Performance assessment of a small-scale adsorption chiller integrated to an already existing solar heating system.

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Abstract

In the context of the solar air-conditioning systems analysis, it is crucial to assess system performance by experimentations in real-time conditions. In this way, it is possible to calculate the energy savings to minimize environmental impact and CO_2 production induced by the operation of such a system in buildings operation. It is proposed to measure the thermal behaviour and the energy performance of a small-scale solar air-conditioning system used to cool a laboratory building in the South of Belgium. The experimental system is recently installed and fully instrumented for both thermal and electrical COP computation. Results of two months operation and data analysis are presented in this work.

Introduction and objectives

A small-scale adsorption chiller has been recently installed in the laboratory building of the BEMS research team at University of Liège. This building was previously equipped with a fully monitored heat and cold production and distribution system. Besides, a solar collector field used for building heating and domestic hot water production. Both economical and architectural limits made difficult to enlarge the existing solar collector field. This paper deals consequently with the experimentation of a solar cooling system plugged into an existing solar system. Previous study [1] on cooling load and available heat for this typical building led to the choice of one of the smaller market available adsorption chiller [2]. The scheme of the installed system is displayed on the figure 1.

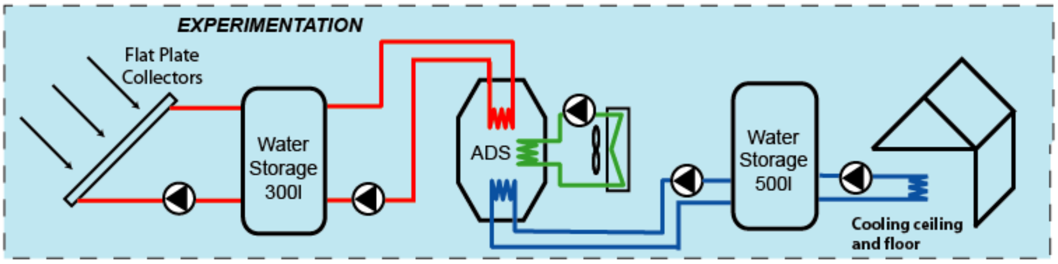

Figure 1 : Monitored solar air conditioning system at the University laboratory

By operating and measuring the solar cooling system in real scale conditions (Belgian Climate), it is proposed to assess its thermal and electrical performance. It is then proposed to optimize the operation of such a system, in connection with pre-defined and reproducible cooling loads. The literature [3][4] gives generally thermal COP in steady state conditions and the daily and monthly performance is evaluated therefore. Moreover Wiemken [5] pointed out that the system electrical performance was largely lower in measurements than expected in simulations. In this work, both electrical and thermal COP are evaluated in real time conditions, the decrease of performance due to non steady state operation is taken into account. The ways to improve electrical COP are also presented. Additionally, to quantify the energy savings, an performance comparison is achieved with an air-conditioning system using classical vapor compression chiller.

Topology

In the frame of the IEA-SHC Task 38 project, a screening of the system technology applied in solar cooling installation has been carried out. Work package A2 [6], focused on providing “generic system schemes” representing standardized solar cooling systems. Main objectives are the enhancement of the system availability and performance. The solar cooling system at University of Liège is represented on figure 2 in accordance to the IEA-SHC 38 standardization.

First of all, the last column represents the **Adsorption chiller** [2] and its **hydraulic module** [7] including a pump for each water circuit. The nominal power of the chiller is 9 kW_{cold}. Due to the solar field size, the achieved cooling power is around 5 kW. Nevertheless, the steady state thermal COP is not much decreased (0.61 (nominal) → 0.55). **The solar loop** (first row) contains 14 m^2 flat plate solar collectors (FPC) [8] (42° slope and azimuth 43° East). A pump drives a mixture of water and glycol through a heat exchanger inside the 300l hot water storage. It implies a significant temperature difference between the solar collectors supply temperature and storage tank (<10℃). This is clearly not an optimal solution as this solar air conditioning system has been integrated to an already existing solar heating system. The solar loop is not pressurized and the maximum temperature allowed is only 95℃. The **rejection loop** is a dry cooling tower especially suited to work with this chiller (the fan speed is controlled by the chiller). The **cold loop** includes the cold emission, a 500l storage tank and a backup chiller. The cold emission can be achieved by radiative cooling and/or by the air handling unit (not mentioned on figure 2). A backup vapour compression chiller is connected to the water storage tank, but not used in these experiments.

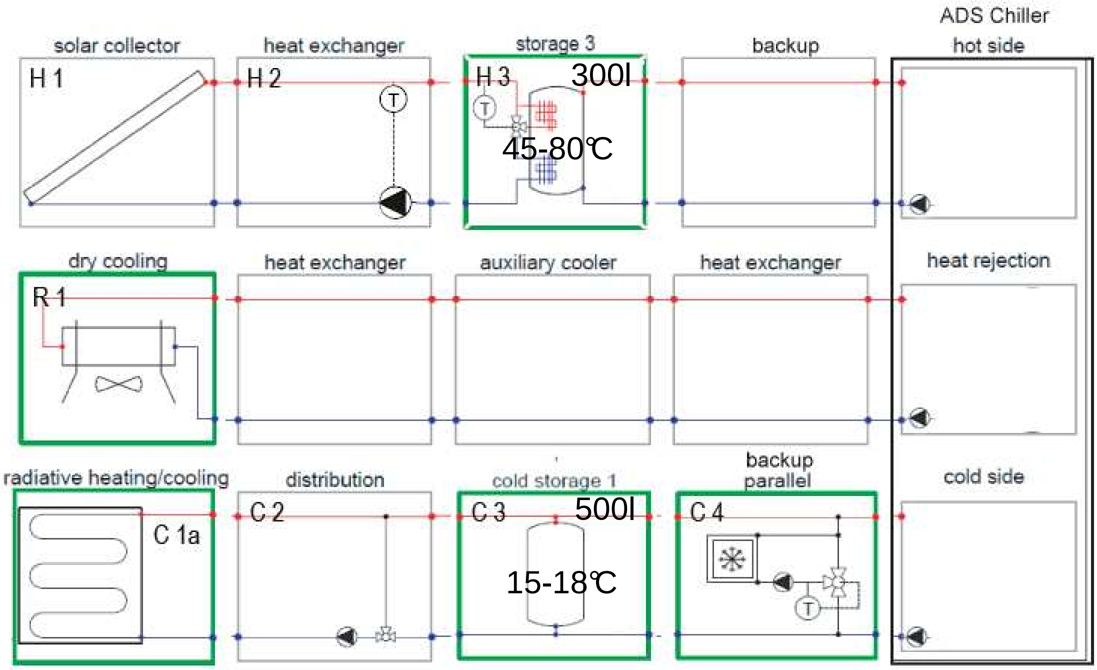

Figure 2 : Solar cooling system at University of Liège (topology standard of IEA-SHC task 38)

Monitoring procedure

Within IEA-SHC Task 38 a monitoring procedure for solar heating and cooling systems was developed [9] [10]. This methodology includes measurements of all relevant energy flows (heat, cold, electricity) to be able to derive key figures such as Primary Energy Ratio (PER), $COP_{thermal}$, COP_{elec}, savings for cooling. For the solar air conditioning system studied here, the temperatures, the water flows, the weather data, the storage temperatures and the electricity consumption are recorded. Those measurements allow the computation of various performance indexes. Measurements (picked up each 10 seconds) are summarized in following table 1 referring to the definitions of figure 2.

Box	
H1	Collector supply and return temp.

H2	Glycol flow Pump elec. Power
H3	Storage temp.
R1	Fan power
C3	Storage temp.
Miscellaneous	
ADS chiller and hydraulic module	For each flow : mass flow, supply and return temp. Elec. consumption
Weather	Dry bulb temp., Relative humidity, Solar radiation on collectors.

Table 1 : Measurement of the solar air-conditioning system

Control strategy

The adsorption chiller ON-OFF command and the temperature set point are controlled by an external computer. In these tests, it is assumed that the building has always cooling needs. In other words the cold water is distributed in the building to maintain the cold storage between 15 and 18℃. Thus , the adsorption chiller produces cold water at 15℃ at all times. On the ho t water side, the start and stop temperatures are fixed. Basically, the machine can generate cold water when the hot water is between 45℃ and 75℃ [2]. To have a bette r thermal COP, the machine starts when the hot water storage reaches 70℃ and stops when the temperature gets lower than 55℃. Finally, the solar loop is on ly dedicated to the solar air conditioning, no domestic hot water is taken into account. The pump of the solar loop has a very common control strategy: it starts if the collector temperature is 5℃ higher than the storage tank and stops if it is 2℃ lower (hysteresis of 3℃).

Results analysis

Currently, 51 days were recorded (between 12th of May and 4th of July 2011). This is a sunny period representative of summer in Belgium. Both thermal and electrical performance are presented on figure 3. They are proposed on different time scales and include mean value on the whole test as well as daily values for two typical sunny days : one with a high ambient temperature (max 34℃) and the other one with a slightly lower temperature (max 26℃). The cold e nergy produced respectively reaches 8.2, 21.3 and 17.8 kWh (mean, 27th June, 4th July). The mean thermal COP on the whole period is 0.47. It is lower than the nominal COP due largely to the supply temperature lower than 72℃ and the ON OFF c ycling of the chiller (two cycles for sunny days, up two five for quite cloudy days). The measured thermal COP is nearly in the performance target of such systems (COP_{therm} > 0.5 [5]). Nine days without cold production were recorded (18% of the test duration). The encountered collector yield (ratio of captured heat to the incident solar energy) is consistent with usually encountered values for FPC operating at high temperature.

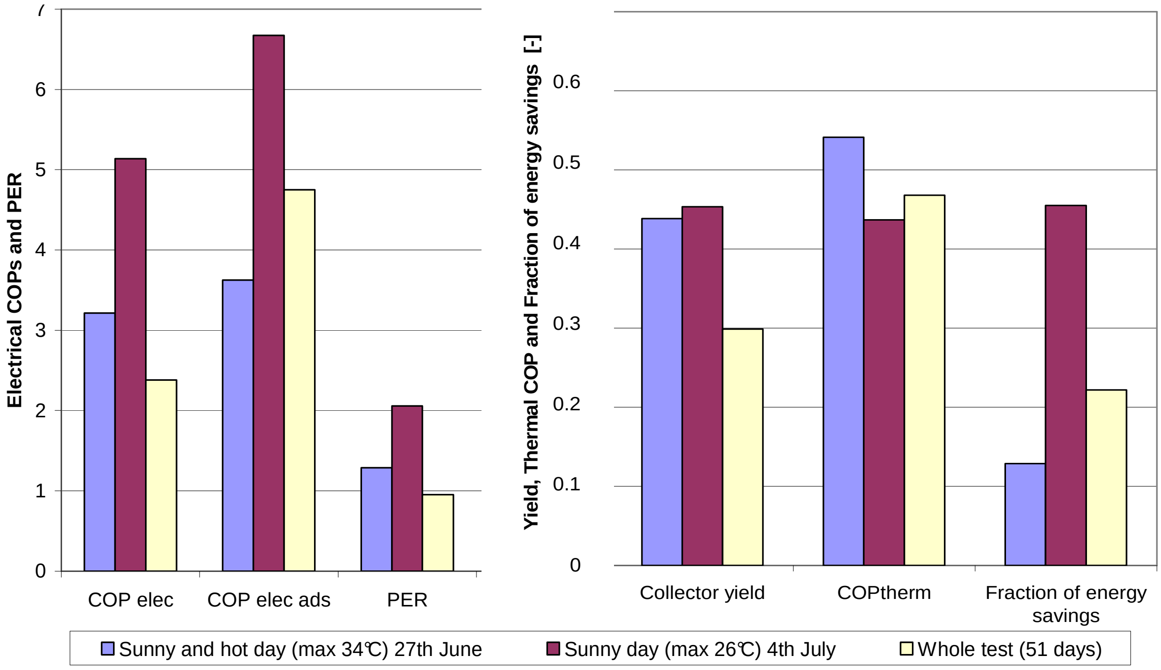

Figure 3 : Electrical and thermal performance results for the whole test and for typical days

On the electrical point of view, two electrical COPs are defined : electrical COP based on the electricity consumed by the adsorption chiller and the cooling tower fan only (called $COP_{elec\ ads}$). The other one includes also the solar loop pump (COP_{elec}). First testing days were run with a 350W pump and a new solar loop pump (power: 83W) was installed on 16th June. The electrical COP for the whole test is really low while sunny days accomplish better values. External temperature has a big influence on the electrical COP (from 5.1 to 3.2 between the two sunny days) because of the high dry cooling tower fan consumption. Moreover, the standby power is not negligible as it represents 36% of the adsorption chiller and fan total consumed power (the adsorption chiller longest operation period is around 4h for one day). Overall electrical COP is 2.38 and it is partially due to the low electrical performance of the first solar loop pump (in operation during 33 days). Electricity consumption is shared as follows for the entire test (and for the hottest day – 27th June) : solar pump 50% (11%), adsorption chiller 35% (33%), cooling tower fans 15% (55%).
The primary energy ratio (PER) is presented based on measured values and follows the trend of the electrical COP. Finally, the fraction of energy savings [9] is 22% for the whole test (taking into account the new pump electricity consumption for the whole test).

Conclusions

Measurements of the recently installed solar cooling system provide a number of performance indicators. On the thermal point of view, the adsorption chiller performance is nearly as high as expected, a better solar loop could easily reach COP_{therm} higher than 0.5. On an electrical point of view, electricity savings compared to a classical vapour compression chiller reach 22%. Furthermore, the installation of a spraying kit for the cooling tower and a better management of standby consumption could allow to reach higher energy savings.

Acknowledgments

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