Energy assessment of the heating-mode operation of a solar-assisted absorption ground coupled heat pump

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Abstract

The behaviour and performance of a solar-assisted absorption heat pump coupled to a geothermal field is studied and presented. The installation is used for heating by means of a radiating floor the CARTIF Technology Center building in Boecillo (Valladolid-SPAIN). Building location has a continental mediterranean climate and this paper presents and analyzes experimental results collected during winter season.

The experimental setup consist in an absorption heat pump (35 kW in evaporator, 80 kW in condenser) coupled to a 84 m^2 solar field with heat pipe technology and to a geothermal system consisting in 12 boreholes, 100 m deep each one. Installation is complemented with a system of 8 m^3 of thermal accumulation by water, distributed in four tanks of 2 m^3 each one, and a natural gas-fired condensing boiler as support in times of low radiation. In winter time the 80 kW condenser is connected to the radiating floor system of the building, and the 35 kW evaporator exchanges heat with the geothermal boreholes.

The energy performance of the system is calculated using continuous measurements of temperature and mass flow rate at different points of the main circuits of the system (generator, condenser, evaporator, radiating floor, geothermal boreholes). Data are captured and stored using a LON communication network.

One of the main results obtained is that the absorption heat pump under study has a COP bigger than 1.3 in the heating mode, with temperatures in the generator of 80 ºC - 90 °C. The winter operation of the absorption heat pump described in this communication increases operating hours of the HVAC system in addition to its usual summer operation

Keywords

Hybrid Heat Pump Systems, Solar Assisted Absorption Heat Pump, Geothermal Heat Pump, Ground Coupled Heat Pump.

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1. Introduction

Worldwide energy consumption by HVAC equipment in buildings ranges 16–50% of total energy consumption, depending on countries and their energy use patterns. More than half of this energy is typically used for heating [1]. The integration of heat pump with solar technology presents a novel hybrid system whereby the performance of the heat pump can be significantly enhanced by taking heat from a natural source solar energy [2]. The applications for solar-assisted heat pump systems include water heating [3–5] and heat storage [6].
Among the works conducted in recent years, new ideas related to the integration of solar-thermal, geothermal and heat pump systems have been conceived to yield novel hybrid systems. This is primarily due to sustained interest in employing renewable energy to improve heat pumping processes [7].
Usually, absorption chillers are used as equipment to generate cold. However, its use as a heat pump to produce heating, using low temperature heat sources, allows a significant improvement in system performance. In this case its operation should be linked to low temperature heating systems.
This paper presents and analyzes experimental results obtained during the initial tests in the winter season (heating-mode) for a solar assisted absorption ground coupled heat pump, GCHP, used for heating the CARTIF Technology Center building (Valladolid, Spain). The GCHP is coupled to a closed loop geothermal heat exchanger, and is thermally driven by a solar field with heat pipe technology. The behaviour and performance of the installation is presented.

2. Description of the experimental setup.

The experimental plant is located in the CARTIF Technology Center building as support of its HVAC system. The tertiary-use building has an area of 1800 m^2 and is located in Valladolid, Spain, a location with a continental mediterranean climate.
Figure 1 shows the experimental setup of the installation. It consists in an absorption heat pump (35 kW in evaporator, 80 kW in condenser) thermally driven by a solar field with heat pipe technology, and a natural gas-fired condensing boiler as support in times of low solar radiation. In winter time (heating–mode operation) the 80 kW condenser is connected to the radiating floor system of the building, and the 35 kW evaporator exchanges heat with the geothermal system.
The absorption heat pump generator is powered by an 84 m^2 solar field with heat pipe technology, and a high efficiency natural gas-fired condensing boiler (Viessman) as support in times of low solar radiation. 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 the solar circuit must use glycol there is a heat exchanger to separate this primary circuit from the secondary circuit which goes to the generator. Pumps, for both primary and secondary circuit, have variable speed drives in order to implement control strategies for the reduction of electrical energy demand.

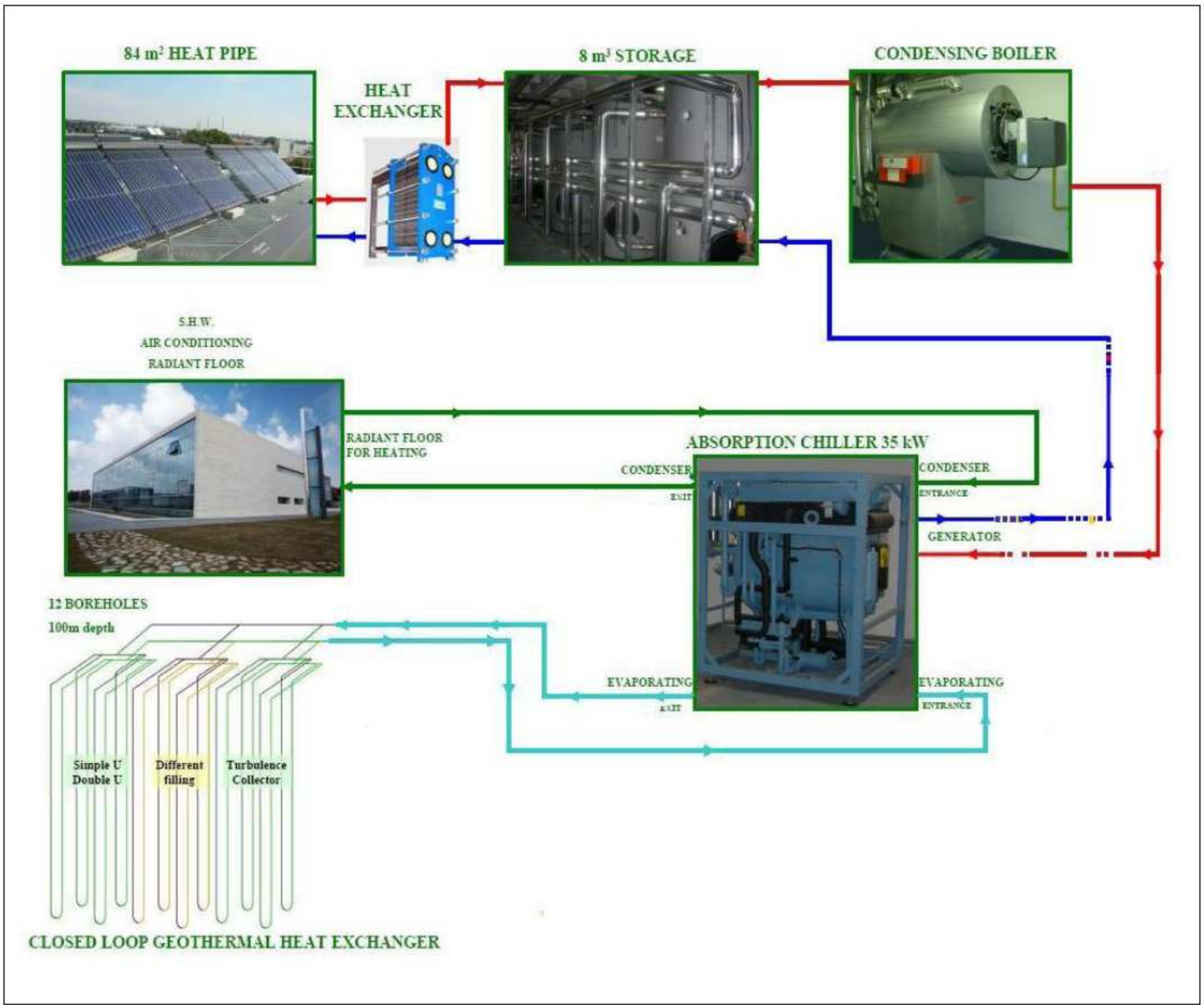

Figure 1: General layout of the solar-assisted absorption ground coupled heat pump for the HVAC of the CARTIF Technology Center building in Boecillo (Valladolid-SPAIN).

In winter time (heating–mode operation) the 80 kW condenser is connected to the radiating floor system of the building. The tertiary-use building has an area of 1800 m2 and is located in a continental mediterranean climate zone. The 35 kW evaporator exchanges heat with the closed loop geothermal system. The geothermal system consists in twelve boreholes (100m 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. These different blocks of tubes allow the study of the influence of tube configuration and design in the whole system performance [8]. In order to avoid sudden changes in the operation of the system, the condenser and evaporator of the absorption heat pump are both connected to two tanks of 2 m3 of total capacity.

The installation has a high level of instrumentation which provides information on their behaviour. Every thermal circuit is equipped with flow meters and temperature probes at different points. The information is collected by a LonWorks ® communications network and data is stored in a database for further reference and analysis

3. Experimental procedure.

Initial tests were performed during the month of February 2011. Obtained results are not representative of the expected working parameters of the installation due to the insufficient vacuum level in the absorption machine in these first running days. These initial test are being used mainly to adjust the working parameters of the solar-assisted absorption heat pump and the geothermal field, in order to achieve an optimum configuration for the steady state operation of the system.
For the starting operation, condenser pumps were set with a flow of 10 m3/h, and evaporator pumps with a flow of 6 m3/h. Generator pump was set to 8 m3/h and then the absorption heat pump was turned on. Flow measurements were made with ABB flowmeters in each of the circuits. Set-point temperatures were 90 ºC at generator, 28ºC at condenser and 12ºC at evaporator. PRT-100 probes were used to measure temperature at different points of the circuits.
When a temperature of 36 ºC is reached at the top of the condenser tank, the pump of the radiant floor circuit is switched on, starting the use in the building of the heating produced by the absorption heat pump.
Data has been recorded by the data acquisition system within 1 minute period. This allows further analysis of system performance, which was assessed on the machine level, considering the heat flow and performance both as instantaneous and as mean values.

4. Results and discussion.

Results obtained for operating variables during a particular day (February the 10th, 2011) are now presented. Figure 2 shows the evolution of the temperatures at the inlet and outlet of the generator, condenser and evaporator circuits.

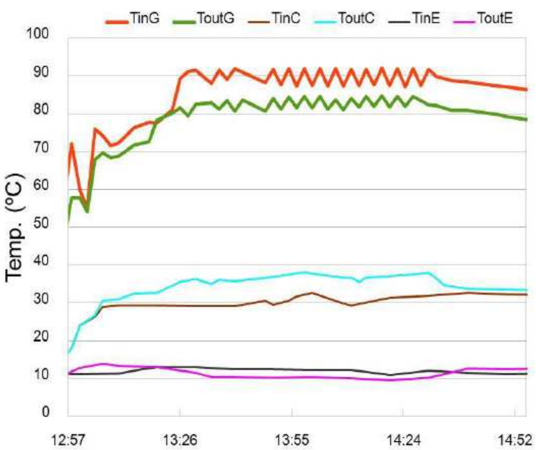

Figure 2: Inlet and outlet temperatures of the generator (TinG, ToutG), condenser (TinC, ToutC) and evaporator (TinE, ToutE) circuits of the absorption GCHP.

In order to avoid thermal stress on the absorption heat pump, the generator operating temperature is reached progressively thanks to the automated control system. The observed generator circuit inlet temperature oscillations between 88 ºC and 92 ºC are due to the non-exactly steady state operation of the boiler. Condenser circuit temperature increases to a preset operating condition, and then water is heated from 29 ºC to 36 ºC. On the other side, the evaporator works at the nominal temperature range and with an appropriate thermal gradient for the use of geothermal energy.

Figure 3 shows the energy flows in each of the main circuits of the absorption machine and the geothermal field. As it can be seen, the geothermal field has enough capacity to satisfy the heat demand of the GCHP evaporator. It is also observed certain imbalances in instantaneous incoming and outgoing energy flows. This is due to the energy accumulation and inertia of the various hydraulic circuits and of the absorption GCHP itself.

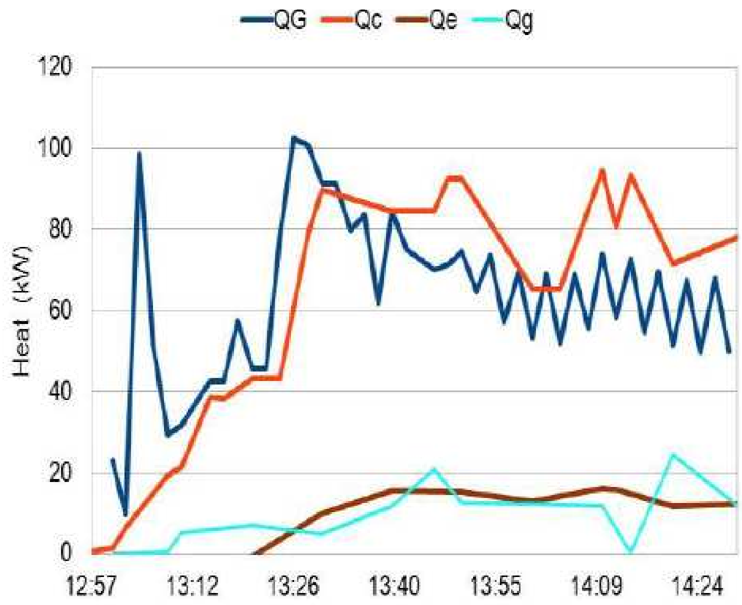

Figure 3: Energy flows at generator (QG), condenser (QC), evaporator (QE) and geothermal (Qg) circuits of the absorption GCHP.

It is important to point out that 80 kW of thermal energy flow are achieved in the condenser of the absorption GCHP when 60 kW are given at the generator circuit. The geothermal field provides the difference of 20 kW of thermal energy flow. Figure 4 shows the time evolution of the COP during operation of the facility in these first tests. An instantaneous maximum COP of 1.7 is obtained after an hour of steady state operation. The mean COP of the machine is approximately 1.3. That is, energy delivered to the building is 1.3 times the energy produced by the natural gas boiler. Results agree with literature values. A COP of 1.43 in the winter operation (heating-mode) of a solar driven adsorption heat pump using geothermal boreholes as low temperature heat source is reported by Nuñez et al. [9] for an installation at the Fraunhofer Institute for Solar Energy Systems (Freiburg, Germany).

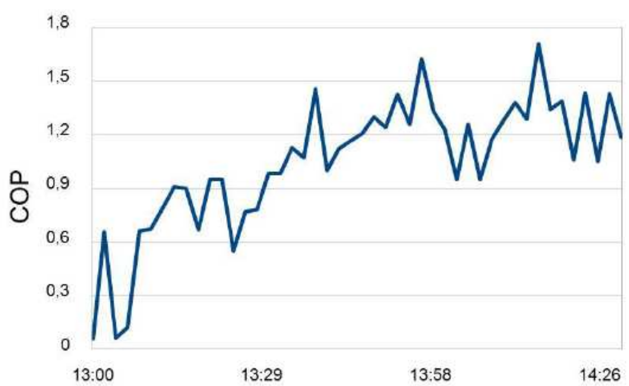

Figure 4: Instantaneous COP of the absorption GCHP

5. Conclusions.

The experimental results obtained give us the following conclusions:
The use of absorption heat pumps in winter operation (heating-mode) allows an increase in the number of hours of operation per year for these HVAC systems. This increases their economic feasibility due to decrease of the amortization periods.
The mean COP of the analyzed absorption GCHP during these first tests is roughly 1.3. An instantaneous maximum COP of 1.7 is registered. 80 kW of thermal energy flow are achieved in the condenser of the absorption GCHP when 60 kW are given at the generator circuit. The geothermal field provides the 20 kW difference.
The performance and energy flows are below expected values due to the low vacuum levels at the absorption heat pump during these first stages of operation. The facility is still undergoing adjustments and better performance values are expected when optimum working parameters will be found.
Continuous operation of the installation and corresponding registration of the working parameters will allow an assessment of the geothermal field heat flow, and its seasonal and annual thermal storage capacity.

Nomenclature

COP Coefficient of Performance
GCHP Ground Coupled Heat Pump
HVAC Heating, Ventilating, and Air Conditioning
QC Condenser energy flow [kW]
QE Evaporator energy flow [kW]
Qg Geothermal energy flow [kW]
QG Generator energy flow [kW]
TinG Generator circuit inlet temperature [ºC]
ToutG Generator circuit outlet temperature [ºC]
TinC Condenser circuit inlet temperature [ºC]
ToutC Condenser circuit outlet temperature [ºC]
TinE Evaporator circuit inlet temperature [ºC]
ToutE Evaporator circuit outlet temperature [ºC]

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Acknowledgements

Andrés Macía would like to thank the grant provided by the Latinamerican Science & Technology Development Programme (Programa Iberoamericano de Ciencia y Tecnologia para el Desarrollo, CYTED)