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Solar combisystem characterization with a global approach test and a neural network based model identification

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Abstract

The market for small Solar CombiSystems (SCSs) is penalized by its lack of common performance test method. The methodology proposed in this paper is based on the SCSPT procedure which tests each combisystem as a whole system on a semi-virtual test bench. Test results are used to identify a "Gray Box" model of the tested SCS, which includes an Artificial Neural Network. This model can then simulate the behavior of the system for any climate and any building. Results of all those simulations are finally used according to the FSC procedure in order to characterize the tested SCS performances with a simple curve. An experimental study of this methodology with two real SCS is presented in this paper.

Keywords: Neural networks; solar combisystems; semi-virtual test bench; performance prediction; characterization

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1. Background

Solar CombiSystems (SCSs) can be very efficient in reducing primary energy consumption of a house. It has already been observed that some of them have reached very good performance criterions (like fractional energy savings f_{sav} around 50%). Unfortunately, such good performances are not met by every SCS installed and currently, it is impossible to predict SCS performances. This kind of prediction is difficult because SCS performances are very sensitive, mainly to two points:

- Firstly, even though every component is efficient, a little mistake in design or installation can make the combisystem behave differently as it was supposed to. Its performances could be then deeply reduced,
- Secondly, combisystem performances strongly depend on its working "environment", i.e. climatic conditions and energy demand.

And yet the SCS market needs a way to characterize systems to win trust of potential users. This methodology then should be able to test systems in real conditions, i.e. installed as they are in real houses, and to predict their performances for any kind of climate and any kind of building.

Nomenclature

G	Total solar irradiance on the collector plane (W.m-2)
G_{ref}	Reference solar irradiation (W.m-2)
$\dot{Q}_{sol,net}$	Net solar energy available at the bounds of the collector (W.m-2)
$\dot{Q}_{coll}$	Heat flow rate supplied by the collector (W)
$\dot{Q}_{aux}$	Power consumed by the auxiliary heater (W)
$\dot{Q}_{aux,nom}$	Auxiliary heater nominal power (W)
$\dot{Q}_{sh}$	Heat flow rate transferred from the radiator to the room (W)
$\dot{Q}_{sh,nom}$	Standard heat load at design outdoor temperature for chosen location (W)
$\dot{Q}_{em}$	Heat flow rate supplied for the heat emitter (W)
$\dot{Q}_{dhw}$	Heat flow rate supplied for the DHW demand (W)
T_a	Ambient temperature (°C)
$T_{a,d}$	Ambient design temperature of heating system at chosen location (°C)

T_{room}	Mean temperature of the room air (°C)
$T_{set,room}$	Room set point temperature (°C)
T_{coll}	Mean temperature of the collector (°C)
T_{em}	Mean temperature of the heat emitter (°C)
T_{sto}	Mean temperature of the storage tank (°C)
T_{tap}	Temperature of water at input of tap water net (°C)
$\dot{m}_{dhw}$	DHW draw off (kg.hr-1)

There are currently some powerful lab tests for combisystems but none of them can reach the two expected goals directly (test in real conditions and evaluation for any kind of environment). Those tests can be classified in two main categories:

- "Component approach" tests consist in testing each component of a SCS separately. They are very flexible, but they don't take into account real interactions between the components of the tested system; as well as they are not considering the whole control system which is a crucial point,
- "Global approach" tests consist in testing each SCS as a whole. Real interactions between components are then taken into account but results are mainly reduced to the working environment and the sizing of the system considered during the test.

A new methodology, based on the "Global approach" SCSPT procedure [1] has been investigated. It analyses test data in a more complete way in order to identify a reliable dynamical model of the tested SCS, which could be used to characterize its performances. A first study with TRNSYS simulations has shown that this approach seems relevant [2]. This paper presents further results, obtained through tests of two real SCS.

2. The proposed methodology

The methodology is largely explained in [3]. It is made of three main steps.

2.1. The Short Cycle System Performance Test (SCSPT)

The first step is to test the SCS (including the auxiliary system) as a whole according to the SCSPT procedure. This procedure is described in [1]. The SCS to be tested is set up entirely on a semi-virtual test bench: the system is plugged to thermo-hydraulic modules which "emulate" the behavior of thermal loads (DHW draw offs, space heating needs) or sources (solar collectors). Those modules act according to a parallel TRNSYS simulation running in a "real-time" mode. The SCS is then physically linked to a virtual environment.

The SCSPT procedure consists then in applying a 12 days weather test sequence. This sequence is made in order to make the system consume proportionately the same auxiliary energy during the test sequence, as it would consume during a complete year with the selected building and climate condition. It closely matches an annual weather cycle of one precise climate to make the SCS behave as it usually does over a year. Energy flows are recorded at the bound of each loop of the system. The SCSPT procedure thus takes into account potential design mistakes, as well as control strategy.

2.2. "Gray Box" modeling of the tested SCS

So far, with the "classical" SCSPT procedure, it was possible to evaluate the tested SCS annual performance only for the situation considered in the test sequence (climate, building and system sizing). This can be enough in the perspective of energy labeling, but is too limited in the objective of providing simplified design calculation tool, or the characteristic curve of SCS.

Instead of simply extrapolate the SCS performance, the new method aims to analyze completely test data to identify a reliable dynamical model. It would let the SCS be simulated for any kind of situation.

The model to be identified is made of two parts.

2.2.1. The "Black Box" part

The "Black Box" part is a pure numerical model. It learns the behavior of the combisystem by identifying its parameters from a dynamical input/output analysis. This part would model how the tested combisystem deals with its energy flows (outputs) according to external variables and the main temperatures of its different elements (inputs).To face non-linear behaviors of the system, an Artificial Neural Network is used in this part.

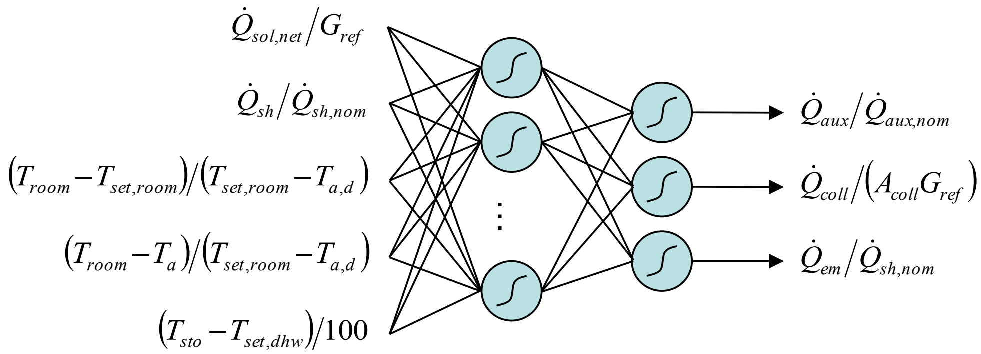

Fig. 1. Structure of the ANN considered in the "Black Box" part

Inputs and outputs of the Artificial Neural Network are not only raw temperatures and energy flows. They are reduced criterions mixing variables and sizing parameters such as, for instance, the heat transferred from the radiator to the room Q_{sh}, divided by the standard heat load of the building, $Q_{sh,nom}$, which also depend on the climate considered. This way, optimization algorithm works more efficiently to find the proper parameters of the neural networks. Moreover, it also helps simulating the SCS behavior within different situations.

2.2.2. The "White Box" part

The "White Box" part is composed of well-known equations, based on some characteristic parameters of the main combisystem components (auxiliary energy system, solar collector, heat emitter). It evaluates the main temperatures of those components according to external variables and energy flows within the combisystem.

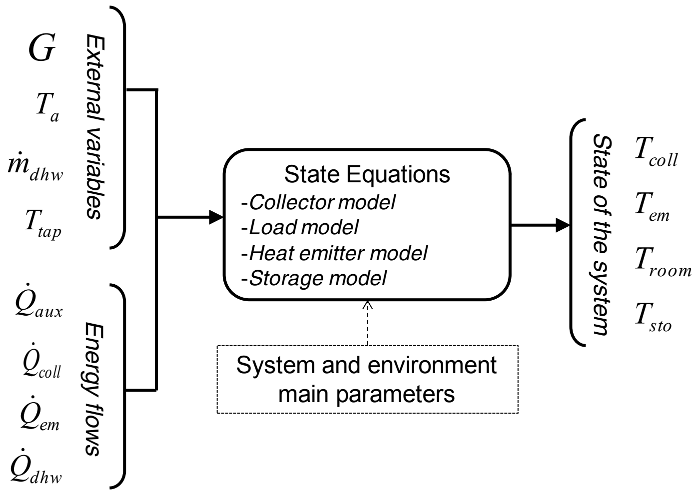

Fig. 2. Scheme of the "White Box" part

So the whole model is called the "Gray Box" model.

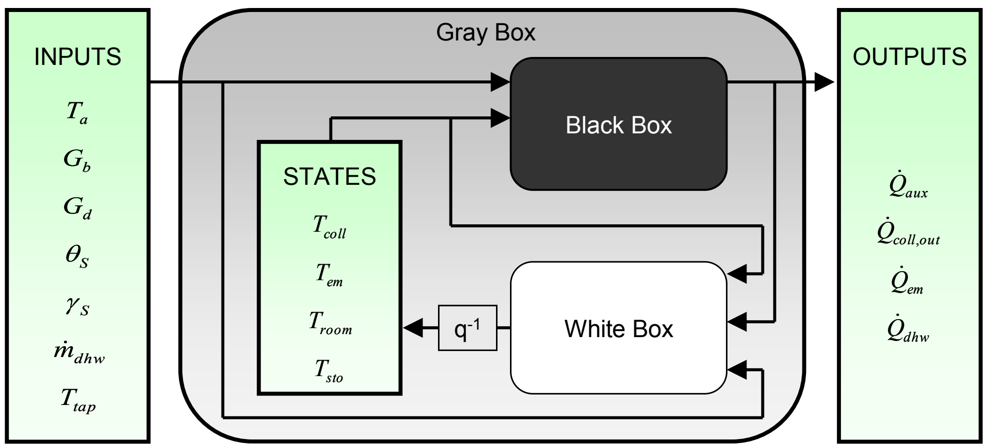

Fig. 3. Architecture of the "Gray Box" model proposed to model SCS behavior from SCSPT experimental results

During simulations, the "White Box" part acts as a dynamical state feedback, supplying components temperatures evaluation as inputs for the "Black Box" model. Therefore, once trained, the whole model can be used to do several simulations by itself, for different "environment".

2.3. Simulations and performances characterization with the FSC procedure

Once a good model of the tested SCS is identified, it can be used for different simulations. Results of numerous annual simulations of the tested SCS can be smartly used to characterize its performances with a simple curve, thanks to the FSC procedure [4]. The FSC method considers that annual fractional energy savings f_{sav} of a SCS can be expressed as a quadratic function of the fractional solar consumption FSC, a dimensionless quantity which only depends on the environment of the SCS. It almost represents the maximum f_{sav} that a SCS can reach for a given location. Each SCS is then characterized by its own simple parabola.

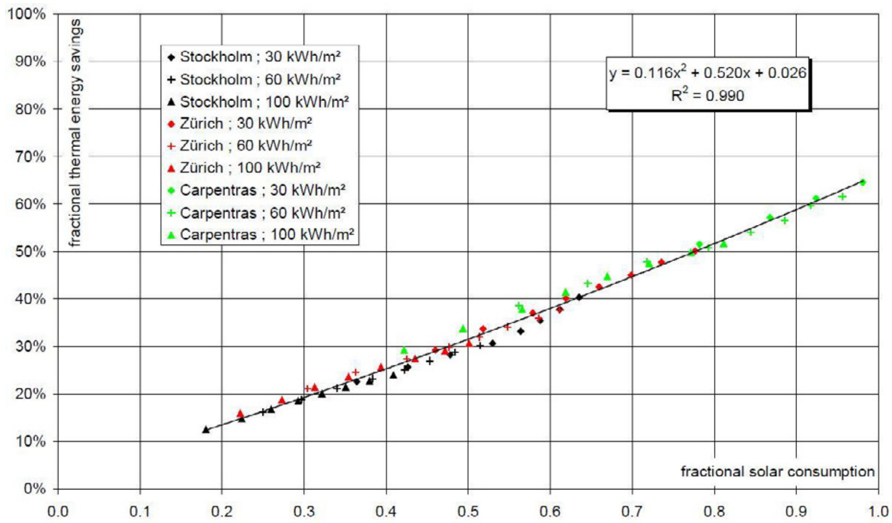

Fig. 4. Example of a SCS characteristic curve (Source: IEA SHC [5])

3. Experimentation on two real SCS

This methodology has been applied for two real combisystems. For both, several “Gray Box” models have been identified, starting from two different “12 days” tests (varying the climate, the building and the collector area).

3.1. The two tested SCS

The two tested systems (called SSCa and SSCb hereafter) are built by the same manufacturer. They can be broadly outlined by the figure below. The main difference between them is the storage capacity (1000L for SSCa and 500L for SSCb).

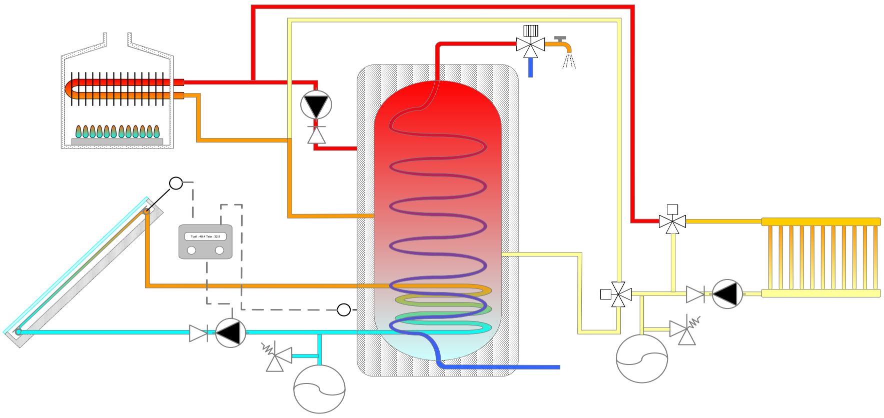

Fig. 5. Scheme of the tested combisystems

3.2. The different test sequences

For the experimentation of the methodology, it was decided to use two different 12 days test sequence, so SCSPT tests are carried out twice for each system. The working situations represented during tests are shown in the table below. The main objectives of these two test sequences were numerous:

- Comparison of the two characteristics curves derived from the identified model based on data from Test1 on one hand, and from Test2 on the other hand
- Evaluate the annual auxiliary energy consumption corresponding to Test1 based on the identified model based on data from Test2, and vice-versa
- Check the sensibility of the test sequence on the identified model
- Verify the accuracy of the extrapolation procedure

Table 1. Virtual working environments considered for the SCSPT tests, for both combisystems

	Name of the test	Building	Climate	Collector area
SSCa	Test1	SFH60	Zurich	16 m²
	Test2	SFH100	Stockholm	10 m²
SSCb	Test1	SFH100	Zurich	16 m²
	Test2	SFH100	Stockholm	16 m2

Buildings SFH30, SFH60 and SFH100 are Single Family Houses with annual space heating loads respectively of 30, 60 and 100 kWhm-2 for the Zurich climate.

3.3. Results

For each combisystem, data recorded from both tests are used to identify several “Gray Box” models. Numerous annual simulations are run with those models, for different situations, made up of the climates, the buildings and the collector areas presented in the table below.

Table 2. Buildings, climates and collector areas considered for annual simulations

Building	Climate	Collector area
SFH30	Barcelona	10 m²
SFH60	Zurich	15 m²
SFH100	Stockholm	20 m²

Simulations results are then used to characterize combisystems according to the FSC procedure. Currently, there is no way to evaluate properly the accuracy of simulations and their estimations. There is no measurement of the same systems working in real conditions for instance.

However, characterizations are relevant since for different test conditions, FSC curves are similar for the same SCS.

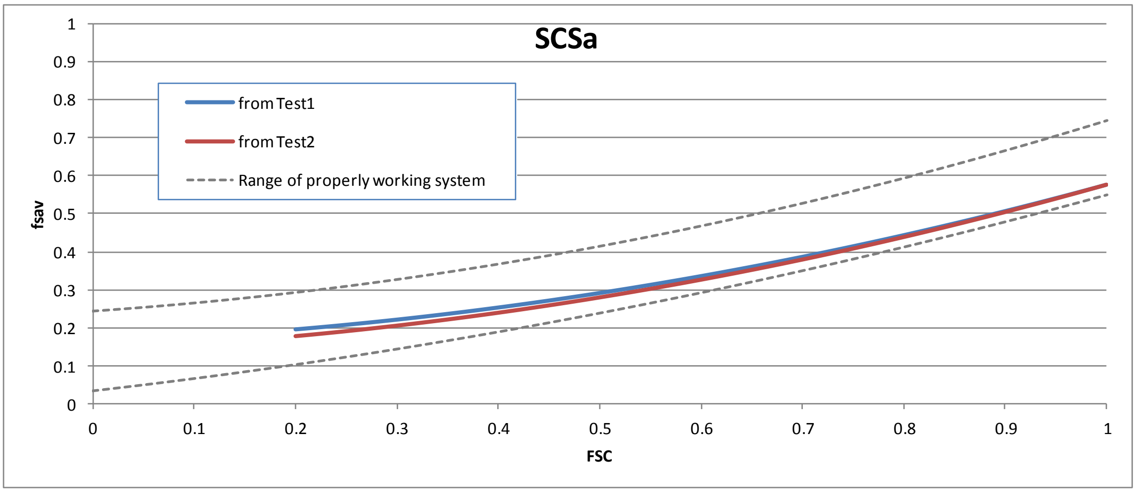

Fig. 6. Characterization of the SCSa from its two different “12 day” tests

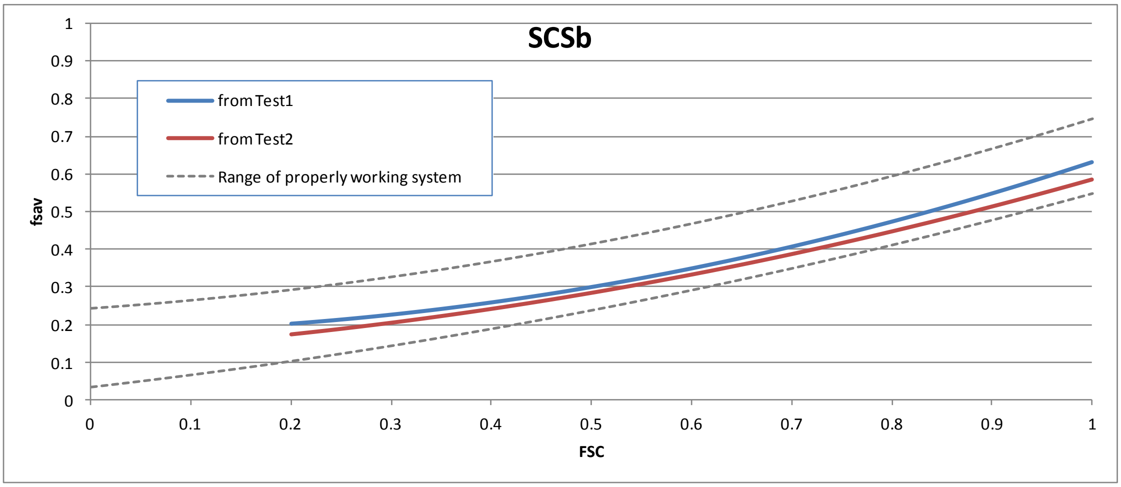

Fig. 7. Characterization of the SCSb from its two different “12 day” tests

4. Conclusions and perspectives

In addition to the first numerical study of this approach [2], those experimental results are really promising for the proposed methodology. Firstly, it has been shown in this paper that the new methodology is suitable with real test data. Moreover, experimental results point out that the proposed methodology is relevant since for two different “12 days” tests, identified models are similar. The resulting characterizations of the tested systems are very close which is really promising for the reliability of this new methodology.

The next steps in the development of the methodology should be to test additional systems to validate completely the procedure, and then to compare performances prediction of systems that have been tested among in-situ monitoring results.

Acknowledgements

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