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Use of Parabolic Trough Solar Collectors for Building Air Conditioning and Domestic Hot Water Production - Case Study

E. S. Quintal, H. S. Bernardo, P. G. Amaral, L. P. Neves

Abstract — The aim of this study is the evaluation of the economic and technical viability for the installation of a solar air conditioning system based on parabolic solar concentrators and adsorption technology, in an existent building. As case study was selected a university canteen located in the centre region of Portugal. Besides air conditioning, this system is also used for domestic hot water production. This solution enables the system use throughout the year in order to maximize the investment.

Results show that the implementation of these systems is feasible for the portuguese reality and the return of the investment can be achieved in 8 years without governmental financial support.

Index Terms — Solar energy, solar cooling, adsorption cooling.

I. NOMENCLATURE

COP – Coefficient Of Performance;
DHW – Domestic Hot Water;
DNR – Direct Normal Radiation;
EE – Electrical Energy;
IRR – Internal Rate of Return;
NG – Natural Gas;
NPV – Net Present Value;
PTC – Parabolic Trough solar Collectors.

II. INTRODUCTION

A few decades ago the demand for buildings was driven mainly by functionality and price of acquisition, being the comfort of the occupants often downgraded to the

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background. Over time arose solutions to answer more directly to users comfort needs. One solution was the widespread use of air conditioning systems based on electric driven compression technology, which have improved greatly the quality of indoor environment in buildings. However, these systems immediately registered high energy consumption, heating and cooling, as well as, and nowadays represent an important share in the overall consumption of the building. With comfort levels ever higher, the costs associated with air conditioning has been increasing and is expected that this growth will be even more pronounced in coming years, either due to the rising standards in comfort required by the occupants or even due to climate changes [1].

Nowadays in Portugal, buildings account for about 60% of the electric energy consumption and about 30% of primary energy consumption [2], this makes this sector a target for intervention as regard the improvement of energy efficiency ratings. Thus, any measure to keep or improve standards in indoor comfort and at the same time allowing the reduction in the energetic bill should be aim of interest and study.

With this in mind, this study proposes to analyze the use of a solar based system to obtain the required thermal energy for heating and cooling, as well as for the production of DHW. This combination allows the maximization of the system use throughout the year, allowing for greater profitability of the project.

III. TECHNOLOGY

Solar cooling is a solar thermal technology that produces cold by exploiting solar energy allowing significant savings compared with traditional air conditioning plants. This is also due to the fact that the main cooling demand can be covered at the moment of maximum solar radiation. Solar energy is used to provide heat to a thermodynamic cycle that allows to produce cold water [3].

Due to the fact that this technology still is at an early stage of development, European Union created a special program named SOLAIR, which goal was to promote and to strengthen the use of solar air-conditioning systems for small and medium application in residential and commercial buildings.

This program was active between 2007 and 2009 and was financed under Intelligent Energy Europe with partners from several European countries [1].

A. Parabolic Troughs

Parabolic troughs are collectors designed to reach temperatures over 100°C and up to 450°C (with a concentration ratio around 26) and still keeping high efficiency due to a large solar energy collecting area with a small absorber surface.



Fig. 1. Parabolic trough solar collector (Solitem PTC 1800).

Smaller parabolic troughs (Fig.1), with concentration ratios between 10 and 15, can operate at temperatures between 100°C and 250°C. The aperture width of these small troughs ranges from 50 cm to 2,3 m. The advantage of these small troughs is that they are relatively lightweight and easier to handle. Some of them can be installed on roofs [4].

B. Adsorption chiller

The adsorption system (Fig.2) can be compared to a conventional air conditioner or refrigerator, with electric powered mechanical compressor replaced by a thermally driven adsorption compressor. The ability to be driven by heat, which is used for desorption, makes adsorption cycles attractive for electrical energy savers. Also, since fixed adsorbent beds are usually employed, these cycles can be operational without moving parts other than magnetic valves.

This results in low vibration, mechanically simple, high reliability and very long life time. The uses of fixed beds also results in intermittent cycle operation, with adsorbent beds changing between adsorption and desorption stages [5].



Fig. 2. Adsorption chiller (SorTech ACS15).

IV. METHODOLOGY

To supply the energy for air conditioning and DHW was considered a system in which thermal energy is supplied through the use of Parabolic Trough solar Collectors (PTC) combined with an adsorption system (for cold production). For this, several approaches were made in what concerns the system sizing. These approaches consisted in sizing the system taking into account the energy required to meet the building energy needs, considering: monthly average area of collectors, average area of collectors in the heating period, average area of collectors in the cooling period and month in which is needed greater area of collectors.

Another aspect to consider is that the installed collector power is equal to the power needed to satisfy the energy demand of the building. It is expected that total energy needs will not always be satisfied due to the fluctuation of the available solar energy along the day.

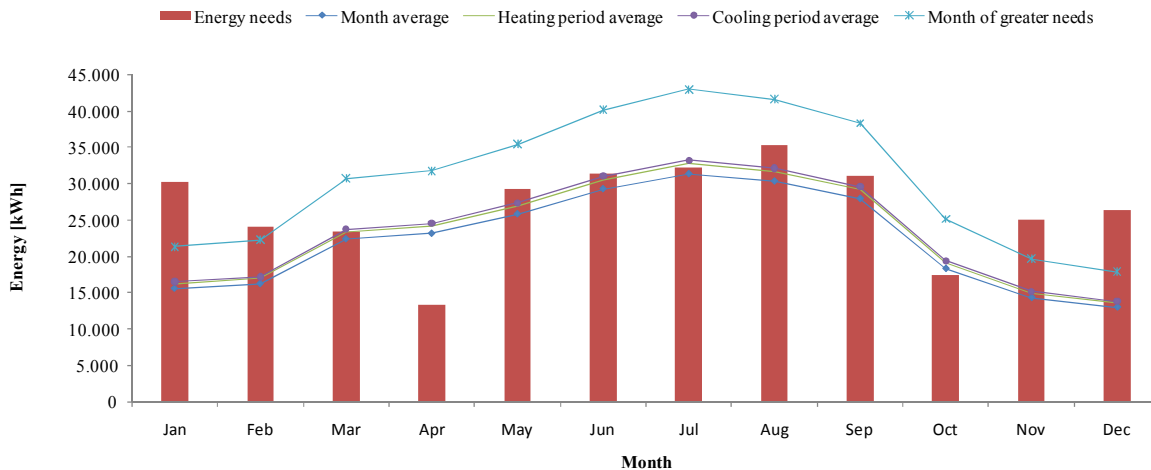


Fig. 3. Produced energy comparison.

In Fig.3 is shown the comparison of the energy produced considering the different approaches meet the energy needs of the building.

As it is shown in Fig.3, the maximum produced energy is obtained by the approach that considers the dimensioning of the system based on the month of higher needs in what concerns the collecting area; this is also the scenario that produces more wasted energy. The other three scenarios have a similar annual energy yield. From among these three scenarios was chosen the one who produce less wasted energy, that is, the one where the system sizing was made taking into account the monthly average area of collectors necessary to meet the energetic demand of the building.

A. Energy costs

The considered energy costs are presented in table I.

TABLE I
CONSIDERED PRICES

EE	0,0935	€/kWh
NG	0,0430	€/kWh

The prices presented in the Table I were obtained from the energy bills of the building. All prices used in this study are reported to 2009.

B. Solar radiation

In Table II are presented the solar radiation parameters used for this study. These values were obtained from the atmospheric science data center maintained by NASA [6] and refer to the project site.

TABLE II
SOLAR PARAMETERS

Month	Insolation	DNR
	[hours]	[kWh/m ²]
Jan	10	3,59
Feb	11	4,14
Mar	12	5,16
Apr	13	5,51
May	14	5,95
Jun	15	6,97
Jul	15	7,22
Aug	14	6,99
Sep	12	6,65
Oct	11	4,22
Nov	10	3,41
Dec	10	3,00

V. CASE STUDY

For this study was selected a university canteen located in the centre region of Portugal. The building is composed by

two floors with a total surface area of 1.487 m². The building is heated using a Natural Gas (NG) boiler which is used also for DHW production. The building does not have any cooling system. Due to the non-existence of a cooling system, it was considered that the cooling of the building is achieved by using an electrical compression chiller with a COP of 3.

Table III lists the heating and cooling periods taken into consideration for this study.

TABLE III
HEATING AND COOLING PERIODS

Heating	From October to March
Cooling	From May to September

A. System description

The thermal energy captured in the solar collectors is transferred to the internal circuit through a heat exchanger, (liquid/liquid). For DHW storage is used a thermal reservoir. The backup will be assured by the existing hot water system (NG boiler), that shall come into operation when the solar collectors do not provide enough energy to satisfy the building energy demand. The system will alternate between the production of heat in the winter and cold in the summer, depending on the direction of the hot water circuit. The heating and cooling of the different indoor spaces will be done through heat exchangers (water/air) mounted in the air handling units of the building.

To mitigate fluctuations in the supply of cold water, as well as to meet peak needs, the system has an inertia tank in the chilled water circuit.

The operating principle diagram is presented in Fig.4.

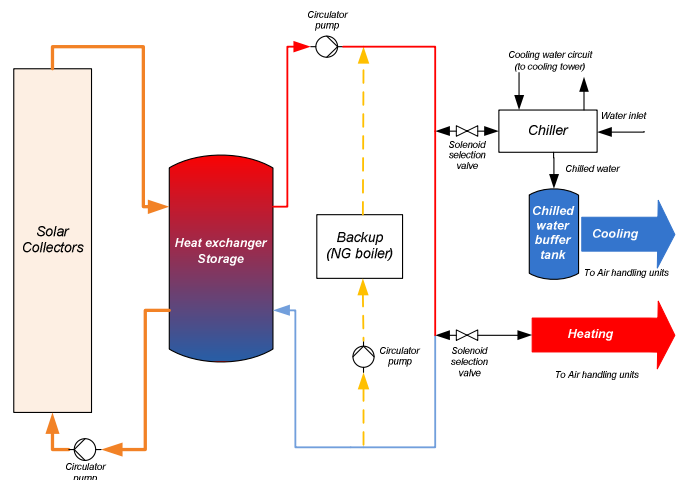


Fig. 4. Operating principle diagram.

For this study were considered NepSolar PolyTrough 1200 solar collectors and SorTec ACS8/15 adsorption chillers.

B. Energy needs of the building

The heating and cooling needs presented in table IV were determined by using a computational simulation program (DesignBuilder/EnergyPlus), which model was validated by an energetic audit, so the presented values are for real utilization conditions.

TABLE IV
ENERGY NEEDS

Month	Heating	Cooling	Total
	[kWh]	[kWh]	[kWh]
Jan	15.620	0	15.620
Feb	10.782	0	10.782
Mar	8.048	0	8.048
Apr	0	0	0
May	0	13.857	13.857
Jun	0	16.749	16.749
Jul	0	18.119	18.119
Aug	0	19.950	19.950
Sep	0	17.014	17.014
Oct	2.736	0	2.736
Nov	10.425	0	10.425
Dec	12.364	0	12.364
Total	59.975	85.689	145.664

The canteen is open all year including in the holiday summer season (August); being the only one from the entire campus, open for service in that period.

C. Produced Energy

Table V shows the monthly produced energy and the costs associated with the use of NG as backup.

TABLE V
PRODUCED ENERGY

Month	Produced energy	Energy balance	Energy backup costs
	[kWh]	[kWh]	[€]
Jan	15.575	-14.762	635
Feb	16.223	-7.939	341
Mar	22.386	-1.048	45
Apr	23.134	9.754	0
May	25.814	-3.430	147
Jun	29.263	-2.202	95
Jul	31.323	-844	36
Aug	30.326	-5.010	215
Sep	27.920	-3.142	135
Oct	18.308	855	0
Nov	14.317	-10.825	465
Dec	13.015	-13.397	576
Total	267.603	-51.991	2.692

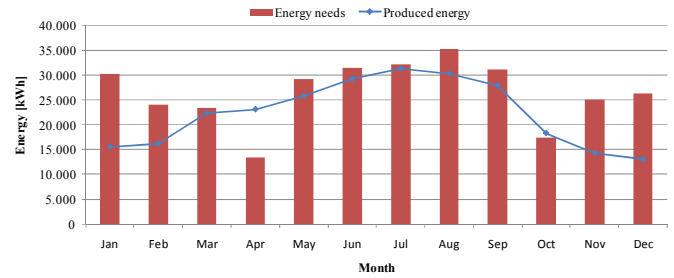


Fig. 5. Produced energy VS Energetic needs.

As it is shown in Fig.5, with this scenario there is only energy surplus in April and October. In the rest of the year the backup system has to be used in order to answer the needs of the building. For this scenario is required a collecting surface area of 140 m² of PTCs (5 NepSolar PolyTrough 1200 solar modules) that result in 73 kW of installed power. For the cold production it was considered an adsorption system capable of delivering 48 kW of cooling power (SorTec adsorption Chillers).

D. Economic analysis

For the economical analysis, was considered a system lifetime of 25 years. The analysis was carried out at constant prices (without considering the rate of inflation); it was considered a nominal discount rate of 3 %; were not considered costs associated with the maintenance of the system and it was considered an annual cost of € 2.692 with backup energy (NG).

The prices mentioned in table VI refer to PTCs and to the adsorption system; and were obtained directly from their manufacturers.

TABLE VI
ACQUISITION COST

System	Acquisition cost	
PTCs	350,00	€/m ²
Adsorption cooling	1.250,00	€/kW

Table VII presents the energy cost savings, per year, that result from the system implementation.

TABLE VII
SAVINGS

Consumption	Energy [kWh]	Cost [€]
Heating (NG)	60.304	2.593,09
DHW (NG)	173.930	7.479,01
Cooling (EE)	28.563	2.671,54
Total	262.798	12.743,64

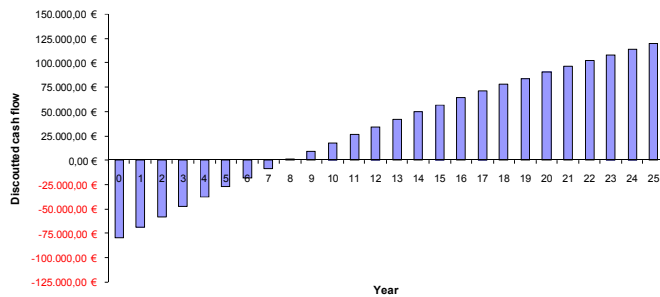


Fig. 6. Discounted cash flow.

Fig.6 shows the discounted cash flow during project life time. Considering an investment of 133.131 €, the break-even point is achieved at the 8th year. The NPV at the 25th year is 119.628 € with an IRR of 13,77 %.

Is expected that the overall maintenance costs will not be much different from what they already are at the present, due especially to the low maintenance needs of the adsorption system. In consequence is expected that the payback period will not be affected by the system maintenance costs.

VI. CONCLUSIONS

Solar water heating reduces the amount of water that must be heated by conventional water-heating system used in buildings, so it can directly substitute fossil-fuel energy for renewable energy, allowing at the same time a reduction in the energy bill, with the possibility of achieving a better energy label for the building.

The use of PTC when combined with adsorption technology can be used for building air conditioning, enabling the production of heat and cold besides the production of DHW, with environmental benefits. The existing technology enables the use of these systems in small size applications (less than 100 kW), once there are available in the market small PTCs that can be roof mounted, and small power adsorption systems (less than 10 kW). This study shows that this system is economical viable in Portugal being the return of the investment achieved in 8 years without any governmental financial support, even not considering the expected rise of energy prices.

VII. ACKNOWLEDGMENT

The authors acknowledge the facilities and technical resources made available by INESC Coimbra.

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IX. BIOGRAPHIES



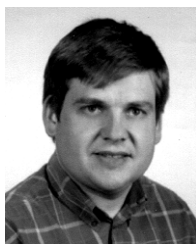
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