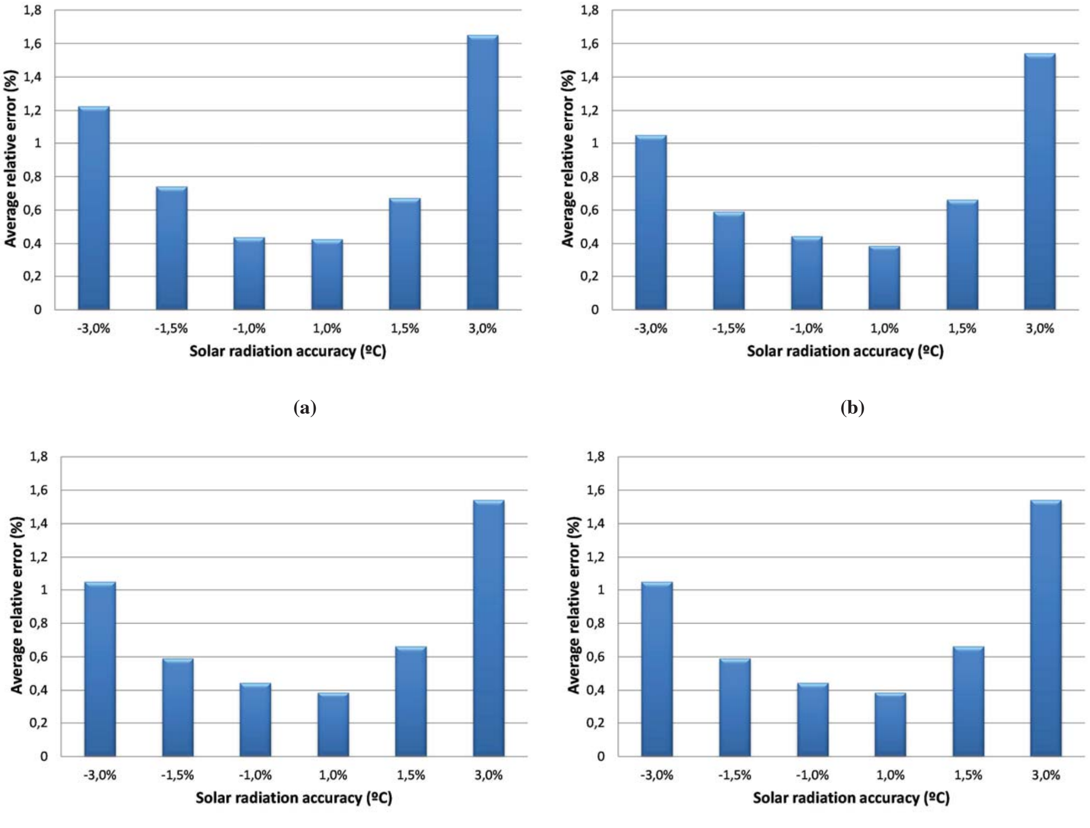
(a) **(b)**



(c) **(d)**

Fig. 7: Variation on f_{SOL} to modify solar radiation measurement accuracy in Stockholm (a) Würzburg (b) Davos (c) and Athens (d)

Figure 8 shows the average relative error of solar fraction with respect of solar radiation accuracy in all reference locations. The maximum average relative error on solar fraction is lower than 0.5% for the measurement accuracies according to Standard ISO 9459-5 (± 1.0 %) and 1.6% for other measurement accuracies proposed in this study (± 1.5 %, ± 3.0 %).



(a) **(b)**

(c) **(d)**

Fig. 8: Average relative error on solar fraction to modify solar radiation measurement accuracy in Stockholm (a) Würzburg (b) Davos (c) and Athens (d)

5. Conclusion

The influence of measurement accuracies of some input parameters is analyzed (inlet water temperature, outlet water temperature and solar radiation) obtaining the following conclusions:

- The maximum differences on solar fraction when using the measurement accuracy according to Standard ISO 9459-5 varies between 0.4% (for the outlet temperature) and below than 0.7% (for the inlet temperature and solar radiation) considering all load volumes in the reference locations.
- The maximum differences on solar fraction when using the new measurement accuracies proposed in this study varies between 1% approximately (for the inlet temperature and outlet temperature) and 1.6% (for the solar radiation) considering all load volumes in the reference locations.
- The maximum average relative error on solar fraction when using the measurement accuracy according to Standard ISO 9459-5 is approximately 0.5% (for the inlet temperature, outlet temperature and solar radiation) in the reference locations.
- The maximum average relative error on solar fraction when using the new measurement accuracies proposed in this study varies between approximately 0.6% (for the inlet temperature and outlet temperature) and 1.6% (for the solar radiation) in the reference locations.
- This study shows that it is possible to increase the measurement accuracies range required in Standard ISO 9459-5 without losing effectiveness on the results obtained in long-term prediction (solar fraction).

6. Nomenclature

Symbol	Quantity	Unit
A^*	effective collector area	m^2
C_S	total store heat capacity	MJ/K
D_L	mixing constant	--
f_{SOL}	solar fraction	--
G	solar irradiance	W/m^2
H	solar radiation	MJ/m^2
T_a	ambient temperature	°C
T_{cw}	inlet water temperature	°C
T_S	outlet water temperature	°C
Q_{aux}	parasitic energy (electricity)	MJ
Q_d	head demand	MJ
Q_L	heat delivered by the solar heating system	MJ
S_C	store stratification	--
u_C^*	effective collector loss coefficient u_C^*	W/m K
U_S	total store heat loss coefficient	W/K
$\dot{V}_S$	flow-meter	l/min

7. Reference

EN 12976-1: 2006, Thermal solar systems and components. Factory made systems –Part 1: General requirements.

EN 12976-2: 2006, Thermal solar systems and components. Factory made systems –Part 2: Test methods.

ISO 9459-2: 2007, Solar heating – Domestic water heating Systems. Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems.

ISO 9459-5: 2007, Solar heating – Domestic water heating Systems. Part 5: System performance characterization by means of whole-system tests and computer simulation.