Evaluation, diagnosis and improvement of a solar cooling plant by means of experimental analysis and dynamic simulation

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Abstract

Although the experimental studies of the solar cooling systems provide more reliable information about the installation performance, the theoretic studies are the first link of the design. In this way, an initial difficulty that the solar cooling planners have to face is how design the whole system. Nowadays several tools are available, from the simplest ones to the most complex ones, as the dynamic simulations tool.

This paper focuses in the validation of a dynamic simulation model used to describe the performance of an existing solar cooling installation located in Zaragoza (Spain). The dynamic model was developed under the simulation environment TRNSYS. The key issue of the model was the absorption chiller type, realized from the results data of the monitoring system

Since the COP of real solar cooling presented a great influence from its heat rejection sink, a dry cooler, once the model was validated with the experimental data, was used to predict the performance of the chiller with the new geothermal sink, which started to operate in 2009. The present work describes the design and validation model process, the same way the comparison between the model results and monitoring ones, depending of heat rejection scenarios.

1. Introduction

Comparing absorption refrigeration systems with mechanical compression ones, the formers are not competitive regarding to economy, but they are much more environmental friendly, and the CO_2 emissions are considerably reduced. However, low power absorption machines are not widely commercialized, they are very expensive, and most of them need refrigeration towers to operate [1]. For that reason, research and development activities are necessary in order to reduce the cost of using solar assisted air conditioning in buildings [2-3]. There are a lot of theoretical studies about powered solar absorption cooling system [4-5], but the information of its experimental performance is in short supply. Away other reasons about this, is the difficulty for designing solar cooling systems. There are not many tools available for accurate dimensioning cooling systems and/or to evaluating the solar thermal contribution to the total energy requirements [6]. One of these available tools is the dynamic simulation used in this work.

2. Description of the installation

Since 2007, the powered solar cooling absorption installation located in the University of Zaragoza has been monitored and analyzed [7]. The solar cooling system consists mainly of 37.5 m^2 of flat plate collector, a 4.5 kW, single effect, LiBr-H_2O rotary absorption chiller and a dry cooler tower to cool the absorption cycle.

In order to improve the performance of the chiller and to increase its COP and its chilling capacity, several studies were carried out to find an alternative heat rejection sink. Finally a geothermal sink was chosen to reject the heat of the absorption cycle. The new geothermal system contains a 25 m^3 buried water tank, which is supplied by a water well. Besides this tank, there is a geothermal horizontal heat exchanger (90.5 m from the total 190.5 m of the geothermal loop were divided into 3 buried pipes in order to increase the heat exchange surface between these pipes and the ground).

3. Components model and experimental validation

During the analyzed period of the experimental installation, a model of the installation has been carried out with the software TRNSYS [8]. The aim of model was to develop a tool to be able to represent the energy behaviour of the real system. In this way, the tool could estimate the potential of possible modifications in the installation, as the improvement of the new heat rejection system.

3.1. Components models

The model of the initial installation was created according the existing components in the solar cooling system. These components were modelled as following:

Firstly, since the model has to show the real behaviour of the installation and due to the performance of the solar cooling chiller depends strongly on the climatic conditions [9], the monitored meteorological data were implemented in the model of the installation using the type 62.

For the simulation of a flat-plate collector, TRNSYS Type1b was used. Although in the daily operation the solar storage does not operate, a stratified tank with uniform heat losses was modelled with the help of the Type4c.

To simulate the performance of the rotary absorption chiller, type 107 was used. Since this type uses a catalogue data lookup approach to predict the output of the absorption chiller, several data files of absorption chillers were created, according to the manufacture technical data and the monitored values of the steady state period of the experimental installation, monitored during the operation of the chiller in the three moths of the summer of the year 2008. To calculate these parameters from the monitored data, a multi-regression fit was carried out from the experimental steady state values of the chiller [10]. The results of the method are shown in figure 1:

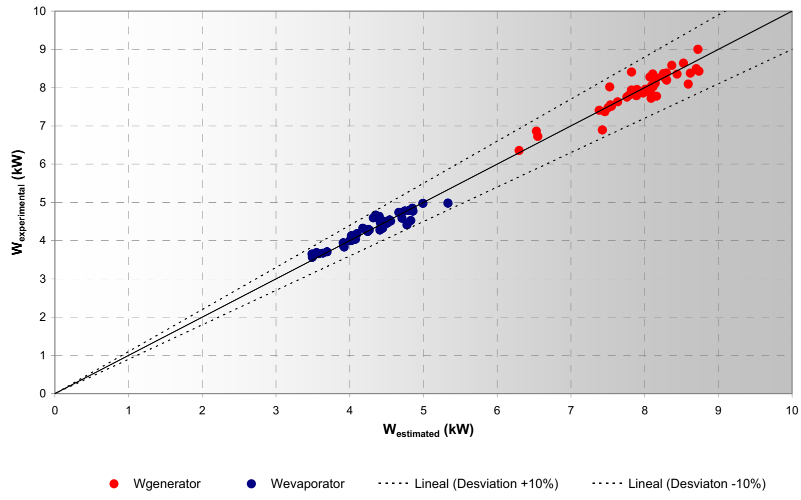

Fig. 1. Results of the absorption chiller model

The multiple correlation coefficient of this regression algorithm was 0.91, showing a good fit between the experimental data and the method results.

For the gymnasium simulation, a TRNSYS type 56 component was used in the model. For the development of the required information for the type 56, the TRNSYS application, TRNBUILD was used. The gymnasium model considers overall the internal gains, since it is located in the underground of the building.

3.2. Validation of the model

To validate the model, the results of the simulation model have to be comparing with the experimental ones. The procedure of validation of the installation model consists of three steps. The first one compares the values of several parameters of the performance of the chiller. As it can be seen in the Table 1, the deviation between the simulation results and the experimental ones belonging to the year 2008 is lower that the 8%.

Table 1. Comparison of experimental and simulation results.

Parameter	Experimental Value 2008	Simulation Value Initial Model	Deviation (%)
$W_{collector}$ (kWh)	6230.50	6468.29	3.68
W_{solar_hx} (kWh)	2217.40	2190.84	1.21
$W_{generator}$ (kWh)	1491.90	1564.02	4.61
$W_{evaporator}$ (kWh)	795.50	740.31	7.45
$W_{electric\_system}$ (kWh)	554.80	565.90	1.96

The second step compares the daily operational temperatures and capacities of both scenarios (Fig. 2). For each analyzed day, the steady state was defined.

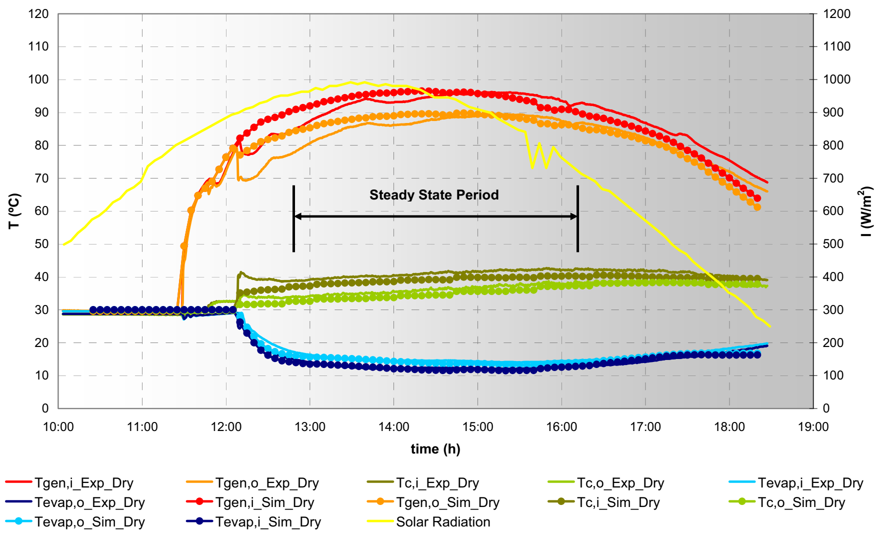

Fig. 2. Comparison of operational temperatures

The deviation of the simulation with the real values is lower than the 5% in the central part of the day, belonging to the steady state period. Therefore the simulation results showed a good agreement with the measurements.

This agreement can be seen too if the results of the capacities of chiller and its COP's. This agreement shows the best values during the steady-state period, due to the absorption chiller was developed from the steady states values of those days in which the chiller has worked.

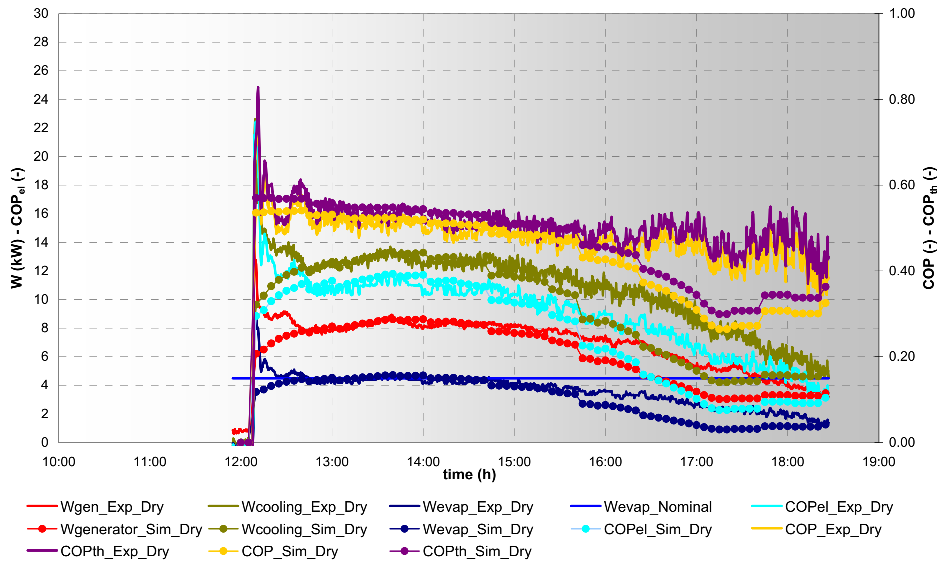

Fig. 3. Comparison of the chiller capacities and COP

Finally the last stage of the validation verifies the influence of some operational parameters of the installation on other performances parameter. As it was mentioned, for example, Figure 4 presents the influence of the outdoor temperature on the power and on the COP.

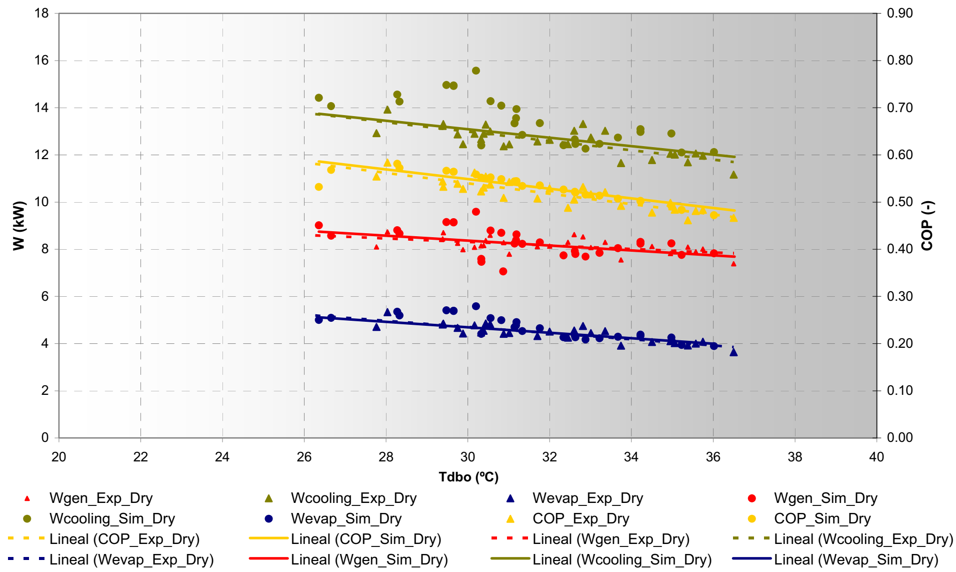

Fig. 4. Comparison of the chiller capacities and COP against the T_{dbo}

In this case the simulation results closely agree with the real data. This fact is due to that to find out the connections between the different parameters of the performance of the chiller has to be done with their daily steady state values. So the all values presented in the Figure 4 belong to the steady state.

After the analysis of the results of the application of the validation procedure on the model, it can be concluded that the installation model is valid to be use as a tool to evaluate the performance of the solar cooling system [11].

4. Design and potential of a new heat rejection system

The great influence of the heat rejection sink temperature on the performance of the absorption chiller led to find and design an alternative heat rejection sink with a better energy characteristics. These characteristics were found in a buried water tank, supplied by water well and located close to the solar system building.

The geothermal system was included in the initial TRNSYS model of the installation, and its component defined with standard types of the software.

A new flat plate heat exchanger with its characteristics according to the manufacturer was defined with the type 5b

As it was mentioned the geothermal system has a water tank and a horizontal geothermal exchanger formed by three buried pipes. These pipes were modelled with a simple buried pipe model (Type 31). The thermal conductivity of the ground was estimated in 1.1 W/m·K.

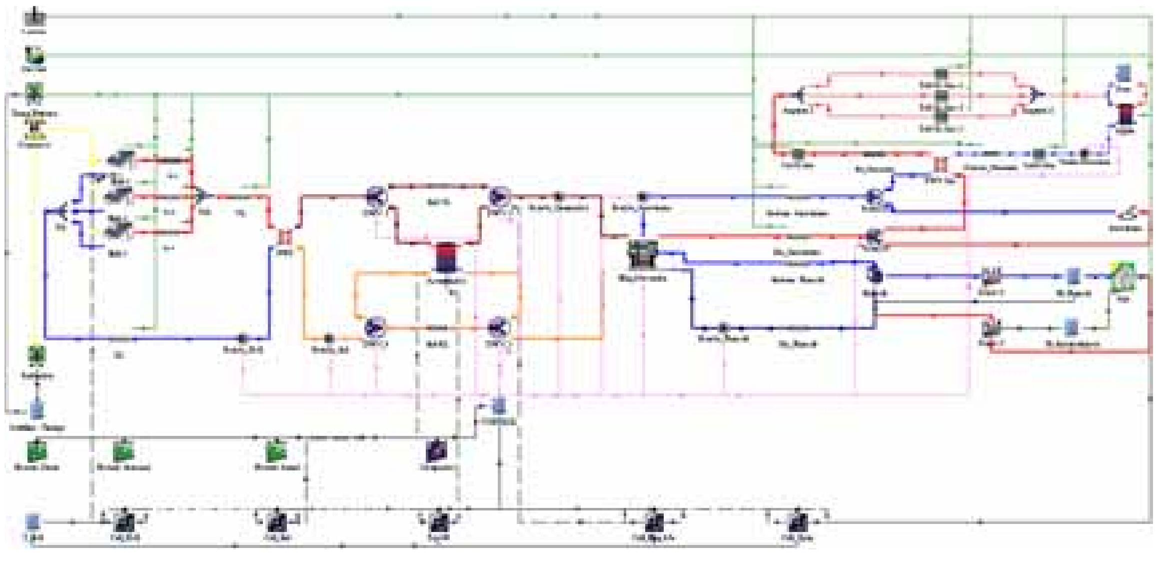

Fig. 5. Trnsys model of the solar cooling installation

The first results of the new model showed that the new rejection sink would increase the chilling capacity and on the COP up to 40% more that the current ones and the negative influence of the outdoor temperature on both parameters will be removed [12].

The results obtained of the new model simulation are shown in the Table 2.

Table 2. Improvement of the performance of the installation with the geothermal sink.

Parameter	Experimental Value 2008	Simulation Value Geothermal Model	Improvement capacity (%)
$W_{collector}$ (kWh)	6230.50	5925.14	5.15
W_{solar_hx} (kWh)	2217.40	2252.63	1.56
$W_{generator}$ (kWh)	1491.90	1742.14	14.36
$W_{evaporator}$ (kWh)	795.50	934.79	14.90
$W_{electric\_system}$ (kWh)	554.80	564.05	1.64

In terms of energy, the new configuration would allow to increase the chilling energy supply in 15%.

According of the effect of the new sink on the daily performance, Figure 6 compares the temperatures of the initial experimental scenario with the daily temperatures of the geothermal mode scenario.

In the new scenario the evaporate outlet temperature reaches lower values due to the heat rejection capacity is much better. The temperatures of the heat rejection loop are around 20ºC instead of 35 ºC – 40 ºC. With the average temperatures of the absorption cycle are lower so that its performance increases.

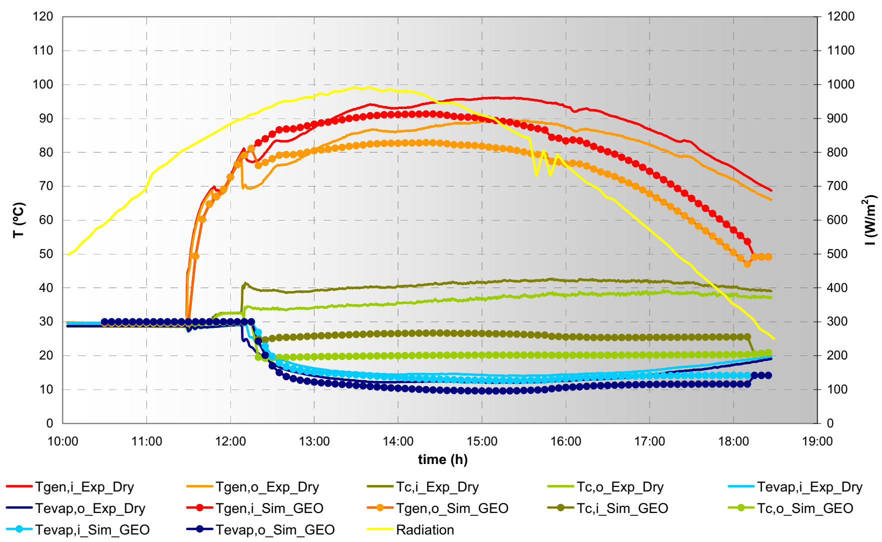

Fig. 6. Simulation results of the operational temperatures of the geothermal scenario

5. Results of the geothermal scenario

Unfortunately these results were not as good as the simulation models predicted. The operational temperature of the water tank was higher than 17 ºC, value obtained from the historical registers of the water well nearby. The operational value of this temperature ascends to 25 ºC. For the reason, the flat plate heat exchanger of the geothermal system must be redesign in order to be able to reject the appropriate heat of the absorption chiller. Although the chiller operated below their capabilities, with the geothermal, the negative influence of the outdoor temperature on the COP and on the chilling capacity was removed (Fig.7).

Faced with the problem of the operational temperature of the water well, the geothermal TRNSYS model was modified with the operational temperature and the characteristics of the right heat exchanger.

The results of the model simulation can be seen on Figure 7, which shows the experimental results of the year 2009 against the results of the modified model.

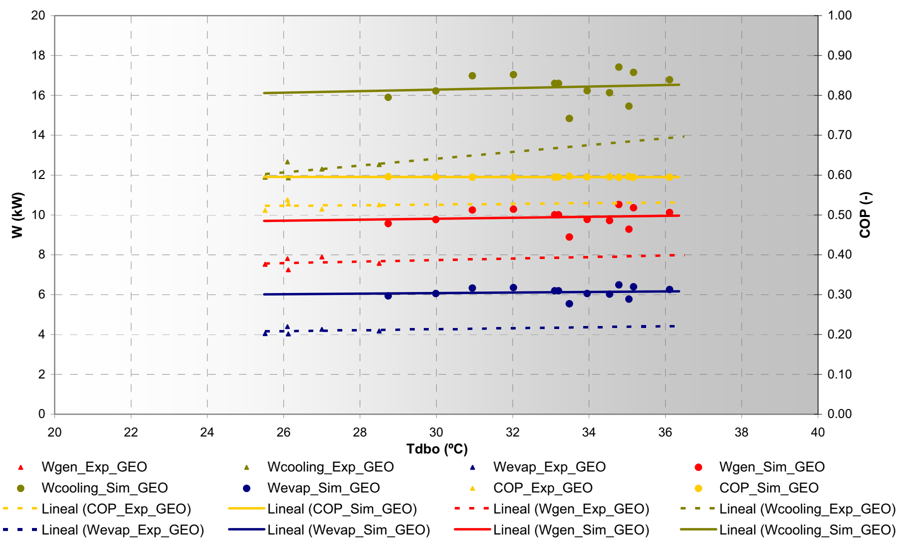

Fig. 7. Chiller capacities and COP of the geothermal scenarios

It can be seen that each experimental parameter has a similar tendency according with its simulation pair. In this case, when the outdoor temperature increases, the operational parameters do not decrease as in the initial scenario, although they keep constant, even, increase slightly.

The effect of the mistake heat exchanger is notice in the values of the experimental parameter. For example the chilling capacity is always lower that its nominal value, however the simulations results show a constant value of 6 kW. Similar conclusion can be drawn from the COP analysis. The experimental COP has a value of 0.51, but it could be reach al least 0.6 with the new heat rejection system.

6. Conclusions

In the present work a dynamic model of a real solar cooling installation has been presented. The model was developed from the experimental data of the real system, and to validate it, its results were compared with the experimental ones, showing a good agreement.

The absorption chiller was modelled using a multi-regression fit, showing deviations lower that 10% between its results and the real ones.

After the simulation validation, the model was used to evaluate the performance of the chiller when it works with a new heat rejection system, an open geothermal sink. The experimental results of de chiller in 2009 with this new scenario were not as good as the expected one. Although the negative influence of the outdoor temperature on the chiller performance was removed, the experimental values were worse that the estimated initially due to the high values of operational temperature of the water well. Therefore the size of the flat plate heat exchanger of the geothermal side must be redesign in order to improve the absorption cycle heat rejected to the geothermal loop.

With the help of the TRNSYS model, the performance of the solar cooling system with the optimal heat exchanger according the real operation temperature of the water well was estimated. Even, with the real conditions of the geothermal sink, the performance of the chiller would be better compared with its operation with the dry cooling tower.

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