# NEW CALCULATION METHODOLOGY FOR SOLAR THERMAL SYSTEMS

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## 1. Introduction

Spain has been one of the first countries worldwide to develop a legal framework that aims to fully develop the potential of the solar thermal systems for DHW in the residential building sector. Given the lack of references and the complexity of the building sector, several problems have arisen as the application in practice has showed more difficulties than expected. One of the problems detected it's been the lack of standardization of sizing methodologies among the installers and engineers; to solve this, the administration has made a big effort to generate a precise and simple sizing method for all the actors in the sector. This paper describes the work carried out to generate that methodology.

The developers have done an F-Chart approach to build such a calculation method: to run a big number of simulations of some detailed TRNSYS models and extract correlations from the results to evaluate the performance of the systems without having to deal with detailed models. However, given the faster computers available nowadays it's been possible to extend the application range for the results.

The results for the 69.000 thousand simulations have yield a total of more than 800.000 integrated data in monthly basis, that have been correlated to generate a monthly based method for the sizing of solar thermal systems, as well as for the prediction of the fulfilment of the solar energy production set by the law for domestic hot water systems. All the procedure has been included in an easy to use and free downloadable graphical user interface. Several extensions of the procedure for solar heating and/or cooling systems are now in a previous feasibility stage to try to increase the application framework of the procedure.

## 2. Boundary conditions: overview of the Spanish market

We find convenient to briefly introduce the requirement that the legal framework states over the solar system. The main indicator stated by the CTE (Spanish building code) for the solar systems in residential and tertiary buildings is the obligation of achieving a certain Solar Fraction of the domestic hot water demand (hereafter, DHW) delivered by the solar thermal system. Since the code also sets the daily DHW demand, mainly as a function of application, this requirement is equivalent for a given building to install a solar system with the necessary properties to generate and deliver in yearly basis a certain amount of solar energy. The solar fraction required is dependent on the daily load, the radiation at the location and auxiliary system planned.

This calculation can be done with a wide variety of available methodologies and software packages, with different degrees of complexity and precision. As the calculation precision is mandatory, a dynamic simulation method is more attractive, but, given the standardization and verification nature of the methodology needed, we are inclined to consider a simple calculation method as a reference for the process due to:

- The final users are mainly installers, engineers and architects so they have an unknown and variable degree of knowledge of engineering and numerical calculation methods.

- The number of inputs and outputs should be small in order to ease the administrative managing of the information.

- It is preferred an instantaneous calculation method since this strengthens its user-friendlessness and is more efficient from the user point of view, what helps its widespread utilization.

- The reference meteorological data (radiation, ambient temperature, cold water temperature) from

available legal codes are set in monthly basis, that is, a format incompatible with dynamic simulations.

Given that, the most popular solution is the F-Chart method (Klein et al., 1975), that it is well-known, user-friendly and precise, but has the following limitations:

- The correlations characterizing the F-Chart method are deduced for a single system configuration; this is, a combisystem for single family solar thermal systems that is very different from most of the solar thermal systems installed in Spain, that are DHW solar thermal systems installed in multi-dwelling urban constructions with different degrees of centralization of the solar storage and auxiliary system.

- The F-Chart method assumes that neither the solar tank nor the solar field reaches its maximum allowed temperatures. This hypothesis is far from the actual behavior of most of these installed systems that, in some cases, should reach up to 70 % of the yearly DHW load coverage.

- The collectors second order coefficient is not considered in the calculations, maybe due to the relatively low stagnation temperatures achieved when the method was developed.

- The daily load profiles used for the F-Chart are somewhat different than those legally established in Spain.

- The range of validity for the input parameters defined in the F-Chart method is relatively small in comparison with the average systems installed in Spain (Klein et al., 1975).

Given all this factors, we decided to develop a specific calculation methodology to fit within the legal validation process for the mandatory thermal systems; the Table 1 summarizes the main differences among the F-Chart and the developed method.

Tab. 1: Summary of differences among F-Chart and the new proposed sizing method

| Field | F-Chart | Aiguasol Chart |
|---|---|---|
| Configurations | 1 | 7 |
| Number of simulations | Over 300 | Over 69.000 |
| Locations | 1 | 5 |
| Load | Up to 560 kg/day | Up to 4.600 l/day |

### 3. METASOL: The New Calculation Methodology

The approach used to generate the new method is identical to the one used to develop F-Chart: starting from a TRNSYS model, a set of key parameters (inputs) is varied, simulations executed and results (outputs) are used to extract a set of correlations (statistical functional dependencies) among inputs and outputs.

In the case of MetaSol, 7 different configurations are considered;. TRNSYS 16 (Klein et al., 2004) models are taken from TRANSOL 3.1 (Salom et al, 2009), a TRNSYS-based application for the dynamic simulation of solar thermal systems. TRANSOL is a GUI that allows parameterizing very detailed models for DHW, space heating, cooling and industrial applications. The systems considered are the following:

- System 1: Solar system with solar field, coiled heat exchanger inside the solar tank, auxiliary system in series, thermostatic valve and single consumption.

- System 2: Solar system with solar field, external heat exchanger, solar tank, auxiliary system in series thermostatic valve and single consumption.

- System 3: Solar system for multiple consumption (dwellings) with decentralized solar tank and auxiliary system.

- System 4: Solar system for multiple consumption (dwellings) with centralized solar tank, decentralized auxiliary system and instantaneous heat exchanger at each consumption point.

- System 5: Solar system for multiple consumption (dwellings) with centralized solar tank, decentralized auxiliary system and direct connection to consumption.

- System 6: Solar system for multiple consumption (dwellings, hotels, etc) with centralized solar tank and auxiliary system and direct connection to consumption.

- System 7: Solar system for multiple consumption (dwellings, hotels, etc) with centralized solar tank and auxiliary system, direct connection to DHW consumption and parallel connection to a swimming pool.

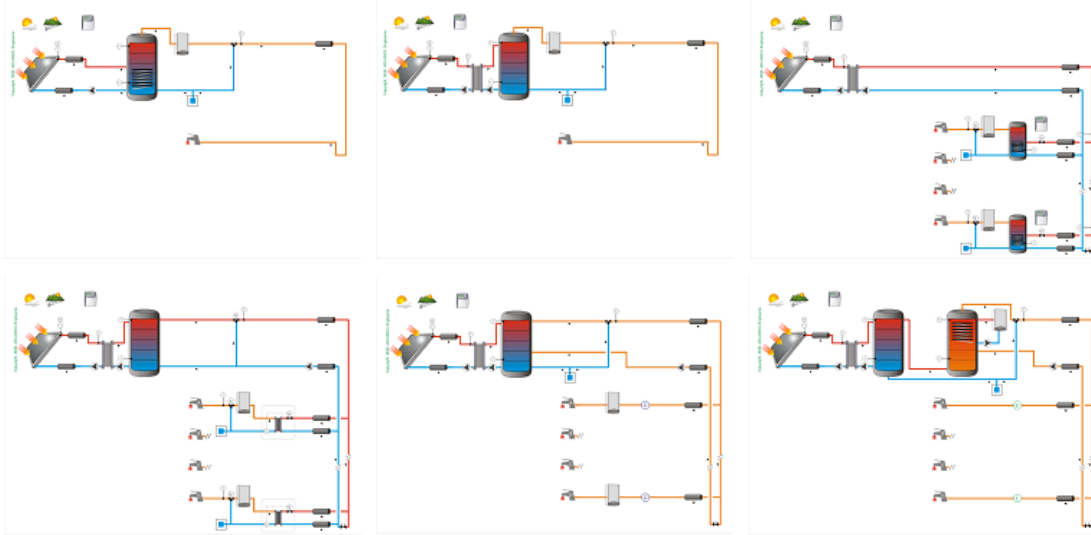A schematic diagram of the systems 1 to 6 is given in Figure 1.



**Fig. 1: Schematic layout of systems 1 to 6. System 7 is the same as the system 6 but with a covered swimming pool in parallel to the DHW consumption.**

Each model has between 110 and 140 TRNSYS units, (including equations, plotter and printers), and a number of parameters ranging from 500 and 1000, so a complete description of the model is outside the scope of this document. Most of the types come from standard TRNSYS libraries, except collector field (type 539, from TESS libraries), storage tanks (type 340, distributed by TRANSSOLAR), piping (type 709, from TESS libraries), boiler and instantaneous heat exchangers (type 801 and 803, developed by Aiguasol) and swimming pool (TRANSSOLAR). It is well known that there exist dependencies between the parameters, based on literature (Heimrath and Haller, 2007), design guides (Martinez, 2008) and sizing criteria of the Aiguasol engineering team.

The dependency between the parameters of the input file is a key fact as it allows keeping consistency in the sizing of all the components of the model. For example, given a certain solar field area, most of the solar field parameters are resized accordingly (solar field flow rate, solar piping diameter, etc) and, given a certain load and number of consumption points, then the distribution loop parameters are automatically sized (distribution length, distribution piping diameters and flow rates, etc). To set a useful model, the number of input parameters must be reduced as much as possible. To this end, the parameters that automatically resize depending on the other inputs are discarded.

Each system is simulated in five different locations: Bilbao, Barcelona, Salamanca, Madrid and Sevilla, each of them representing the five different climatic regions described in the Spanish Building Code, and meteorological data are taken from Meteonorm6.1, a meteorological database distributed by Meteotest. Load profiles and cold water network temperatures are generated according to Spanish thermal systems for building regulation.

### 3.1. Exploratory analysis and nomenclature

As a first step, an exploratory set of simulations was carried out to determine the most influencing parameters on the model output. Although the collector efficiency parameters show a non negligible impact, as well as distribution loop thermal losses and other parameters specific for some systems (for instance, the instantaneous heat exchanger for system 4 or the thermal losses coefficient for system 3), it was, as expected,

evident that there are two parameters that basically determine the *solar useful gain* (denoted by $Y1$ and defined in this work as the solar energy delivered to the auxiliary system connection point): solar radiation on the absorber, $G$ (kJ), and energy demand, $D$ (kJ). Notice that the kind of relation described by the FSC method (Letz, 2003) is close to a quadratic polynomial on the quotient $G/D$, but in that reference they relate it with the fractional energy savings, instead of the solar useful gain, however the relation among this two variables is straightforward. In Section 3.3 we show that $G$, $D$ and specially the dimensionless ratio $G/D$ play a key role in the final model.

As a second step, also exploratory but oriented to initiate the model building process, new parameters and more simulations were added, yielding 30501 cases for the system 1. At this stage, it was found that a multiple linear model[1] could be adjusted at logarithmic scale, that is, considering a linear model that expresses the response[2], ln $Y1$, as a linear combination of the *regressors*[2], ln $G$ and ln $D$. The Figure 2 shows this regression plane, with $R^2=0.9529$, for the simulations of system 1. This multiple linear model seems to fit properly but the residuals, that is, the dot lines projecting individual cases over the plane, are too large for accurately predicting the output.

*Remarks:*

- The notation ln represents the natural or base-*e* logarithm.

- $R^2$ or *R-square,* also called *determination coefficient*, computes the proportion of the variability of the dependent variable (output) explained by the functional model in the explanatory parameters. Referring to Figure 2, it should be interpreted that a 95.29% of the variance of ln $Y1$ is explained by taking only account the projections over the regression plane. See (Jobson, 1991) for knowing more on this and other statistical concepts.

- Most statistical computations were obtained using the GNU-R programming language or using some of their packages (see the references section).
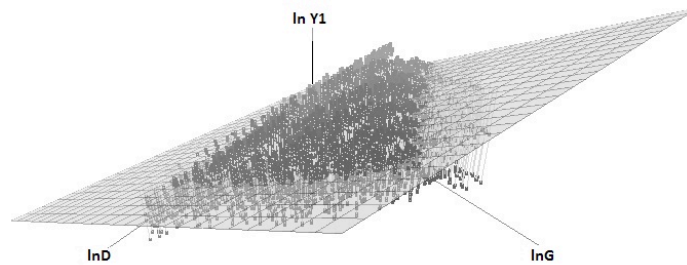


**Fig. 2:   Graphical representation, at logarithmic scale, of the regression plane fitting the solar useful gain (*Y1*) as a linear function of two explanatory variables:  the radiation (*G*) and the demand (*D*).  The values of *Y1* are simulated by TRNSYS and correspond to 30501 cases for system 1. This regression plane representation has been obtained with the *Rcmdr* package developed in GNU-R programming language.**

By the discussion above, it seems clear that in order to adjust a good model for the useful energy gain, the parameters $G$ (the radiation on the absorber) and $D$ (energy demand) must be used.  Note that $G$ also includes implicitly the absorber area, as the radiation is the total energy incident.  To improve the model predictive potential, some new inputs where added o the parametric simulations; they are:

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[1] When the relationship between two or more variables appears to be nonlinear, the technique of linear regression can still be applied if the model can be written as a linear combination of variables which themselves are nonlinear functions (quadratic, logarithmic, etc.) of the initial parameters. This class of models is called *intrinsically linear*.

[2] In regression analysis, the output is also called dependent variable or response, and the input parameters are often called *regressors*, as well as explanatory or independent variables.

- First order coefficient of the solar field (that is collector lineal coefficient corrected by solar field collectors in series, solar field flow rate, solar field piping insulation and length and heat exchanger effectiveness, as described in (Duffie and Beckmann, 1980)).

- Meteorological data (this includes ambient temperature and cold water network temperature).

- Storage volume per solar collector area.

- Collector second order coefficient.

- Number of users.

- Collector field area.

- Number of dwellings (for systems 3, 4, 5 and 6).

- Distribution loop thermal losses coefficient (systems 3, 4 and 5).

- Domestic storage overall thermal losses coefficient (system 3).

- Distribution loop set temperature (systems 6 and 7).

- Instantaneous heat exchanger power (system 4).

- Pool volume and surface (system 7).

The range of the most important parameters considered appears in Table 2. Note that the range specified here is for the whole simulation set, and individual configurations may have reduced applicability ranges. The Table 3 summarizes the symbols used to denote the parameters (explanatory variables) used in the equations describing the final models (see the next subsection).

**Tab. 2: Range of the system simulated principal parameters**

| Variable | Minimum | Maximum |
|---|---|---|
| Collector field area ($m^2$) | 2 | 160 |
| Collector 1st order coefficient ($W/m^2 \cdot K$) | 2.5 | 5.8 |
| Ratio storage/collector area ($m^3/m^2$) | 0.05 | 0.1 |
| Users | 4 | 300 |
| Dwellings | 8 | 36 |
| Collector 2nd order coefficient ($W/m^2 \cdot K^2$) | 0.005 | 0.225 |
| Daily load (l/day) | 190 | 4600 |

For the 30501 simulations in system 1, statistical analyses were applied to indentify factors main effect and interactions. Some results are shown in Figure 3: All the graphics in the panel analyze the effect of factor $A2$

**Tab. 3: Notations for the parameters used in the final models. In two cases, two different notations are used interchangeably: $F1$ or $G$ denoting radiation on the absorber and $A3$ or $D$ denoting energy demand.**

| (var) | Description | Systems |
|---|---|---|
| $A1$ | First order coefficient of the solar field (corrected*) | All |
| $A2$ | Collector field area | All |
| $A3$ (D) | Energy demand | All |
| $A4$ | Storage volume per solar collector area | All |
| $A5$ | Collector second order coefficient. | All |
| $A6$ | Distribution loop thermal losses coefficient | 3, 4 and 5 |
| $A7$ | Instantaneous heat exchanger power | 4 |
| $A8$ | Domestic storage overall thermal losses coefficient | 3 |
| $A9$ | Distribution loop set temperature | 6 and 7 |
| $F1$ (G) | Radiation on the absorber | All |
| $F2$ | Meteorological data ($\approx$ Mean ambient temperature) | 4, 5 and 6 |
| $F3$ | Meteorological data ($\approx$ Cold water network temperature) | 4, 5 and 6 |

* That is collector lineal coefficient corrected by solar field collectors in series, solar field flow rate, solar field piping insulation and length and heat exchanger effectiveness, as described in (Duffie and Beckmann,1980).

on the mean response, each time interacting with a second factor (*A*1, *Users*, *A*4 and *A*5) and leaving the remainder factors varying freely. The following facts can be observed: (a) A direct increasing trend effect of the size collector area (*A*2) on the mean response value. (b) A curvilinear type curve is suggested when the number of users is fixed. (c) The influence of factors *A*4 and *A*5 seem to be poor at mean level, but will be non negligible for prediction purposes. See Table 3 for the descriptions of these parameters.
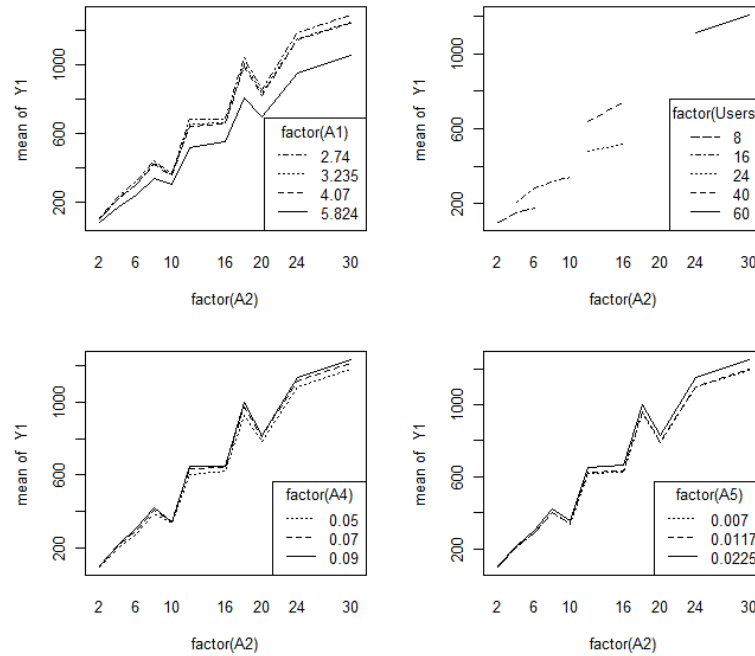


**Fig.3: The graphics in this panel show some factors individual influence and second order interactions over the useful energy gain. All the cases correspond to simulations of system 1. In all the graphics, the mean values of *Y*1 (averaged within the groups defined by factor *A*2) are represented in the vertical axis. Moreover, a second factor is considered in each graphic (*A*1, *Users, A*4 and *A*5, from top left to down right); each line corresponds to a different level of the second factor.**

### 3.2 Statistical methodology

Once completed the exploratory analysis, several functional transformations for the initial parameters are tested and a handmade variable selection has been performed sequentially (introducing new parameters one by one). The aim was to obtain a final model with a good predictive behavior. Different data sets are considered for defining and validating the models. The goodness of fit is evaluated by:

a) The *R-square* coefficients, at the logarithmic scale first and at the usual scale secondly.

b) A primary analysis of the residuals, at the logarithmic scale.

c) The analysis of the *relative residuals,* at the usual scale (non logarithmic), that is,

$$\text{relative residuals } = .\frac{Y1\text{- predicted } Y1}{Y1}. \quad \text{(eq. 1)}$$

The relative residuals are often multiplied by 100 and expressed in %.

Furthermore, only statistically significant variables are introduced in the final model. Multicollinearity is taken into account and some redundant variables are eliminated, but some collinear variables are kept in the final equation because they do not reduce the reliability of the model and, moreover, it is observed that coefficients do not change erratically with small data changes. In Jobson (1991) there is a complete discussion on linear models analysis.

At the end of the mathematical process, several models are evaluated by Aiguasol Engineering. The models presented in this paper are chosen because they balance simplicity and goodness of fit. The results are analyzed in the Section 3.3.

## 3.3 Main result: equations of the models

The key results of the METASOL methodology are summarized in Table 4. This table gives the necessary information for predicting the useful solar gain for each system from 1 to 6. The system 7 is treated separately and does not appear in the following sections.

The METASOL's approach to STS consists in to compute $Y1$ through a linear expression for $\ln Y1$. For each configuration, Table 4 shows the coefficients of this linear equation in the parameters expressed in the first column of the table. For instance, for the system 1, the equation is

$$\ln Y1 = -0.53 + 1.06 \ln F1 - 0.02 \ln A3 - 0.06 X^2 - 0.04 X^3 - 0.01 X^4 - 0.07 A1 - 23.32\ (A2/A3) + 2.07 A4 - 3.06 A5$$

$$(\text{eq. 2})$$

where

$$X = \ln(F1/A3) = \ln(G/D). \quad (\text{eq. 3})$$

For the systems 2 to 6, the equations can be obtained in the same way.

**Tab. 4: Summary of coefficients for each system. The explanatory variables appear in the first column, and the model coefficients in the subsequent columns. Recall that ln$A$ means base-$e$ logarithm of $A$. The term $F1F2$ denotes $F1$ times $F2$.**

|  | system 1 | system 2 | system 3 | system 4 | system 5 | system 6 |
|---|---|---|---|---|---|---|
| (Intercept) | -0,52849919 | -0,17352839 | -0,87138227 | -1,90944159 | -0,73550385 | 1,3348784 |
| ln$F1$ | 1,06087913 | 1,12695378 | 0,77652561 | 0,88981308 | 0,89949822 | 0,95731909 |
| ln$A3$ | -0,02008222 | -0,09126768 | 0,37556283 | 0,2720786 | 0,22688735 | -0,01741347 |
| $X^2$ | -0,06270279 | -0,06593306 | 0,02711028 | -0,04533852 | -0,09178239 | -0,05237765 |
| $X^3$ | -0,03782808 | -0,05819713 | -0,0412086 | -0,02627021 | -0,00919135 | -0,02668652 |
| $X^4$ | -0,01152248 | -0,01403032 | -0,02135282 | 0,05491462 | 0,05467863 | 0,05470568 |
| $A1$ | -0,07211289 | -0,04599847 | -0,03261289 | -0,03547851 | -0,03714765 | -0,05754523 |
| $A2/A3$ | -23,3244249 | -45,9672722 | -12,1873339 | -24,2126945 | -27,7105928 | -26,407206 |
| $A4$ | 2,06557417 | 0,82504083 | -0,06083965 | 0,01511333 | 1,14048506 | 0,80450244 |
| $A5$ | -3,06340657 | -1,41551984 | -0,71907997 | -0,68177441 | -0,86638184 | -1,72811438 |
| ln$A6$ |  |  | -0,04381463 | -0,16347837 | -0,14943719 | 0,05107806 |
| ln$A8$ |  |  | -0,09197948 |  |  |  |
| ln$A7$ |  |  |  | 0,09388373 |  |  |
| $F1F2$ |  |  |  | 9,76E-07 | 8,87E-07 | 8,28E-07 |
| ln$F3$ |  |  |  | 0,08617483 | 0,06435627 | 0,03248366 |
| ln$A9$ |  |  |  |  |  | -0,28998103 |

## 3.3.1 Analysis of the models

The Table 5 and the Figure 4 show some important features of the models. The value of $R^2$ is close enough to one in each model for $\ln Y1$ (see Table 5, column $R^2$ (logarithmic scale)). Moreover, coming back to the usual scale, the values of $R^2$ in Table 5, last column, are close to one too, indicating that models fit reasonably well.

**Tab. 5 Linear models quality of fit.**

| System | $R^2$ (log sccale) | Absolute residuals | | Relative residuals (quantiles) | | | | $R^2$ |
|---|---|---|---|---|---|---|---|---|
|  |  | min | max | 05 | 25 | 75 | 95 | |
| 1 | 0,991 | -493.73 | 157.97 | -12.13 | -4.30 | 4.28 | 10.40 | 0,986 |
| 2 | 0,997 | -2090.46 | 1114.31 | -7.94 | -3.27 | 3.42 | 7.23 | 0,995 |
| 3 | 0,992 | -415.18 | 407.01 | -11.53 | -3.37 | 3.80 | 8.18 | 0,991 |
| 4 | 0,994 | -442.55 | 302.65 | -9.57 | -3.48 | 3.44 | 8.22 | 0,992 |
| 5 | 0,996 | -386.21 | 269.68 | -7.28 | -2.97 | 2.95 | 6.54 | 0,994 |
| 6 | 0,991 | -819.28 | 449.77 | -9.71 | -3.55 | 3.57 | 8.64 | 0,991 |

Nevertheless, as it is said before, the most important indicators are those referring to the relative residuals (eq. 1). Looking at (eq. 1), it is clear that the negative values of residuals indicate overestimation of $Y1$ and

that the positive values correspond to underestimation of this variable. The lowest and the highest quantiles in Table 5 express a bound for the percentage of cases giving rise to predictions far from the simulated value of $Y1$. Indeed, the quantile values can be understood as follows: in system 1, the 05-quantile equals -12.13 (an underlined value in the table), telling us that only a 5% of cases are highly overestimated with predictions for $Y1$ of the order of $1.1213\,Y1$ or higher. Symmetrically, the underlined value +10.4 of the 95-quantile for system 1 indicates that only a 5% of cases are highly underestimated with predictions of the order of $0.896\,Y1$ or lower (0.896=1-0.104). All the relative residuals are represented in the schematic box plot graphics in Figure 4. The highest relative errors arise in systems 1 and 3.
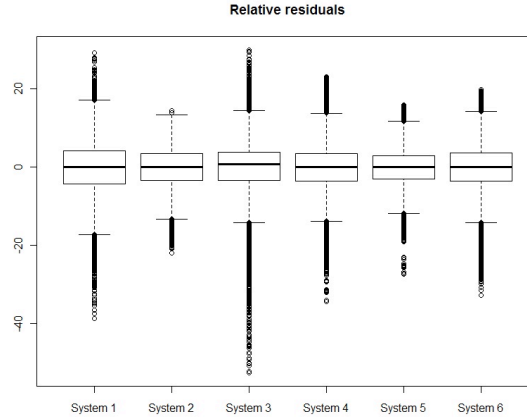


**Fig.4: Comparative box plot of the relative residuals, in % (see (eq. 1)) of the six systems models. The scale in the vertical axis corresponds to the relative residual (%). The horizontal line near the middle of the box is the median (50th percentile) relative residual, which is close to zero; the bottom and top of the box are the 25th and 75th percentiles. Any data not included between the whiskers is plotted with a small circle and so it is considered an outlier. Only a one percent of data are outlier.**

### 3.2 Synthetic expressions

For description purposes, the model equations can be transformed to more compact expressions. For instance, the model of system 1, described by (eq. 2) and (eq. 3), can be easily changed to appear as an expression of the type

$$Y1 = f(G/D)\exp(g(A1,A2,D,A4,A5)), \quad \text{(eq. 4)}$$

where, for the sake of simplicity, we use $G$ instead of $F1$ and $D$ instead of $A3$, the functional $f$ is

$$f(G/D) := (G/D)^{1.06}\exp(-0.06\,X^2 - 0.04\,X^3 - 0.01\,X^4), \quad \text{(eq. 5)}$$

with $X=\ln(G/D)$, and the functional $g$ is defined by

$$g(A1, A2, D, A4, A5) := -0.53 + 1.04\ln D - 23.32\,(A2/D) - 3.06\,A5 - 0.07\,A1 + 2.07\,A4. \quad \text{(eq. 6)}$$

By analogous reasoning, similar but more complex equations can be derived for systems 2 to 6. Going a little bit further, an approximate expression is obtained relating two dimensionless quantities $Y1/D$ and $G/D$, with an exponential correction term:

$$\frac{Y1}{D} := f(G/D)\exp(-0.53 + 0.04\ln D - 23.32\,(A2/D) - 3.06\,A5 - 0.07\,A1 + 2.07\,A4). \quad \text{(eq. 7)}$$

## 4. Contrast between F-Chart METASOL and F-Chart

Nowadays, due to its speed and simplicity, the F-Chart method (Klein et al., 1975) remains one of the most used. However, the calculation of systems with this methodology involves important simplifications and assumptions, which are not always taken into consideration.

In the beginning, F-Chart was designed to calculate a single type of system (DHW systems for single family and heating). Although subsequent amendments, allowed its use in more types of configurations, their range of validity remains limited.

The use of F-Chart for the calculation of the most common systems in the Spanish market (residential buildings) is often inadequate. These limitations motivate the creation of a new methodology.

### 4.1 Differences in the process of developing methods

During the process of developing the F-Chart method (Klein et al., 1975), a number of hypotheses were assumed. Thus, it could obtain a physical phenomenon governing equations relatively simple. Analyzing these equations it was found that the physical phenomenon depended mainly on only two dimensionless groups. Thanks to this fact, it was possible to generate a model of precision, from a small number of simulations.

With a single curve, function of two dimensionless groups, F-Chart can predict the solar fraction of the system with high accuracy (as long as they fulfill all the hypothesis assumptions).

If the complexity of the systems increases, the above procedure may not be reproduced and no dimensionless group can be determined. Because of this, the subsequent statistical treatment should be much more complex and the number of simulations required will be higher.

### 4.2 Results contrast

Below there's a comparison between the results of the two methodologies. It is not meant to be a rigorous analysis of their accuracy. It's just an example to illustrate their key differences.

The case analyzed corresponds to an apartment building with a demand of 3740 l/day, located in Seville. All the systems calculated have the same collector area (40.2 m2) and a volume of 7m3 of accumulation. As a reference, it has also has been simulated using TRNSYS (Transol).
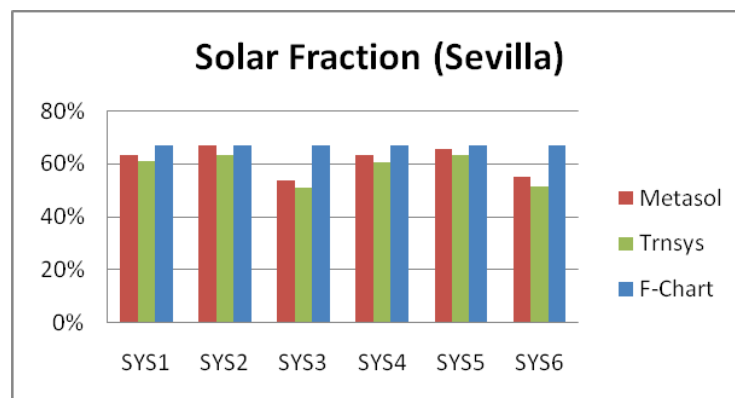


**Fig. 5: SF of the different systems calculated by METASOL, TRNSYS and F-Chart.**

As already mentioned in the previous section, F-Chart only considers a single type of system and its use for other configurations can lead to major deviations. Another problem associated with the use of F-Chart for the calculation of such systems is the lack of consideration of the distribution losses. In detached systems, as originally proposed in F-Chart, such losses can be considered negligible. However, in systems for residential buildings they may mean a significant percentage of total losses.

As shown in Figure 5, using the F-Chart for the calculation of any of the systems would mean an undersized of them.

## 5. CHEQ4: Implementing METASOL

The calculation methodology METASOL it's created with the aim to offer to all the sector players, a simple tool for dimensioning. For this reason, it has been necessary to develop an intuitive interface, called CHEQ4.
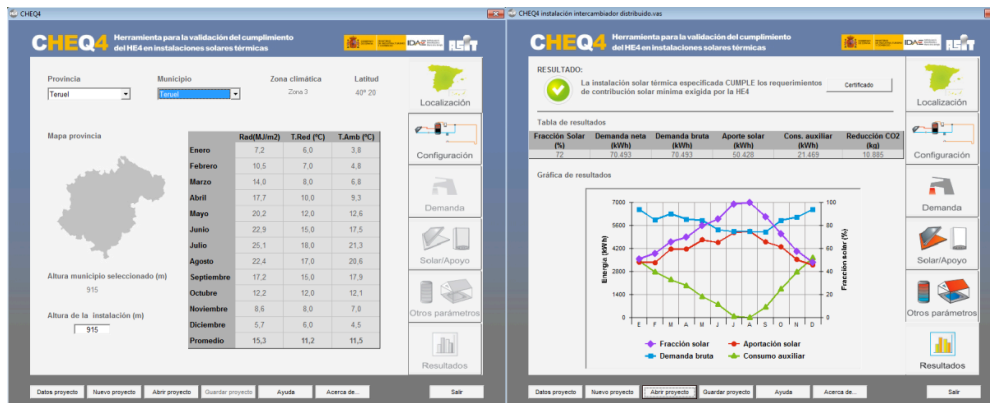
**Fig 6. Screenshots CHEQ4 software.**

CHEQ4 is a free downloadable software that allows validating compliance with the minimum solar contribution, as required by Spanish law. The software incorporates all the necessary government databases and generates an official justifying report; see an example of some of its windows in Figure 6.

## 6.  Conclusions

Spain has been one of the first countries worldwide to develop a legal framework that aims to develop the potential of the solar thermal systems for DHW in the residential building sector. However, it is necessary to define a clear and standard sizing methodology in order to keep developing its full potential.

The METASOL methodology, displayed in this paper, allows to predict, in a quickly and accurately way the behaviour of the main types of solar thermal systems that are more common in Spain.

The models are close to natural solutions for the heat transference equations, as (eq. 7) says, and show satisfactory predictive behaviour. In the future, more accurate models could be tested.

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