Energy performance of a solar system used for space heating, DHW and cooling

Razvan Ştefan Popescu – Universitatea Tehnică de Construcţii Bucureşti
Email : razvan22@yahoo.com

Andrei Damian – Universitatea Tehnică de Construcţii Bucureşti
Email : adamian7@yahoo.com

Lelia Letitia Popescu – Universitatea Tehnică de Construcţii Bucureşti
Email : lelialetitia@yahoo.com

The present paper presents a numerical study applied to an active solar system used in a family building, equipped with two different solar systems. These systems are designed to produce directly hot water for two building facilities: heating and domestic hot water (DHW) preparation, and indirectly cooled water for cooling purposes, by means of an adsorption heat pump and an auxiliary chiller installed near the building. The study is performed by using the software TRaNsol, appropriate for the annual energy analysis of the solar systems implemented in buildings. The main objective of the paper was to perform a comparison between a solar system that use flat plate collectors and a solar system using evacuated-tube collectors, both systems being installed in a low-energy family building, with very good thermal insulation. This comparison relies on the annual coverage degrees obtained for heating, DHW production and cooling, as well as payback times obtained for the two systems. In the studied case, the solar system using evacuated-tube collectors seems to be more efficient in terms of payback time than the system using flat-plate collectors (10 years instead of 16 years), for almost the same annual coverage degree (84% instead or 87%) for DHW production.

Key words : solar energy, space cooling, space heating, solar systems simulation

1. Introduction

In the last decade, the humanity has coped with the reduction of fossil fuels stocks, due to the growth of the global economy, in the industrial or non-industrial sectors. As a result, the total emissions of greenhouse gases (GHG), especially CO_2, have shown a significant growth, with a poor effect on the environment air quality. Since year 1997, when the Kyoto Protocol had been assumed by the majority of the countries throughout the world [1], many strategies have been proposed to reduce the emissions of GHG and to increase the role of the Renewable Energy Sources (RES) in the economy.

The building sector is responsible for 40-45% of the total energy consumption in Europe and China, and for 30-40% at the world level. The most part of this consumption is dedicated to the building facilities, such as: heating, ventilation, cooling and lighting.

In order to implement the extensive use of the RES at the European level, the European Union (EU) has set-up the National Renewable Energy Action Plans –NREAP's [2] that fixed two main targets:

- The reduction with 20% of the GHG emissions by the year 2020, and
- The raise of the RES contribution from the total energy consumptions up to 20% until year 2020

At present, the main measures to be taken worldwide to minimize the energy consumptions in buildings are the following ones:

- The increase of the thermal resistance of the building envelope elements in order to reduce the heating losses ;
- The use of low-energy lighting appliances (ex. LED) and the better valorization of the natural lighting ;
- The passive heating and cooling techniques ;
- The use of natural and hybrid ventilation systems ;
- The extensive use of RES within buildings : solar energy, biomass, wind or geothermal energy
- The smart building integration of the systems using RES within the buildings envelope

From the great majority of systems using RES in buildings, those employing solar energy are the most frequent used worldwide [3-9]. It is well known that the Sun gives continuously a great amount of "free" energy and the caption of this energy has been a challenge from the humanity from several centuries. Nowadays, there are used "active" and "passive" solar systems within buildings, integrated or not in the building envelope. The difference between these two systems is due to their operational mode: while active systems use directly the heat yield by the solar collectors, the passive systems use an indirect heating of the air or building elements by the Sun (ex. Double-skin facades).

A revision made by the ENERPLAN association [10] had shown that almost 2.700.000 m^2 of solar panels were installed in Europe in 2007, with an increase of 10% compared with 2006. In Europe, Greece, Germany and Austria are the countries that exploit the most the solar energy, while other countries with greater solar potential (Spain, Italy, France or Cyprus) have less developed this field, because of their national legal constraints.

The perspectives fixed by the EU for the year 2020 are focused on the installation of 18 million m^2 of solar collectors in Europe, according to the target of 20% use of RES from the total energy consumptions.

In the present paper is outlined a numerical study of an active solar system used in a multi-family building to produce directly hot water for heating and domestic hot water (DHW) preparation, as well as indirectly cooled water for cooling purposes, by means of an adsorption chiller installed near the building [11-13].

The study, performed with the dedicated software TRaNsol [14] for the solar systems, is focused on the comparison between an active solar system that use flat plate collectors and a similar system using evacuated-tube collectors.

The annual energy yield calculations for both systems has shown that the case using evacuated-tube collectors is largely better, in terms of energy efficiency and payback time for initial investment.

2. Method of investigation

Solar energy is an important renewable source which can help to reduce significantly the fossil fuel consumptions for buildings facilities like: Domestic Hot Water (DHW) production, heating or cooling. According to the solar potential all over the world, many studies have been performed by now to investigate the opportunities to implement “solar systems” (e.g. systems of installations using the solar potential) within different types of buildings, under various climatic conditions.

The present paper has as main objective to find out, by using simulation tools adapted to solar systems operation, the energy performance of an adsorption cooling machine in Romanian climate conditions.

First of all we should describe the case study: a 124 m^2 of developed area single family house, located in Bucharest (belonging to the climatic zone II of Romania), having 4 inhabitants and 170 l/day domestic hot water consumption. The thermal insulation of the walls is composed by a 35 cm-thick layer of mineral wool, obtaining a mean value of the walls thermal resistance : R_{wall} = 8,85 m^2K/W. The windows are also very performing ones, being composed by a triple glazing filled in with Xenon, and resulting an overall thermal resistance R_{window} = 1,5 m^2K/W. Therefore, the building investigated could be easily labeled as a “low-energy house”.

In order to perform correctly our numerical study by means of the simulation of the house thermal regime, including the solar system, we used the simulation software TRNSYS for the estimation of the building and cooling loads, and TRANSOL

First simulations in TRNSYS were conducted to obtain the heating and cooling loads of the house. TRANSOL software unfortunately doesn't have the possibility to choose the desired U value for walls, ceiling or floor, only predefined values. It's the same regarding the windows U value.

The results obtained from TRNSYS, in terms of heating and cooling loads, were used consequently in the TRANSOL software, to simulate the consumptions related to the low-energy house investigated. The adsorption cooling machine is used only for cooling purposes, not in heat pump mode, as it is described in figure 1.

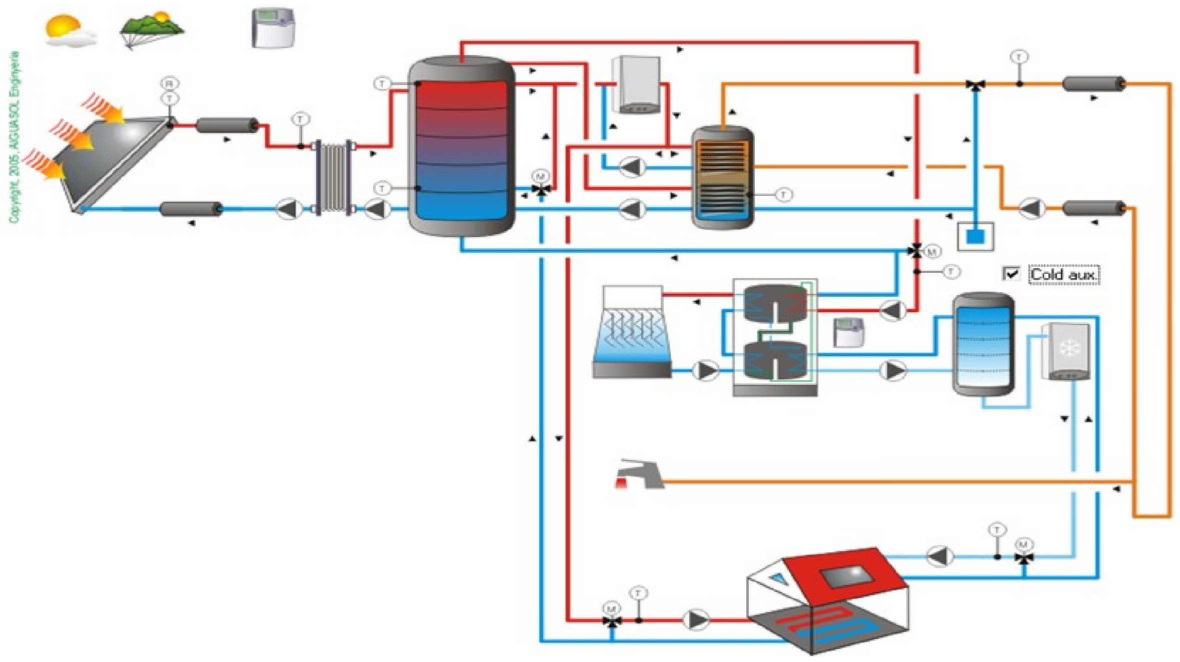

Figure 1. Sketch of the TRANSOL model for the solar system investigated

Two solar systems had been analyzed:

- a system with 9 evacuated-tube solar panels (total installed area 9,54 m^2) and 700 l volume solar tank and respectively,
- a system with 10 flat-plate solar panels (total installed area 21 m^2) and 1500 l volume solar tank.

In both cases a 100 l volume DHW tank was used, as well as a 1000 l volume chilled water tank. For both systems a 6,2 kW (installed cooling power) adsorption heat pump was chosen, having an annual COP of 0,7.

3. Results and discussions

First of all it's interesting to find out how much energy the simulated house is consuming. The figure 2 below presents how many kWh of energy are needed for heating, cooling and domestic hot water production (DHW), for each month of the year.

The results correspond to the Bucharest climate, which is taken into account by means of a weather file of TMY (Typical Meterological File) type, contained in the TRaNSol weather database.

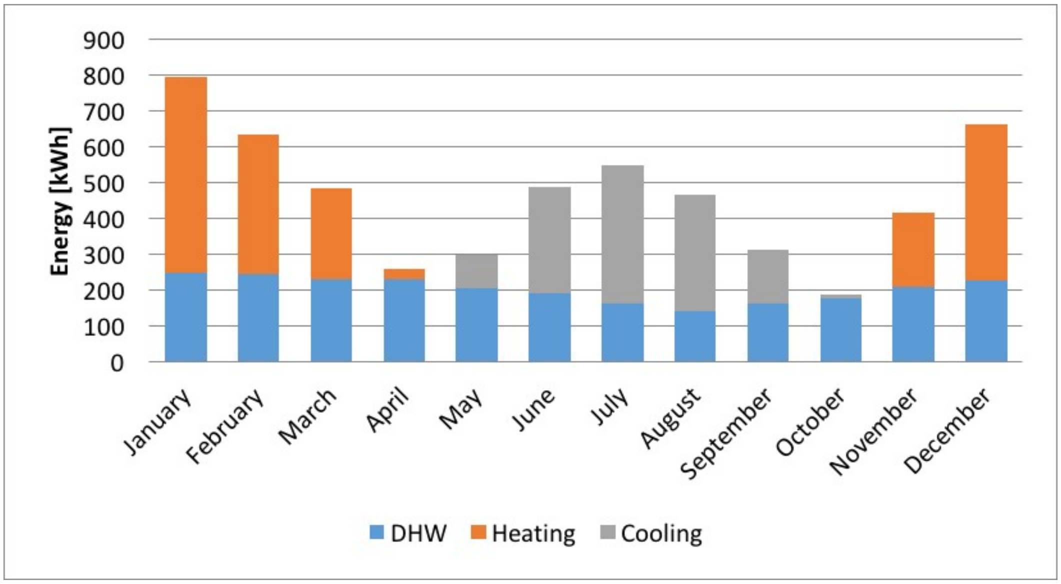

Figure 2. Energy requirements for the simulated low energy house

In terms of annual and monthly coverage degrees for heating, cooling and DHW production, the results obtained in TRaNsol show similar performances for the two solar systems investigated, which make use of evacuated-tube or flat plate solar panels. A comparison is shown in the figures 3,4 and 5 for heating, cooling and domestic hot water production. For space heating we obtained an annual coverage degree of 35% for vacuum panels and 52% for flat type.

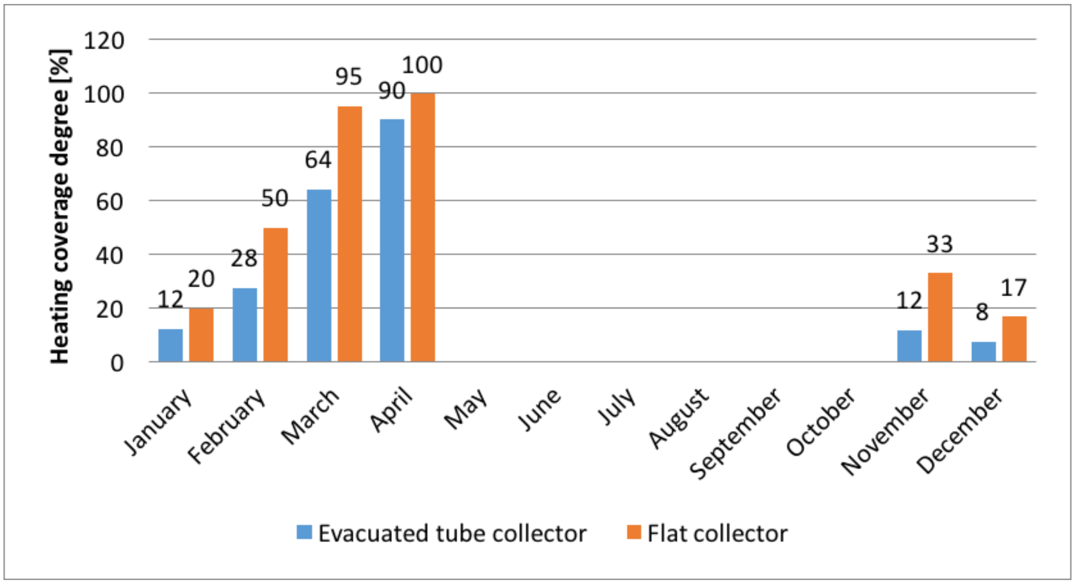

Figure 3. Heating coverage degree for the systems investigated

For the cooling months (May to October), the coverage degree is 37% for evacuated-tube panels and 54% for flat type, showing an important difference of cooling production in summer period.

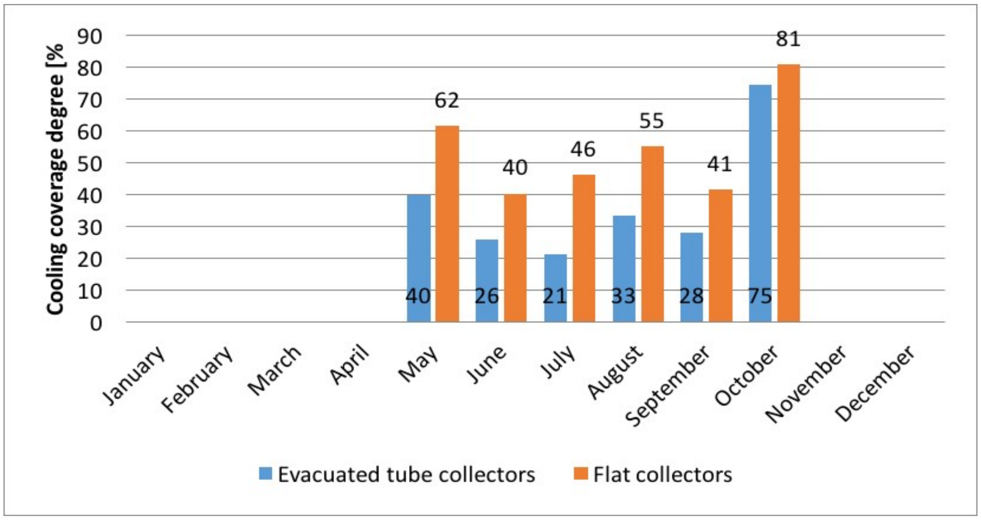

Figure 4. Cooling coverage degree for the systems investigated

Concerning DHW production there is not such a big difference in energy production, 84% vacuum collectors and 87% flat-plate collectors. So only for space heating and cooling the differences in energy production is important. As we expected, flat solar panels which are of course more expensive, are able to obtain a higher energy production, their surface being almost double. In terms of costs the evacuated tube collectors have a lower price.

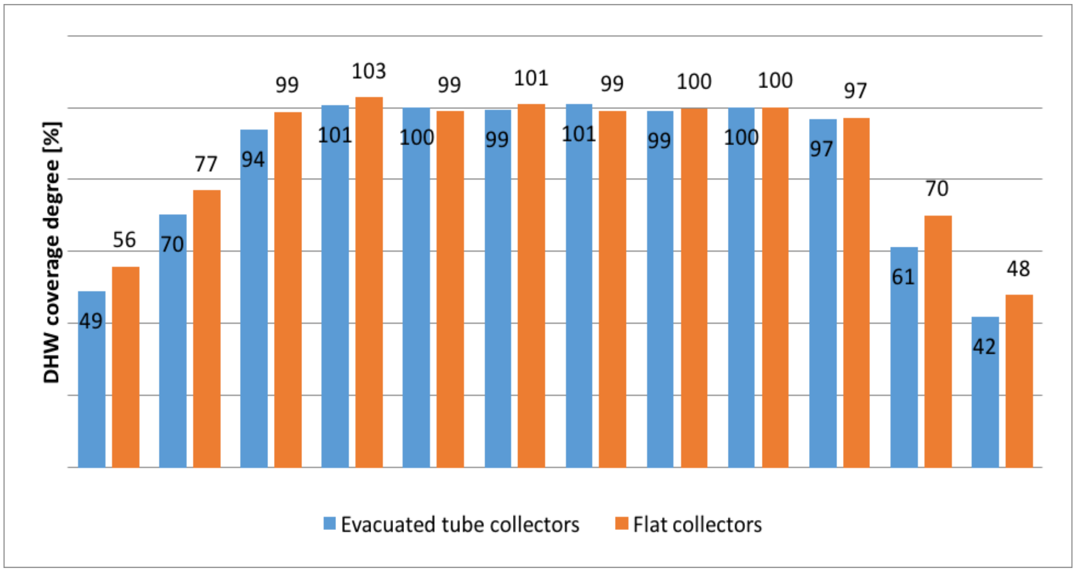

Figure 5. Domestic Hot Water coverage degree for the systems investigated

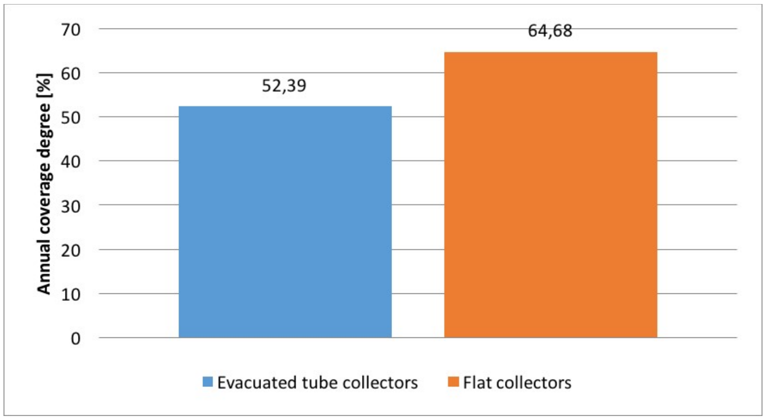

Figure 6. Comparison of global annual coverage degree of the two systems

In terms of annual coverage degree of the solar system the flat-plate system has a higher value of 64% compared to 52% for the evacuated-tube type. That doesn't mean that the flat-plate type is better or has higher performances, it's just another system with different collector area and different equipments chosen.

Concerning the payback time (PB), it seems that the most expensive flat-plate system of 25036 Euros has a 16 years PB compared to evacuated-tube system having a cost of 20268 Euros and 10 years PB. For such a complex system, which has an adsorption cooling machine and a mechanical compression backup one, the costs are not very high. The payback time between 10 and 16 years seems reasonable compared to 25 years-the life span of such an installation.

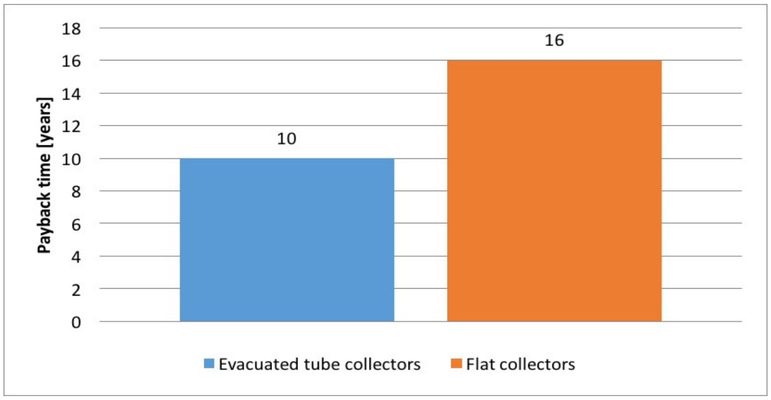

Figure 7. Payback period for the analyzed systems

4. Conclusions

The present study shows the behavior of an adsorption cooling machine used for cooling, heating and DHW, for a low energy house located in Bucharest. Two different systems were studied, energetically and economically, presenting a payback period of time between 10-16 years. The results show better performances for the evacuated tube collectors, probably because the higher temperature needed for the adsorption cooling machine. To be able to "feed" the cooling machine with high temperature fluid, the flat collectors have almost double surface to have almost similar performance. Further studies should be done to simulate almost zero energy houses, as a next step.

Acknowledgement

The work presented in this paper was conducted by a consortium of three universities (Romania, Bulgaria and France), under the framework of international research project (ISERBATURB) financed by the Romanian Agency of Atomic Physics and the French University Agency (AUF).

5. References

[1] Protocole de Kyoto a la convention-cadre des Nations Unies sur les changements climatiques, available at : *http://unfcc.int/resource/docs/convkp/kpfrench.pdf*

[2] Official Journal of the European Union from 15.07.2009 - Commission Decision of 30 June 2009 establishing a template for National Renewable Energy Action Plans under Directive 2009/28/EC of the European Parliament and of the Council

[3] L.L. Popescu, R.S.Popescu, A.Damian, Simulation study of a solar residential heating system, Energy Procedia 112 676-679, 2017

[4] Solar Thermal Industry Federation, www.estif.org

[5] Analysis of performance of a DHW system in different operational conditions, RRIC journal, vol.1, 2010, Matrix Rom

[6] Matteo Dongellini, Stefania Falcioni, Gian Luca Morini, Dynamic Simulation of Solar Thermal Collectors for Domestic Hot Water Production, Energy Procedia, vol.82, pg.630-636, 2015

[7] Kim D.S., Infante Ferreira C.A., Solar absorption cooling. 1st progress report, Delft University of Technology, 2003

[8] Kim D.S., Infante Ferreira C.A. - Air-cooled solar absorption air conditioning. Final Report - Delft University of Technology, 2005

[9] Nazif G. and Altan H., Zero energy house design for cyprus: enhancing energy efficiency with vernacular techniques, Proceedings of Building Simulation 2013 conference, August 2013, pp. 2978-2984

[10] ENERPLAN – Syndicat des Professionels de l'Energie Solaire, available at : http://www.enerplan.asso.fr/

[11] Hasan Demir, Moghtada Mobedi, Semra Ülkü, A review on adsorption heat pump: Problems and solutions, Renewable and Sustainable Energy Reviews, vol.12. pg.2381-2403, 2008

[12] Angelo Freni, Belal Dawoud, Lucio Bonaccorsi, Stefanie Chmielewski, Anddrea Frazzica, Luigi Calabrese, Giovanni Restuccia, Basics Adsorption Heat pump Processes, Springer, 2015

[13] Infante Ferreira, D. Zaytsev, Experimental Compression – Resorption Heat Pump For Industrial Applications, Purdue e-Pubs, 2002

[14] TRANSOL – Solar Thermal Energy software, available at : *https://aiguasol.coop/energy-software/transol-3-solar-thermal-energy/*