NEW SIMULATION MODEL OF ABSORPTION PUMP WITH INTERNAL STORAGE

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ABSTRACT

This article presents the study of the energy performance of a new absorption cooling system with internal storage. A full dynamic simulation including the solar collector field, the absorption heat pump system and the building loads has been performed. The system, which is based on a new technology, is composed by four heat pumps that store energy in the form of crystallized salts so that no external storage capacity is required. For this purpose, a new model has been specifically developed. The energy performance of this system has been compared to a conventional system composed of one liquid absorption pump and external storage in a water tank. The influence of the control strategies in the operation of the four CW10 has been analysed. Additionally the results of the simulations show the performance of both cooling systems when varying solar field surface and the storage capacity of the water tanks.

INTRODUCTION

The use of air conditioning systems to provide an acceptable level of thermal comfort during the warming periods is increasing in hot climates. The combined use of solar energy with absorption pumps is a renewable way to supply the cooling loads demanded by the building. In this context, the Spanish Ministry of Science and Innovation is promoting the Singular Strategic Project of Research and Development called ARFRISOL (Bioclimatic Architecture and Solar Cooling, in Spanish). This project evaluates the energy savings of five bioclimatic offices building placed in different locations of Spain.

The work presented in this article is based on the simulations of the solar cooling systems performed within the frame of the ARFRISOL project. Two different technologies have been adopted in this project. On one of the buildings, a conventional system composed of one liquid absorption pump (LiBr-Water) and external storage in a water tank has been installed. On the other buildings, a new technology based on small heat pumps that store energy in the form of crystallized salts has been used (Climatewell CW10). No external storage capacity is required by this second option.

There are many theoretical studies about the performance of absorption cooling systems -based on the COP of the chiller, the efficiency of the solar field and the storage system capacity (Izquierdo et al,. 1997; Mendes et al., 1998; Mittal et al., 2005; Mittal et al., 2006), but only a few of them have modelized the whole system considering the coupling between the solar field, the absorption systems and the building loads (Eicker et al., 2009; Wilbur et al., 1975). The simulations presented in this article belong to this second group. Tasks 25 and 38 of the International Energy Agency (Henning, 2004, IEA) have been working on solar assisted cooling in buildings, providing of some simulation tools and monitoring methodology.

The case of study of the present work is one of the office buildings belonging to the ARFRISOL project, constructed and based in the Plataforma Solar de Almeria (PSA), see Figure 1. A comparative study of the performance of the two absorption cooling systems, one with internal storage and one with external storage, has been done. The first system analyzed is composed by four heat pump units that store energy in the form of crystallized salts (Model CW10). The behaviour of these units is compared with a conventional system composed of one liquid absorption heat pump (Model SC20 Yazaki), and external storage in a water tank. A dynamic model in TRNSYS which couples hourly the solar absorption system with the building energy demands has been used.

Figure 1: Office building in Plataforma Solar de Almeria (PSA)

METHODOLOGY

The methodology that has been carried out in order to analyze both systems is:

- Creation of a Typical Meteorological Year (TMY) weather file .
- Building loads calculation.
- Modelization the absorption systems (with internal and external storage).
- Development of a simulation environment that couples the solar cooling system with the building hourly demands.

SIMULATION

The simulation tool TRNSYS has been used to analyze the performance of the cooling system of the building study. This model incorporates all the elements involved in the whole system: the building loads, the solar thermal collector field and the absorption pumps (standard and TESS Types are used). The coupling between all the elements implicated takes special importance in order to achieve high levels of energy savings.

Climate file

The TMY weather file used for these models as an input file of weather data has been created from a long series of measured data at the Plataforma Solar de Almeria (Zarzalejo et al., 1995).

Building loads calculation

The case study is an office building with approximately $1000m^2$ of surface area, recently constructed and based in the Plataforma Solar de Almeria (PSA). The building consists in a ground level building, developed around an East-West axis. It has been projected following the principles of Bioclimatic Architecture. The offices are facing south to collect the solar radiation in winter in order to warm up naturally these rooms. The South façade is protected by a 2 m projection (acting as a porch) to avoid the direct radiation during the summer. The basic project of the construction comprises the use of massive walls to prevent the interior from extreme temperatures and to reduce the effects of the daily variation of external temperatures. This wall with high thermal inertia assures a good insulation of the building and mitigates the wave amplitude of the interior temperature.

A collector double wing structure put over the roof has been designed with fixed slopes to work as a shading device during the summer time and to let solar radiation reach the building during the winter time. On the south facing wing, solar collectors will supply the heating and cooling energy to satisfy the demand. The collector field has a total area of $180m^2$ and it has 90 high efficiency flat plate collectors (FPC) with transparent insulation material, from Unisolar (Model UNISOL CP-1) (website Grupo Unisolar). The solar collector has an optical efficiency of 0.7 and a loss coefficient of 3.1 W/m2K-1. On the north facing wing, a series of radiative panels will supply nocturnal cooling though the radiant floor.

The model created for the PSA building includes all passive techniques implemented as: thermal mass walls, ventilation, shading strategies, ventilation through solar chimneys and nocturnal radiative cooling, as well as detailed internal gains. With all of these input variables, the building cooling loads have been obtained. To evaluate the conditioning loads of the building two different schedules have been used: one for heating period (set temperature: 20ºC) and other for cooling period (set temperature: 26ºC). The figure 2 shows the cooling loads obtained for the building.

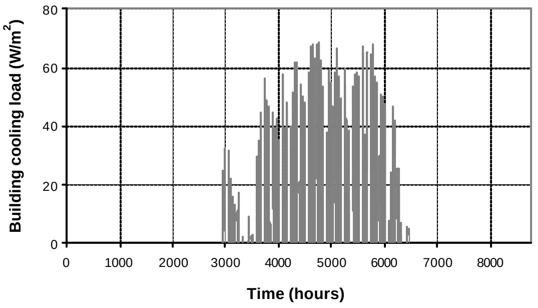

Figure 2: Building cooling demands

The integration of the precalculated loads into the transient model has been done using a model of a fluid pipe (type 682 TESS libraries). This TRNSYS model imposes a user-specified load (building cooling loads) on the flow stream (chilled water) at the outlet of the absorption system, and calculates the resultant outlet fluid conditions returning to the machine. This way the effect of the building is included in the dynamical hourly simulation.

Modelization of the absorption system with internal storage

The solar absorption system with internal storage is composed of four units CW10. Each unit has two barrels with a cooling power of 10 kW, a storage capacity of 30 kWh each and a rated COP of 0.68. Each one of the two barrels has two separate bowls, the one is filled with salts (reactor) and the other is filled with water (evaporator). The salt used for the process is Lithium Chloride –LiCl. During the discharging process, the bowl containing the salts absorbs the water from the evaporator. In the charging process the salt in the bowl is dried with the heat coming from the solar collector field, and the water returns to the evaporator. When both barrels discharge simultaneously, CW10 can deliver a peak cooling power of 20 kW. Figure 3 show the components of the CW10 heat pump system with internal storage. Figure 4 shows the TRNSYS schema of the performance of the Climatewell CW10 unit.

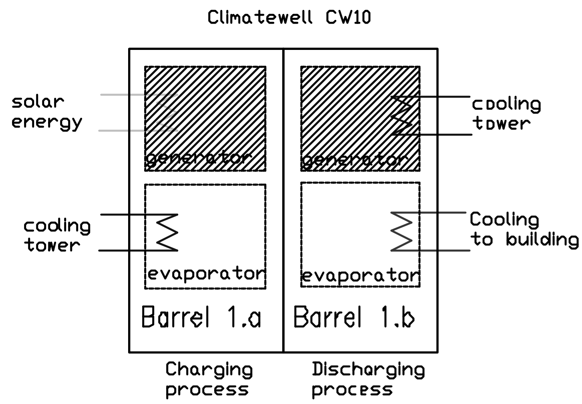

Figure 3: Components of the heat pump system with internal storage.

A new TYPE in TRNSYS to characterise each barrel of the absorption unit has been created. The barrels work with fixed fluid flows in the three circuits: charging heat from the solar field, discharging cooling energy to the building, and the dissipation circuit to the cooling tower.

The modelization has been based on experimental curves of efficiency provided by the manufacturer (Climatewell). The partial load performance of the machines is addressed because these curves modelize the performance of the machine for the different temperature conditions. For the charging process, the model estimates the charging power rate as a function of the temperatures of the water flow from collectors and the temperature of the water flow from the cooling tower. In the same way, for the process of discharge, the model estimates the cooling rate depending on the temperature of the cooling water flow returning from the building and the temperature of water flow from the cooling tower. For example, for a fixed temperature in the cooling tower, when the temperature from the solar field descends, the charging power rate also descends and so does the COP.

The basis of the performance of each barrel is the same as a storage tank: the barrel has a maximum storage capacity of 30 kWh which is measured with the storage level. The model contains an internal variable that represents the energy level (accumulated in crystallized salts), which is stored at each time step in charging process until it reaches the maximum capacity. In the same way, during the discharge process, this variable represents the descending level until it reaches the minimum capacity.

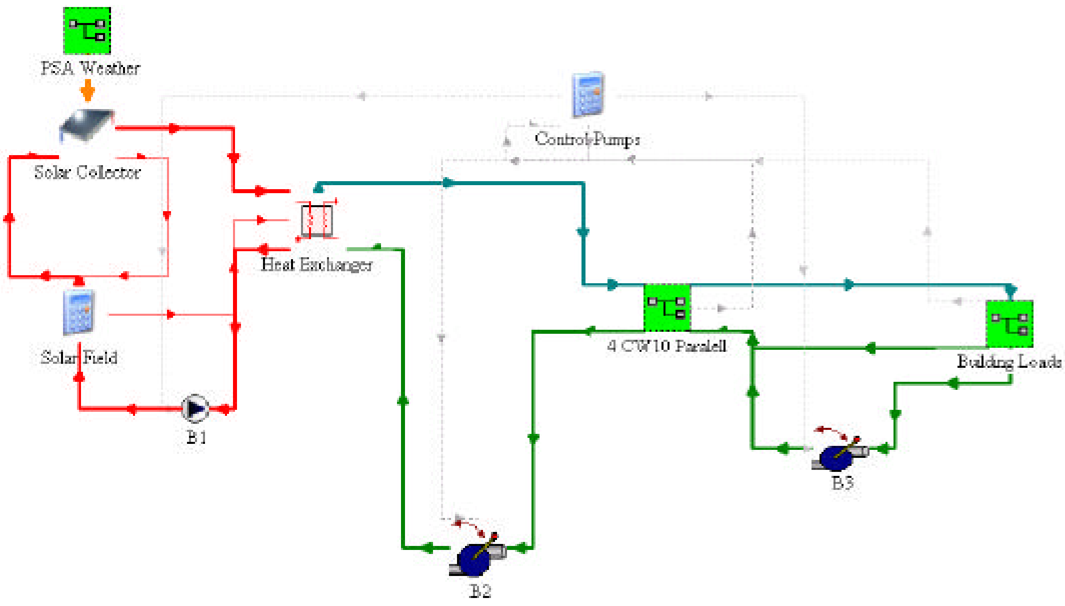

Figure 4: Configuration of the absorption system with internal storage in TRNSYS

Additionally, to optimize the performance of a system composed by any number of units, a model that rules the charging and discharging sequences of the barrels has been developed. This model identifies the status of each barrel, and at each time step, depending on the energy production on the collector field, the energy demand of the building and the energy level of each barrel, the model decides the sequences of charging and discharging, and how many units must work at each time step.

Modelization of the absorption system with external storage

The solar absorption system with external storage is composed of one single effect absorption chiller (Model WFC-SC20 Yazaki) with a cooling power of 80 kW and a rated COP of 0.65. The WFC-SC Yazaki machine uses in the refrigerant cycle a solution of lithium bromide (absorber) and water (refrigerant). The system is completed with an external storage water tank.

For the simulation of the conventional absorption system with external storage, types of the standard and TESS library have been used. The Yazaki absorption pump has been modeled using the single-effect hot water-fired absorption chiller (type 680 TESS libraries). This model makes use of a normalized catalogue data based on the efficiency curves of the absorption pump, in order to predict the performance of the chiller at any load. The thermal performance of external storage has modeled with a standard type of TRNSYS, which calculates the energy balances in a stratified tank. Figure 5 shows the configuration of the whole system modeling in TRNSYS.

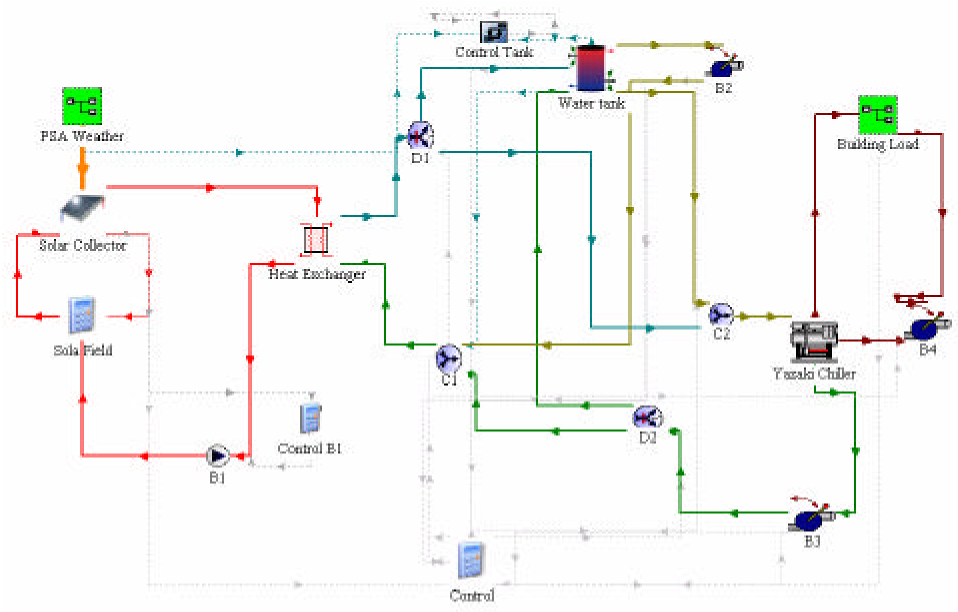

Figure 5: Configuration of the absorption system with external storage in TRNSYS

ANALYSIS AND RESULTS

Two different analyses have been carried out:

- The influence of the control strategy on the operation of the four CW10 in order to optimize the overall performance of the system with internal storage: The effect of the total power fractioning.
- Comparison of the performance of both absorption cooling systems, with internal and with external storage. Values of solar fraction (SF) and primary energy ratio (PER) are shown.

For the first analysis, different configurations on the connection of the CW10 units have been modelled. Three cases have been simulated: Case 1, in which the four absorption heat pumps are operated as one big unit. This case corresponds to the base case when the four units are connected in parallel without specific control strategy. Additionally, two more cases have been simulated: Case 2, in which the four absorption heat pumps are operated in two parallel blocks, and Case 3, where the four units can work independently.

Figure 6 shows the energy balances of the solar system for the Case 3. Solar energy in the collector's field (black line), energy demand of the building (dotted line) and cooling energy delivered to the building (grey colour area) as well as the storage energy level of each barrel (lines on the bottom of the graph), have been represented.

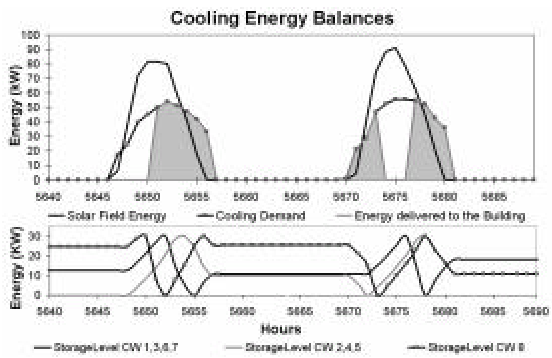

Figure 6: Energy balances of the solar cooling system with interior storage (Case 3).

In this figure two days of august have been plotted. The absorption system is capable to supply the 57% of the cooling demands. As it can be seen, the system one charged barrel switches to discharging mode.

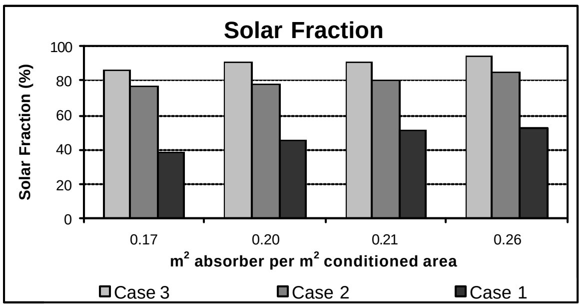

Figure 7: Cooling solar fractions. Comparison between the three cases modelled.

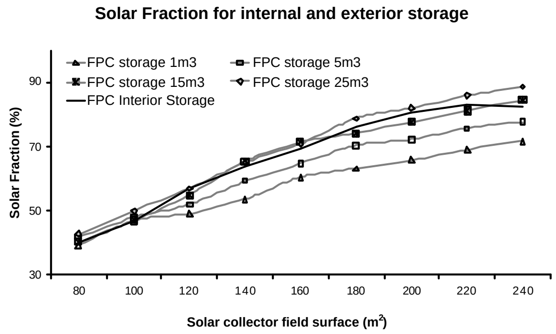

Figure 8: Solar fraction obtained for interior and exterior storage systems

Figure 7 shows the expected solar fraction for Cases 1, 2 and 3. To allow the comparison with other systems, the resulting solar fraction is represented as a function of the ratio between the collector field surface (m^2) and the conditioning building surface (m^2). The storage size in hours of complete covering maximum cooling load is 4 hours in the three cases.

The energy balances obtained for the three cases show that for the same total power, the efficiency of the system improves when increasing the number of modules being controlled independently. Case 3 reaches higher percentages of solar fraction because each absorption unit can swap independently from charging mode to the discharging mode depending on the necessities of the system.

The results of the second analysis compare the performance of the two cooling systems: CW10 and Yazaki SC20. For the case of the system with internal storage, Case 3 has been used in the comparison. For the case of the system with external storage, the influence of different storage volumes have been analysed (variation between 1-25 m^3).

Figure 8 compares the values of solar fraction achieved by both cooling systems as described above. The values of the solar fraction are represented as a function of the solar field surface which varies between 80-240 m^2. With the increasing of the solar collector field, the solar fractions achieved vary from 40% to 85%. The system with internal storage reaches its asymptotical limit before the system with external storage. In the case of external storage, the different cases show that the influence of the storage volume which is almost imperceptible for small collector field increases with the size of the solar collector field. The comparison between the curves shows that the SC20 Yazaki with an external storage tank of 15 m^3 reaches values similar to those obtained by the set of 4 CW10 in Case 3.

Figure 9 provides information on the auxiliary energy consumption of the two systems. The values of the primary energy ratio are represented according to the following equation:

$$PER = \frac{Q_{cooling,Abs}}{\frac{E_{elec,tot}}{e_{elec}}} \quad (1)$$

Where $Q_{cooling,Abs}$ is the energy demand provided by the absorption system, $E_{elec,tot}$ is the total electrical consumption of the solar field and the absorption system, including the auxiliary conventional chiller, the pumps, the absorption machine and the cooling tower. Finally, e_{elec} is the primary energy conversion factor for electricity. The cooling and electricity fluxes comes from the simulation results while the primary energy conversion factor for electricity has been set with the following value e_{elec}= 0.4, being based on European Directives, IEA Task 25 and IEA Task 32.

As it can be seen, the cooling system with internal storage reaches an asymptotic limit with 190m^2 of solar collector area. Until this limit, the primary energy ratio achieved by the CW10 units obtains the highest values.

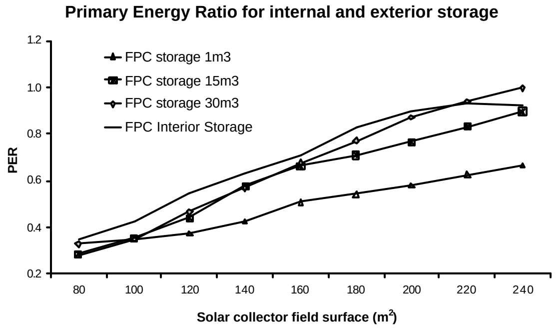

Figure 9: Primary energy ratio obtained for interior and exterior storage systems.

CONCLUSIONS

In this work, a new technology based on small units of solar absorption cooling with internal storage has been investigated. A new model for the absorption unit and a new model for the operation of several units working in parallel have been developed. The results of the simulations for the different configurations of the system analyzed (Case 1, 2 and 3) show the big influence of the control strategies on the performance of the system. Depending on the system operation, the solar contribution can be highly elevated. The adaptability of the system increases with the number of independent blocks (even when the total power is constant). Additionally, this new technology has been compared to a conventional system (liquid absorption chiller and exterior storage). The volume of the storage tank to achieve similar solar fraction is 15 m^3. Although same levels of solar fractions can be achieved with both systems, the main differences lay on the additional storage room that is needed in the case conventional system.

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