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Influence parameters on the performance of an experimental solar-assisted ground-coupled absorption heat pump in cooling operation

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ABSTRACT

This work describes a novel HVAC system consisting in a solar-assisted absorption ground coupled heat pump (GCHP). The aim of this work is to analyze some of the influence parameters on its energy efficiency. The installation has a complete instrumentation which provides instantaneous information on its actual behavior. The monitoring system consists mainly of temperature probes and flow-meters located in the main five water circuits of the installation: the three circuits that enter the absorption GCHP (generator, condenser and evaporator), the radiant floor circuit and the geothermal circuit, the information is collected by a communications network and data is stored in a database for further reference and analysis.

The experimental plant is located in a tertiary-use building in Valladolid (Spain). A model of the experimental installation has been developed using the TRNSYS software. The model has been validated with experimental results obtained in the installation for its cooling mode operation during the summer of 2011. For a defined control strategy, the influence of the generator and condenser temperatures on the heat pump COP and on the overall system energy efficiency is analyzed.

1. Introduction

Due to mounting concerns about climate change and resource depletion, meeting building heating and cooling demands with renewable energy has attracted increasing attention in the energy system design of buildings. From this point of view, solar-assisted cooling can be a solution to address the energy and environmental challenges faced by building designers. Solar assisted thermal cooling systems refer to the systems which use solar energy as the thermal source which drive a special kind of heat pump, such as an absorption heat pump or adsorption heat pump, to provide cooling to the buildings [1]. The main advantage of solar cooling systems is the coincidence in time between cooling demand from the building and energy supply in the form of solar irradiance [2]. This implies the reduction of primary energy consumption and the decrease of global warning impact of HVAC systems [3]. However, until today this type of systems has not widely penetrated the market and the accumulated experience and performance data related to solar cooling systems are relatively scarce [4,5]. Absorption refrigeration systems are not yet competitive to mechanical compression ones. Furthermore, low power absorption machines are not widely commercialized [6]. For that reason, research and development activities are necessary in order to reduce the cost of using solar assisted air conditioning in buildings [4,7]. There are also just a few works dedicated to the study of solar absorption cooling systems, both simulation [8–10] or experimental [2,11,12]. The number of solar cooling systems operating in the European Union in 2010 was estimated in about 100 and around 70 of them were based on absorption cooling technology [13–15].

Due to the fact that ground temperature is always higher than air temperature in winter, and lower in summer, the technology of ground-coupled heat pump (GCHP) increases heat pump efficiency and makes it a very attractive technology [16,17]. GCHP systems in combination with solar energy have been described and tested with different system designs, mostly for heating purposes. In most cases the solar collector supplies heat directly to the domestic hot water system, the building heat distribution systems, the geothermal system or a combination of all of them [16,18,19].

Nevertheless studies of solar absorption cooling systems integrated with geothermal energy through GCHP are really scarce. The

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purpose of this work is to analyze some of the influence parameters on the energy efficiency of a solar-assisted absorption GCHP in its cooling mode operation. The experimental plant is located in a tertiary-use building in Valladolid (Spain). A model of the experimental installation has been developed using the TRNSYS software [20]. The model has been validated with experimental results obtained in the installation for its cooling mode operation during the summer of 2011. For a defined control strategy, the influence of the generator and condenser temperatures on the heat pump COP and on the overall system energy efficiency is analyzed.

2. Description of the experimental plant

The experimental plant is located in the CARTIF Technology Center building as a support of its HVAC system. The tertiary-use building has an area of 1200 m^2 and is located in Boecillo, Valladolid, Spain (41°31′09″ N, 4°43′03″ W, elevation: 700 m amsl), a location with a continental Mediterranean climate. The building is occupied only on weekdays (Monday–Friday) from 7:00 to 15:00. In summer it is cooled by a radiant floor system.

Fig. 1 shows the experimental installation setup. It consists of an absorption LiBr-water heat pump (Thermax LT 1) thermally driven by a solar field and by a natural gas-fired condensing boiler as support in times of low solar radiation. The heat pump is coupled to the ground through a closed loop geothermal system. For the cooling operation in summer time the evaporator is connected to the radiant floor system of the building and the condenser exchanges heat with the geothermal system. The main characteristics of the experimental plant are summarized in Table 1.

The absorption heat pump generator is powered by an 84 m^2 solar field with heat pipe technology (Vitosol 300), and a high efficiency natural gas-fired condensing boiler (Viessman, Vitocrossal 300) as a support when solar radiation is not high enough. Generator arrangement is complemented with a system of 8 m^3 of thermal accumulation by water, distributed in four tanks of 2 m^3 each. The storage was designed through a set of valves and pipes connections that allows different configurations (one, two, three or four in series, two by two in parallel, etc.). Because of the use of glycol in the solar circuit, there is a heat exchanger to separate this primary circuit from the secondary circuit which goes up to the generator. Pumps, for both primary and secondary circuit, have variable speed drives in order to implement different control strategies for the reduction of electrical energy demand.

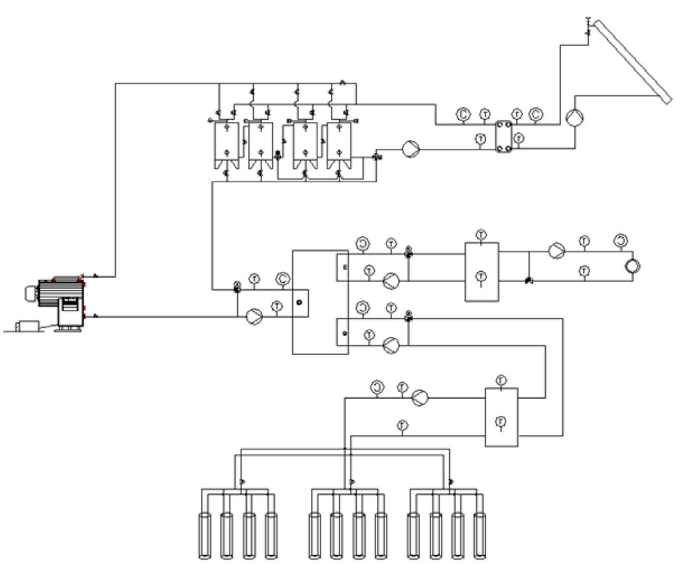

Fig. 1. Schematic representation of the experimental setup.

Table 1
Main characteristics of the experimental plant.

Variable	Value	Unit
Building		
Area	1200	m^2
Absorption Chiller		
Thermax LT 1 single effect (BrLi-H_2O)		
Nominal cooling capacity	35	kW
COP nominal	0.7	
Solar Field		
Heat pipe collector (Vitosol 300)	84	m^2
Flow of the primary circuit	5.5	m^3/h
Flow of the secundary circuit	4	m^3/h
Solar storage	8	m^3
Geothermal heat exchange		
Mouvitech collector PEN 32 × 3.0		
Number of boreholes	12	
Depth borehole	100	m
Center to center half distance	0.0254	m
Radiant floor		
Area	1000	m^2
Pipe spacing (center to center)	0.25	m
Pipe outside diameter	0.016	m

In summer operation the nominal 35 kW evaporator is connected to the radiant floor cooling system of the building. The peculiarities of solar cooling systems should be compensated with appropriate design choices, such as high inertia air conditioning distribution systems like radiant floor which regularizes the cooling load [21].

The nominal 80 kW condenser exchanges heat with the closed loop geothermal system which consists in 12 boreholes (100 m each) grouped in three blocks of four tubes. The first group has 2 simple and 2 double probes. The second group has 4 tubes with different fillings. The third group has 2 double and two high turbulence probes. In order to avoid sudden changes in the operation of the system, the condenser and evaporator of the absorption heat pump are connected to two storage tanks of 2 m^3 of capacity each.

The installation has a complete instrumentation which provides instantaneous information on its actual behavior. The monitoring system consists mainly of temperature probes and flow-meters located in the main five water circuits of the installation: the three circuits that enter the absorption GCHP (generator, condenser and evaporator), the radiant floor circuit and the geothermal circuit. The temperature sensors are TAC 100-100 with an accuracy of 1.3 °C. Six temperature probes are located at the inlet and outlet of the three water circuits that exchanges energy with the GCHP: generator ($T_{gen,i}$, $T_{gen,o}$), condenser ($T_{cond,i}$, $T_{cond,o}$) and evaporator ($T_{evap,i}$, $T_{evap,o}$). Two temperature probes measure inlet and outlet temperature of the radiant floor circuit ($T_{floor,i}$, $T_{floor,o}$) and two more temperature probes measure inlet and outlet temperature of the geothermal heat exchanger ($T_{geot,i}$, $T_{geot,o}$). Furthermore, there is an electromagnetic flow meter (ABB FXE4000, model DE43F) in each one of these circuits, which allows to measure the water flow that goes through the circuits connected to the generator (m_{gen}), to the evaporator (m_{evap}), to the condenser (m_{cond}), to the radiant floor (m_{floor}), and to the geothermal heat exchanger (m_{geot}), with an accuracy of 0.5% of the measured value. The information is collected by a LonWorks® communications network and data is stored in a database for further reference and analysis.

3. Development and experimental validation of the simulation model

A model of the experimental plant described above has been implemented with TRNSYS [20] in order to have an appropriate