Design and operational experiences of an alternative heat rejection sink for an existing absorption solar cooling system

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Abstract

The paper focuses on a critical issue of the solar cooling facilities based on absorption chillers. The heat rejection system of this kind of chiller is a key factor because the condensation and absorption temperatures will affect the COP and the cooling capacity. The paper describes the performance of a solar cooling installation located in Zaragoza (Spain). The solar cooling system consists of 37,5 m2 of flat plate collector, a 4,5 kW, single effect, LiBr-H2O rotary absorption chiller and a dry cooler tower. The installation, designed to mitigate the overheating problems in the existing solar collectors, is being monitored and provides cooling to a gymnasium belonging to the sports center of the University. In the last three years, 2007, 2008 and 2009, several studies have been carried out to analyze the full system operation. In the first two years, the measured data showed the strong influence of the cooling water temperature on the COP. Based on these results, a geothermal sink for heat rejection was studied and installed. The paper shows the results of the system performance in its first year of performance with the new heat rejection sink, and compares them with its dry cooler performance.

1. Introduction

The majority of buildings have been designed with heating installations but they do not have refrigeration equipments. Refrigeration needs are covered by air conditioning machines which are usually fed with electricity, and this kind of equipment is becoming very common in houses. Besides, in the last years, because of the increase of the annual mean temperatures, the air-conditioning market has grown in a spectacular way [1]. Due to the operation of these air conditioning machines, in summer, electricity consumption reaches high values, overcoming the electricity generation limits, causing technical problems and increasing electricity prices.

Therefore, alternative refrigeration equipments driven by renewable or residual energies are being developed. One of these alternatives is the solar absorption refrigeration system, which uses solar thermal energy integrated with an absorption cycle to refrigerate. This configuration is especially interesting because the hours in which more solar radiation is available, are the hours with more refrigeration needs.

Nowadays about 400 solar cooling air-conditioning systems are installed throughout Europe [2]. There are many researches referring to theoretical studies but the information of experimental studies in this kind of installations is scarce. While theoretical and simulation studies only work with arbitrary parameters, an experimental study works with the real variation of this parameters. That is the first advantage of this type of studies because in that way we can see the real performance of the system analyzed.

2. Integration of an absorption chiller in an existing solar thermal

In 2003 a solar thermal system was installed in the indoor sport centre of the University of Zaragoza. The aim of this system was to contribute to the domestic hot water demand of the building. Unfortunately, the solar field of the installation was oversized and it suffered severe overheating problems in summer. Therefore, several options were analyzed and finally an absorption chiller was integrated in the existing system in order to use this wasted energy in the summer time (Figure 1).

The total surface of the solar field is 85 m^2 and 37.5 m^2 are used to supply heat to the solar air conditioning system in summer. Solar radiation is absorbed and transformed in thermal energy to feed the absorption machine.

The systems also contains a commercial 4.5 kW air-cooled, single effect, LiBr-H_2O absorption chiller. It has a rotary drum in which the single effect absorption cycle is carried out with a drum rotating at 400 rpm. The rotation favors the mass and heat transfer of the absorption cycle. Inside the drum are situated the evaporator and the condenser and instead of a traditional compressor fed with electricity.

In addition, the secondary loop includes a hot water tank and an auxiliary boiler but both are not in use. In this way, the absorption chiller will only work when the solar field can provide it enough energy.

In the gymnasium, two fan coils with 6.21 kW of nominal chilling capacity transfer the chilling power from the evaporator of the absorption machine to the ambient air.

And finally, a dry cooling tower was installed to reject the cycle heat from the condenser and the absorber of the chiller to the outdoor air.

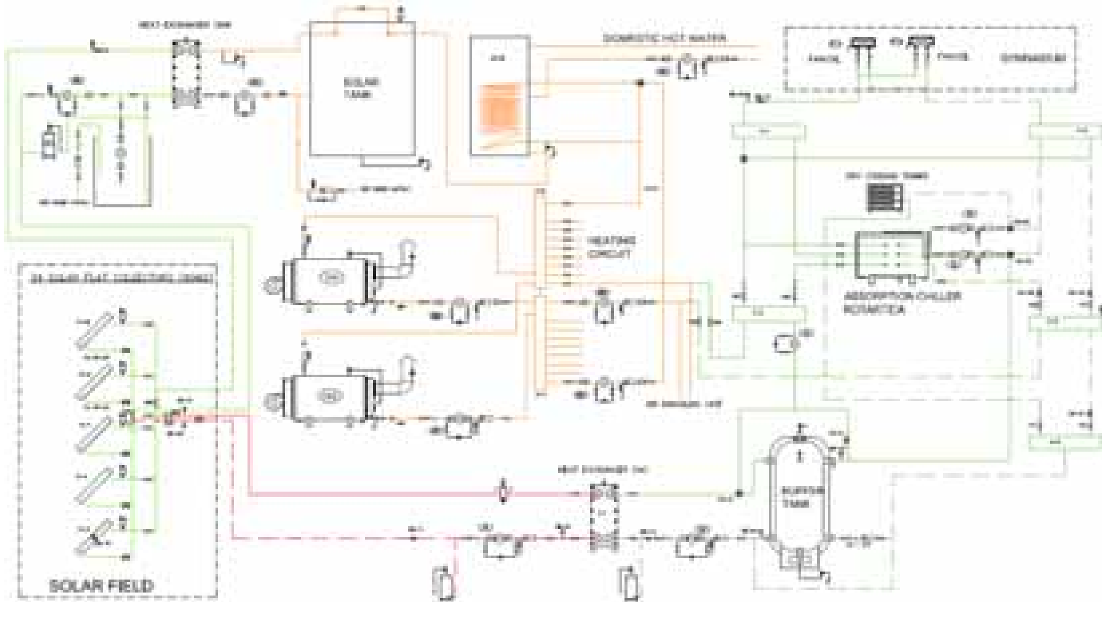

Fig. 1. Initial scheme of the solar thermal installation

The installation is completely monitored. The procedure of the implementation of the monitoring system was designed in order to carry out the energy balances of the different components of the installation [3]. There is a PLC unit and a web controller which form the controlling and recording values system.

During the first two years, the installation operated with the initial dry cooler tower. After the analysis of the two first years, the conclusion was that there was a strong influence of the cooling temperature on the COP of the chiller (Figure 2), as is also quoted by other authors [4-5].

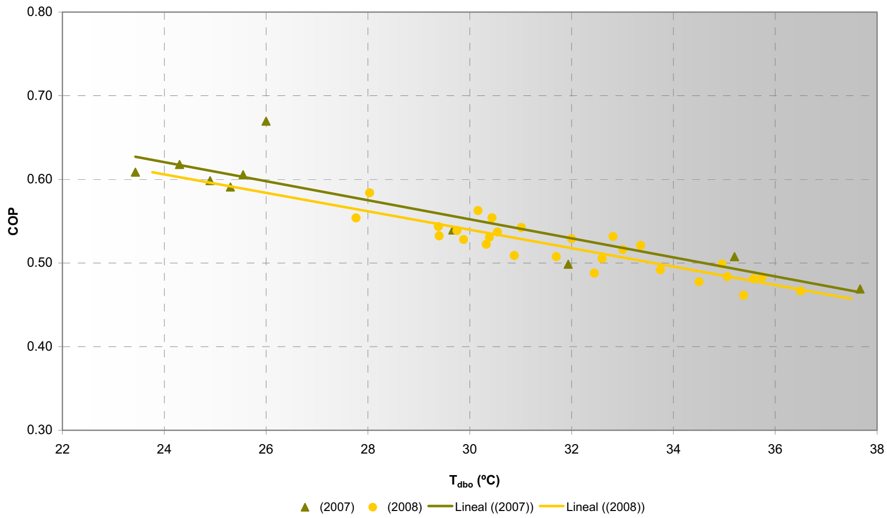

Fig. 2. Influence of the dry bulb temperature on the COP

The studies carried out in this two years were focused in the analysis of the steady state of the chiller The Table 1 shows the steady state mean values of the chiller in both years. In the year 2008, the cooling capacity was lower due to the outdoor ambient temperature was higher that in the year 2007, so, the COP was lower too [6].

Table 1.Experimental mean values of the chiller in 2007 and 2008

Year	W_{ch} (kW)	W_g (kW)	W_c (kW)	COP (-)	T_{dbo} (ºC)
2007	5.8	9.7	15.4	0.56	27.7
2008	4.4	8.0	12.5	0.51	31.2

3. Design of an alternative heat rejection system

Because of the results showed in Figure 2 and in the Table 1, several studies were carried out. The aim of these studies was to find an alternative heat rejection sink in order to improve the performance of the absorption machine [7].

Two options were proposed in order to find an alternative heat rejection system, a wet cooling tower and a geothermal system. With both of them, the performance of the installation should be improved.

The first option, the wet cooling tower, was ruled out due to its problem of legionela risks. Besides of this disadvantage, the performance of the wet cooling tower operation would have been limited by outdoor temperature and humidity conditions too. Besides, the water consumption has to be taken into account.

The second option was using a geothermal system as a rejection sink. At this point, two further options for the geothermal system were examined: open cycles and closed cycles. Technical and economic feasibility studies were carried out in order to compare three different geothermal systems [8]: closed geothermal circuit with vertical heat exchangers, closed geothermal circuit with horizontal heat exchangers and an open geothermal circuit using a water tank close to the building. Finally, the heat rejection system chosen was the open circuit one due to the being of water wells close to the sport centre. With this geothermal system, the performance of the heat rejection system will not depend on the outdoor temperature.

The new circuit installed uses a buried water tank of about $25 m^3$, located in the surroundings of the solar cooling installation and it's used as an irrigation tank. The tank is supplied by an underground well.

Daily, the water tank is renewed in summer, because it is used to irrigate the sports ground of the sport activities centre. Therefore, the water temperature of the tank will keep constant, solving the possible problems of thermal saturation of the water. The new geothermal installation is showed in Figure 3.

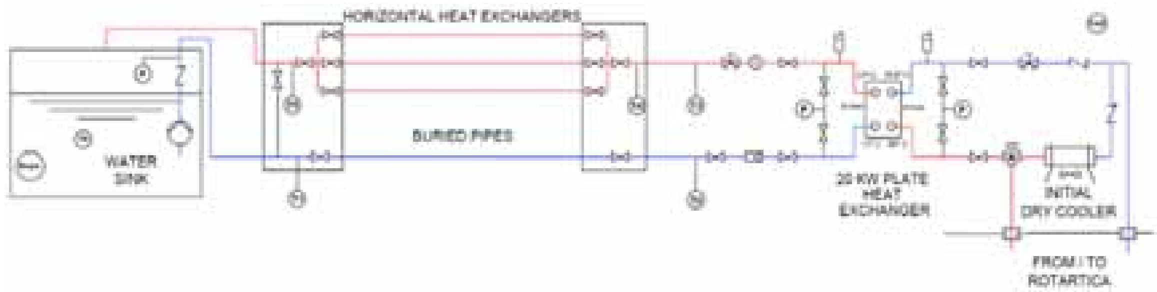

Fig. 3. Scheme of the new heat rejection system

The new heat rejection system extracts the heat produced by the absorption cycle by means of a 20 kW plate heat exchanger. There is a by-pass that leads the water directly to the plate heat exchanger, avoiding the dry cooling tower. The overall length of the new circuit is 190.5 m, of which, 90.5 m have been divided into three pipes with a diameter smaller. The aim of the geothermal system configuration is to increase the heat exchange surface between the pipes and the ground (Figure 3). With this configuration, the rejection of heat can take place in the two sinks of the geothermal system. On one hand, the absorption chiller can reject its cycle heat to the initial heat rejection device, the dry cooler, due to it hasn't been removed from the installation. On the other hand, the new geothermal system allows reject the residual heat into the water well and in the ground heat collectors in the supply pipe. Therefore the solar cooling system is equipped wit an hybrid system to reject the absorption heat.

4. Estimated and experimental performance of the system with the new heat rejection system

Based on the realized analyzes in the year 2007 and 2008, the design of the new heat rejection was carried out. To estimate the performance of the chiller with the new system and its results with the new operation conditions, several tools were used. Firstly, a simple estimation of the new values of COP and the chilling capacity were realized and studied. The estimated values of chiller power and COP are driven as function of the potential cooling capacity and the possible temperature of the water well as shown in the Figure 4.

After the evaluation of the potential of this sink, the initial TRNSYS model, developed and validated with the experimental installation, was modified to implement the geothermal heat rejection system.

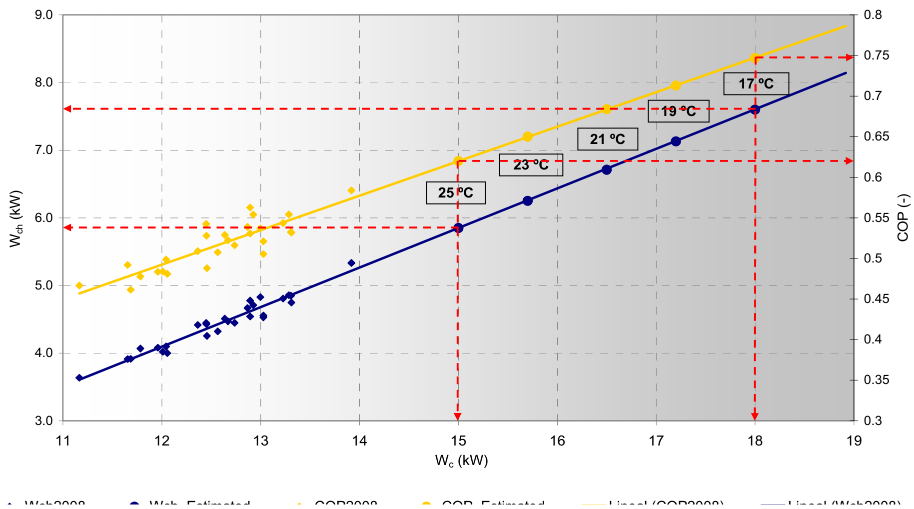

Fig. 4. Estimated values of chilling capacity and COP

The Figure shows the estimated COP and the estimated chilling capacity of the chiller for different operation temperatures of the water well. According to the owner of the water wells nearby, the water temperature of these wells was 17 ºC. So, the chilling capacity and the COP of the absorption chiller with the new operation situation will reach, respectively, values above 7.0 kW and 0.7

With this value and the obtained ones of the simulations results, the geothermal system was design and installed.

5. Results and experimental experiences of the geothermal heat rejection system

In the year 2009 and 2010, the rotary absorption chiller operated with the geothermal heat rejection system. To enlarge the knowledge of the performance of the chiller, two flows were tested on the geothermal system, 95 l/min and 49 l/min. The aim of theses tests were evaluated the influence of the flows on the heat rejected in the geothermal exchanger and in the performance of the chiller.

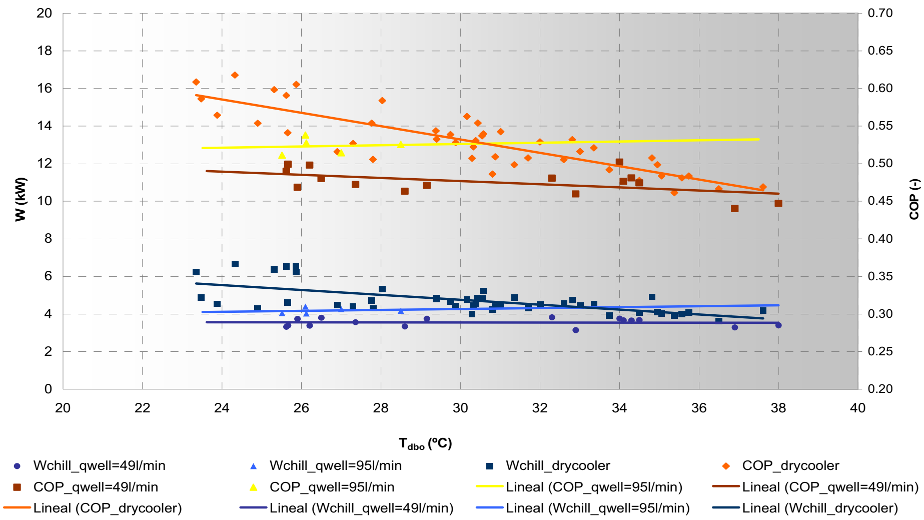

Fig. 5. Obtained values of chilling capacity and COP

Unfortunately the experimental results weren’t as good as the expected ones. The improvement of performance of the chiller was partial. Although the alternative heat rejection system performance doesn’t show any influence of the outdoor temperature, the obtained results were lower than the expected ones.

Figure 5 shows the chilling capacity and the COP of the chiller when operated with the initial dry cooler system and with the two different flows in the geothermal system. As can been seen in the figure when the outdoor temperature is below 31 ºC- 32 ºC, the chilling capacity and the COP of the absorption chiller is higher when it operates with the dry cooler, although the chilling capacity show constant values in the case of operation with the geothermal system. In this point, a hybrid heat rejection system could be implemented in order to optimize the use of the optimal heat rejection sink in every moment [9].

The explanation for this fact is related to the operation temperature of the water well. The temperature of the water tank in its first year of operation was 25 ºC, instead of 17 ºC. This temperature difference is owing to situation of the water tank. Whereas the water well is deeply underground, the ceiling of the water tank is close to the surface of the ground, so its temperature can be influenced by the solar radiation and by the ambient temperature. Unfortunately the design of the flat heat exchanger of the geothermal system was designed with the temperature provided by the historic data of the wells placed in the surroundings of the system [10].

Figure 6 shows the temperatures of the geothermal system when its flow is 95l/min. The inlet temperature of the horizontal heat exchanger is heated by the residual heat of the absorption chiller. After the heat rejection in the geothermal exchanger, the flow reaches the water well. Finally the water is pumped from the low level of the water well to the flat exchanger in order to cool the water of the rejection cycle of the absorption chiller. As can be seen in the figure, the temperature used to cool the absorption cycle is around 25ºC.

On the other hand the daily increase of the water tank temperature is lower than 1 ºC. So, the heat rejection sink is suitable to be used as a constant temperature sink.

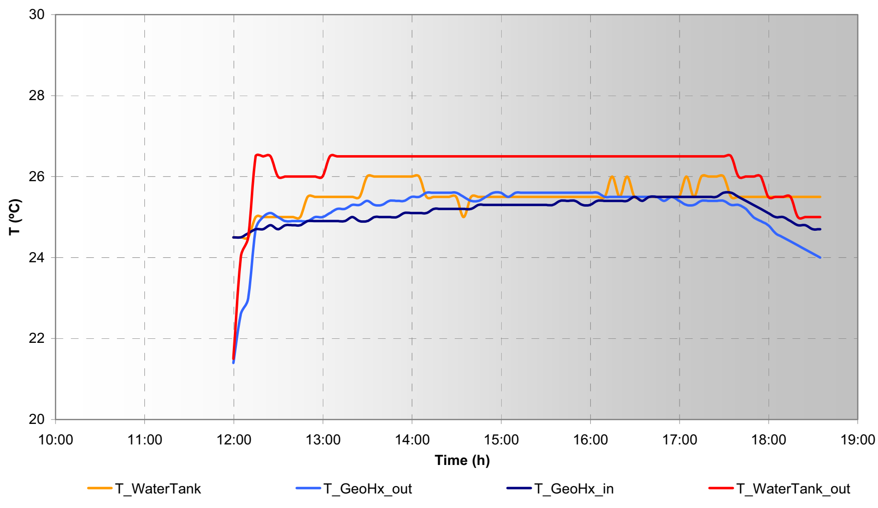

Fig. 6. Temperatures of the Geothermal system

Another parameter to be studied in the Figure 6 is the rejected heat by the buried horizontal heat exchanger. The mean temperature difference of the flow between its inlet and the outlet temperature in the operation period was approximately 1.1 ºC. That means that the mean heat rejection capacity in the geothermal heat exchanger is 7.15 kW, approximately the 55% of the total heat rejection capacity of the geothermal system. The high efficiency of the buried heat exchanger is due to the high thermal conductivity of the ground, since it is irrigated everyday. Figure 7 shows the heat rejection capacities of each sink.

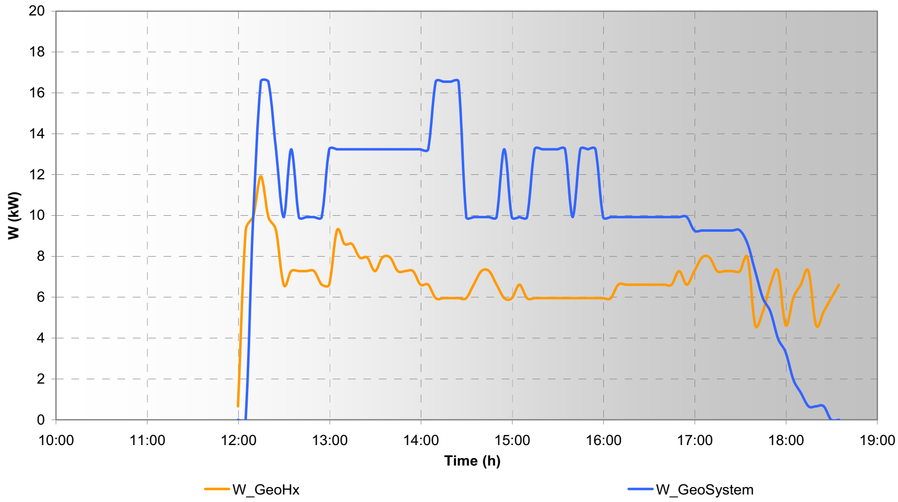

Fig. 7. Scheme of the new heat rejection system

In the case of the geothermal system operates with a lower flow (49 l/min), the rejection capacity of the exchanger and the total geothermal decreases. The capacity of the geothermal system in this situation is 11.09 kW, and the buried exchanger rejects only 4.6 kW.

Finally the mean values of the performance of the absorption chiller when operates with the geothermal system are shown in the Table 2.

Table 2. Experimental mean values of the chiller with the geothermal system

Flow rate (l/min)	W_{ch} (kW)	W_g (kW)	W_c (kW)	COP (-)
49	3.5	7.1	10.5	0.47
95	4.2	7.6	12.2	0.52

Although, with the new heat rejection system the improvement of the chiller performance didn't reach the expected results, the COP of the chiller when the geothermal system operates with a high flow, has been improved slightly according the COP of the year 2008.

6. Conclusions of the work

In this paper have been presented the results of the analysis of the performance of a solar powered absorption system. Initially, the chiller operated with a dry cooler tower to evacuate the absorption cycle heat. The first conclusions showed a great influence of the outdoor temperature on the chiller COP. Because of this an open geothermal cycle was designed and installed.

With the new circuit, the COP dependence from the outdoor temperature is removed, and therefore a constant COP is obtained in function of this temperature.

The study has proved the importance of a good design of the flat heat exchanger placed between the cooling loop of the chiller and the geothermal circuit. Due to differences between the estimated operation conditions and the real operation conditions, the measured performance results are worse than the expected ones. In any case, the mean value of the chiller COP has been improved compared with the mean value of the year 2008. Several studies have been already planned for the next year in order to optimize the geothermal installation, in order to reach the expected results.

The influence of the residual heat of the absorption cycle on the temperature of the ware tank has been analyzed. The rejection of this heat into the water tank produces a minimum increase of its water temperature; consequently, the water tank is suitable sink to be used.

The influence of the flow in the geothermal system has been studied too. High values of flow, 95 l/min favors the improvement of the heat rejection in the geothermal horizontal exchangers as well as the total geothermal system. In this case the buried heat exchanger rejects the 55% of the total heat of the total heat.

Lastly, depending on the planned optimization of the heat exchanger, a condensation hybrid system control must be designed. The possibility of using a hybrid system (air / water cooled) to reject the produced heat in the absorption cycle is another optimization measure to take into account.

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