Simulation And Optimization of a Solar Absorption Cooling System Using Evacuated Tube Collectors

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SUMMARY

Summer air conditioning represents a growing market in commercial and residential buildings. Solar energy is a very interesting energy source because of its advantages. Instead of a compressor system, which uses electricity, an absorption cooling system needs only heat produced by a solar collector plant. Furthermore, Reunion Island has a high solar energy potential. The yearly average solar-radiation and is 5.4 kWh/m²/day. This paper presents a solar-powered, single stage, absorption cooling system, using a water–lithium bromide solution. The first part of this work deals with the dynamic modeling of an evacuated tube collector used for the simulation of heat production. In a second part, simulation and optimization of the system has been investigated in order to determine the optimum of solar collector plant surface, storage tank volume and nominal capacity of the absorption chiller. A new building code was added under TRNSYS16, to have dynamic coupling between building loads and cooling production.

INTRODUCTION

Reunion Island is a French overseas department located in the southern hemisphere characterized by a tropical humid climate. Conventional energy will not be enough to meet the continuously increasing need for energy in the future. In this case, renewable energy sources will become important. Solar energy is a very important energy source because of its advantages (insulation > 5 kWh/m²/day in Reunion Island). Of share our insularity an orientation towards renewable energies is today a perennial solution to obtain certain energy independence, cf. Figure 1.

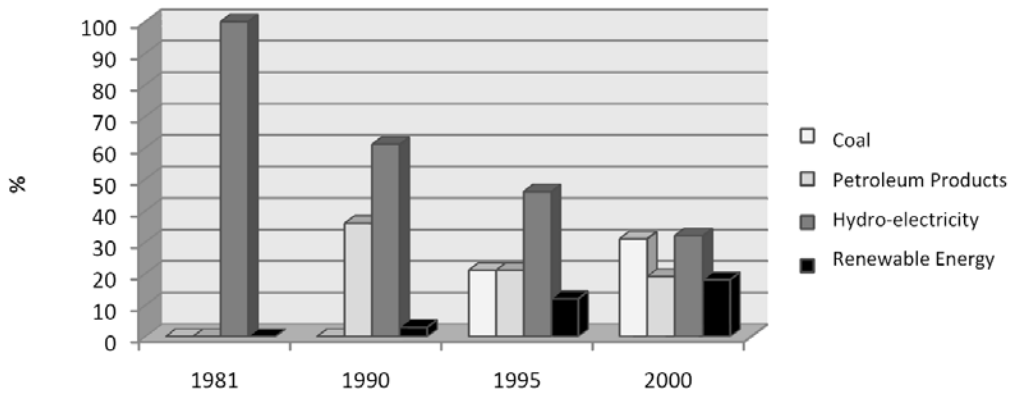

Figure 1. Evolution of the repartition of energy production in Reunion.

The building remains at the present time the most consuming sector in electricity. Under our latitudes, one of the most important demands for electricity relates to the air-conditioning of the buildings during the summer (period active of November 1 to April 30). Thus solar cooling system are particularly interesting as it is an application in which the demand for cooling energy closely matches the availability of solar energy, both in seasonal and the daily variations. One of the many categories of solar cooling systems is the solar absorption cooling. As no CFCs are used, absorption systems are friendlier to the environment. The possibility of cooling system using solar energy was initiated by the technological developments in the solar field, [1]. Absorption air-conditioning systems are similar to vapor compression air-conditioning systems, but differ in the pressurization stages. In general an absorbent in the low pressure side absorbs an evaporating refrigerant (H_2O). The most usual combinations of chemical fluids used include lithium bromide–water ($LiBr–H_2O$), where water vapor is the refrigerant, and ammonia–water ($NH_3–H_2O$) system where ammonia is the refrigerant, [2]. The electric quantity of power consumed by the pump is almost negligible. One needs nevertheless a contribution of heat, cf. Figure 2.

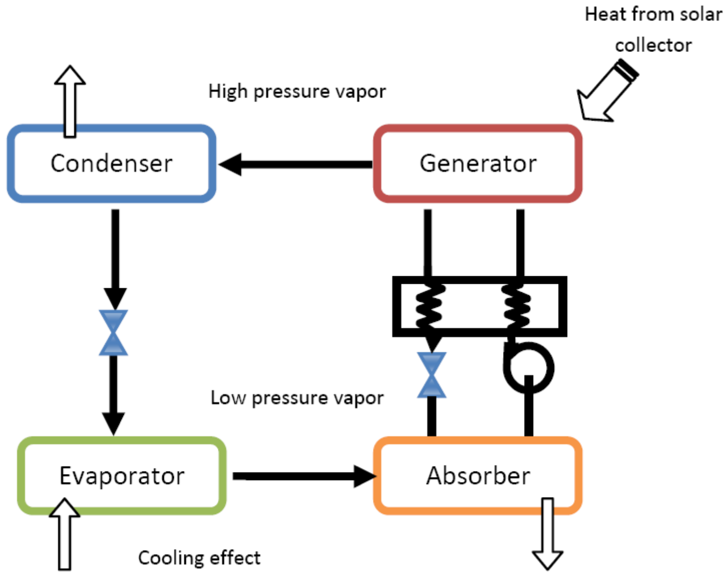

Figure 2. The basic principle of the absorption cooling system.

The single effect absorption chillers require for their operation a hot water temperature on the level of the generator of 80°C - 150 °C. Moreover, the temperature of cooling water must lie between 7°C and 43°C, [2]. The higher limit is founded in order to limit the differences in pressure between the generator and the absorber and the condenser and the evaporator. The lower limit makes it possible to avoid the crystallization of lithium bromide which is carried out at low temperature.

An European research program, IEA Task 25, was set up in 1998, in order to study these installations. Two approaches are classically used within the framework of this working group. The first consists of the establishment of real pilots, one counts at the present time an about sixty systems installed,[3]. The second consists to simulate and optimize existing or future systems via various codes. It is within the framework of second axis that this article is registered. The objective of this present work is to model the behaviour of the future installation at the Civil Engineering Department. Solar collectors represent the heart of the performances and the investments (~ 57%) of the installation. Thus, a good prediction of the performances of the solar loop is particularly judicious. The first part of this study was first interested in the dynamic modeling of the solar collectors. Then a coupling between the various components under TRNSYS has been investigate.

METHODS

There are three types of solar collectors which can be used within the framework of solar cooling: flat-plate, parabolic and vacuum collectors. Necessary heat for absorption chiller will be produced by evacuated tube collector. The literature contain numerous works on the modeling of solar collectors. These models developed have different levels of complexity. Usually, solar collectors are described by stationary models, considering the collector working under steady-state conditions. These approach are generally based on the work of Klein, [4].

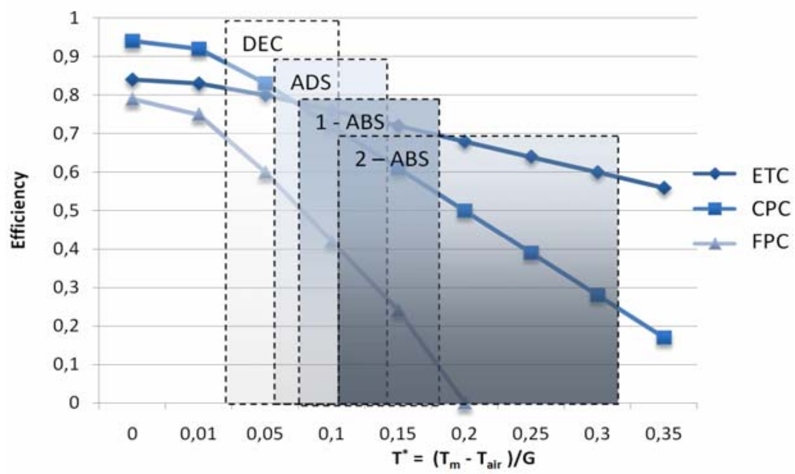

Figure 3. Comparison of Evacuated tube / compound parabolic / flat-plate collector for Desiccant / Adsorption / Absorption cooling systems.

A dynamic approach is more interesting in several cases: control strategies, dynamic testing procedures, coupling with others elements, particularly, in predicting the behaviour of collectors for short time step. The model developed corresponds to direct flow collector. The starting point of the model is a mathematical description proposed by Kamminga, [5]. The model consists of three nodes corresponding to the fluid, the absorber plate and the transparent glass cover. It is considered that the temperature of the fluid is a function of x. The fluid is moving in a single channel with the velocity u, along x-axis, see Figure 4.

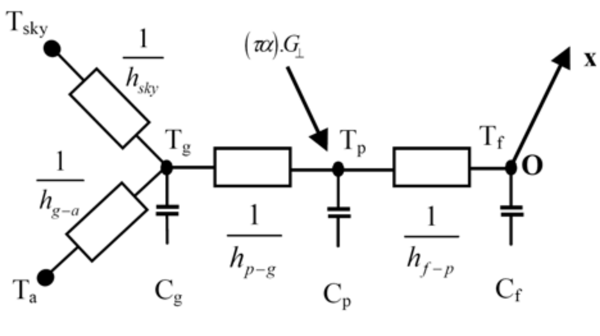

Figure 4. Thermal networks of the ETC model

The details of the model developed and elements of validation associated have been previously described by Praëne, [6]. A comparison between model forecast and measurements is presented in Figure 5. The simulation is carried out at the minute time step. A new type has been created under TRNSYS, in order to coupling with the rest of the solar cooling system.

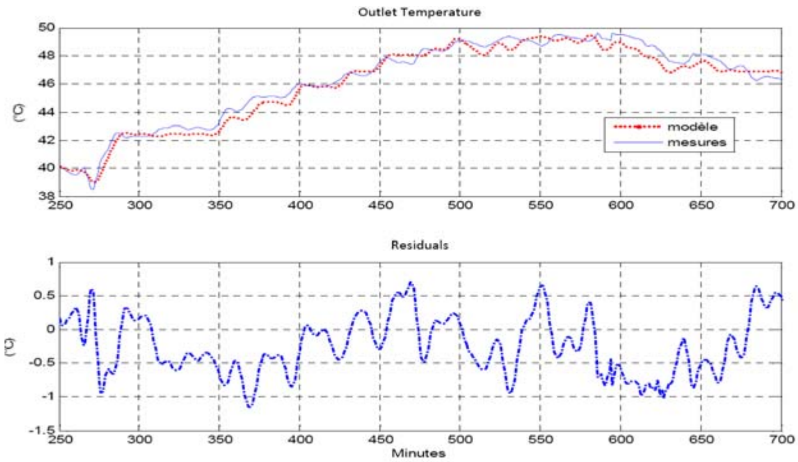

Figure 5. Simulation of the outlet temperature of the solar collector model.

The thermal behavior of the building was initially simulate over a whole year in order to observe cooling period. We used for that CODYRUN, [7], a thermal building code translated under TRNSYS to replace the TYPE56, this code has good accuracy for short time step. We evaluated over one year the level of comfort inside the classrooms and the building load to calibrate the absorption chiller refrigerating power.
We first simulate the evolution the inside classroom air temperature under natural ventilation during one year. The first condition of comfort is fixed for a temperature lower than 25°C. The graphic at Figure 6 shows that period spreading out May to October offers conditions of comfort. This period approximately corresponds to the southern winter.

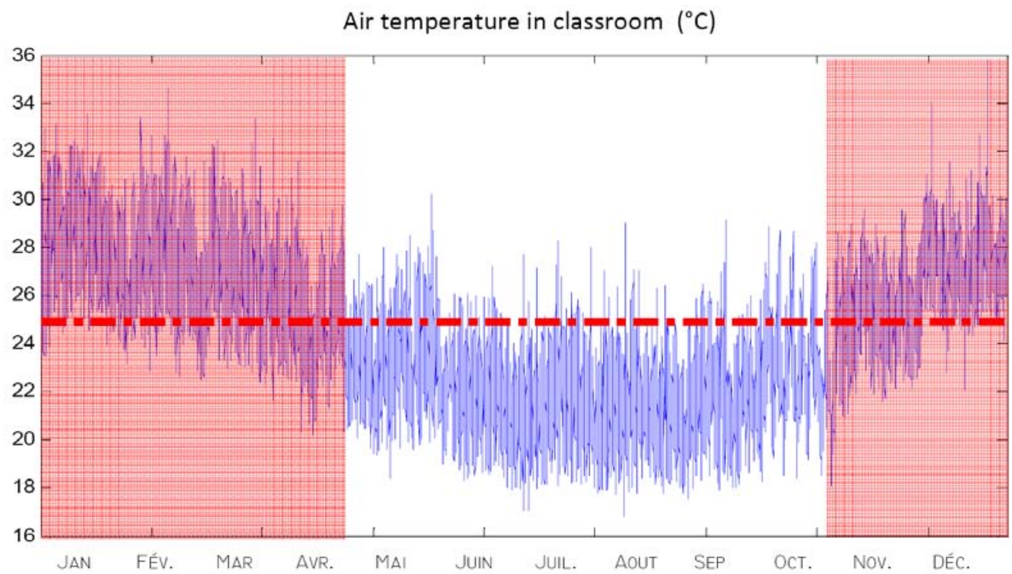

Figure 6. Yearly evolution of air temperature in classroom.

Many researches were carried out by the researchers in order to create simplified tools of indication of comfort, [8], [9]. We were thus based on the computation results of these indices of comfort within the framework of our simulations over the past year, in order to determine the building loads in relation to the indices of comfort. The starting point for the definition of the levels of comfort is based on the value recommended of PMV* (Predicted Mean Vote). That involves values of $-0.5 < PMV^* < +0.5$. In what concerns us, one is interested only in the positive part of this equation, which accounts for the requirements in air-conditioning. The evolution of the PMV*, according to Figure 7, comes well to confirm the zone of natural comfort which one has on the level of the building. This indices is particularly interesting because it considered the influence of air temperature and relative humidity.

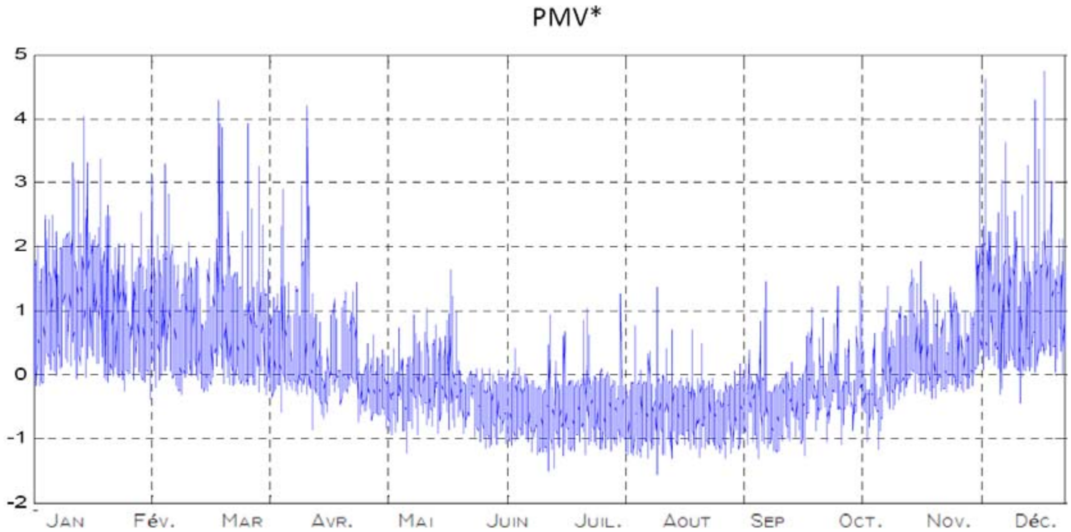

Figure 7. Yearly evolution of PMV* inside the classroom in natural ventilation condition.

The period from November to April corresponds to the period with maximum needs of solar cooling system. In order to evaluate the building, a sequence of January has been used. An air temperature of 25°C and humidity of 55% are fixed as comfort criteria to dimensioning the air-conditioning system, cf. Figure 8.

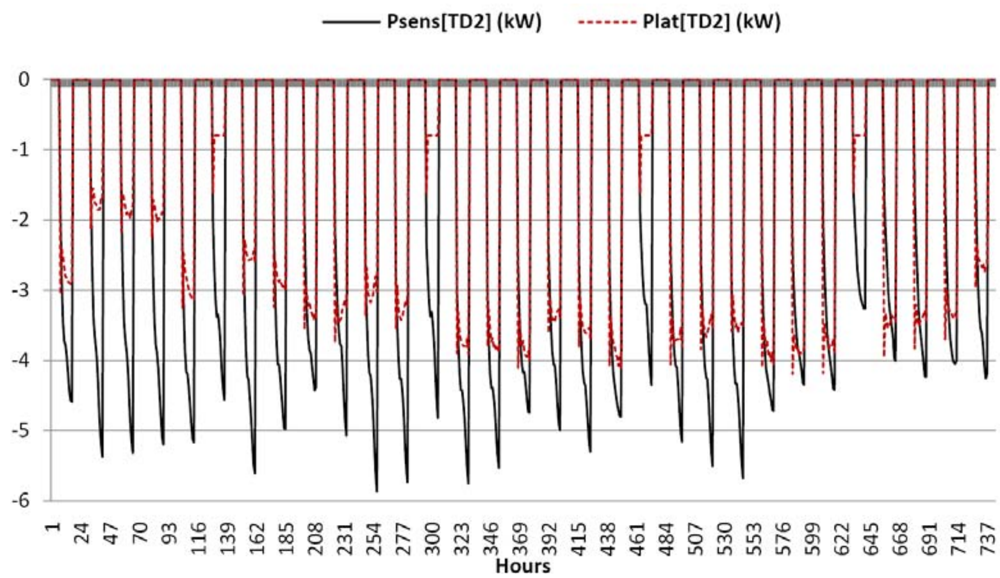

Figure 8. Sensible and latent power called by the classroom TD2 during January.

The maximum cold power called y the building is 9.5 kWf. This peak occurs after midday that is due to the accumulation of the walls inertia of the building and consequently restitution of this heat. Thus, for the four classrooms of the Civil Engineering Department, an absorption chiller of 35 kWf is necessary.

RESULTS AND DISCUSSION

This section presents the principal results obtain under TRNSYS16 for simulation of the global solar absorption cooling system. This program consists of the use of several “subroutines” which represents the components of the system described by ordinary or algebraic equations. Two types were added to the models existing under TRNSYS. It is about the model of simulation of the building and the model of vacuum collector. The useful surface area of collector used during simulation is 60 m ². The storage of hot water uses Type 38. That corresponds to a vertical roll of 800 L made up of copper insulated thermically with polyurethane. We consider a use of the machine with absorption without additional contribution of a contribution of auxiliary heat. We chose a sequence of January, to carry out our simulation, see Figure 9.

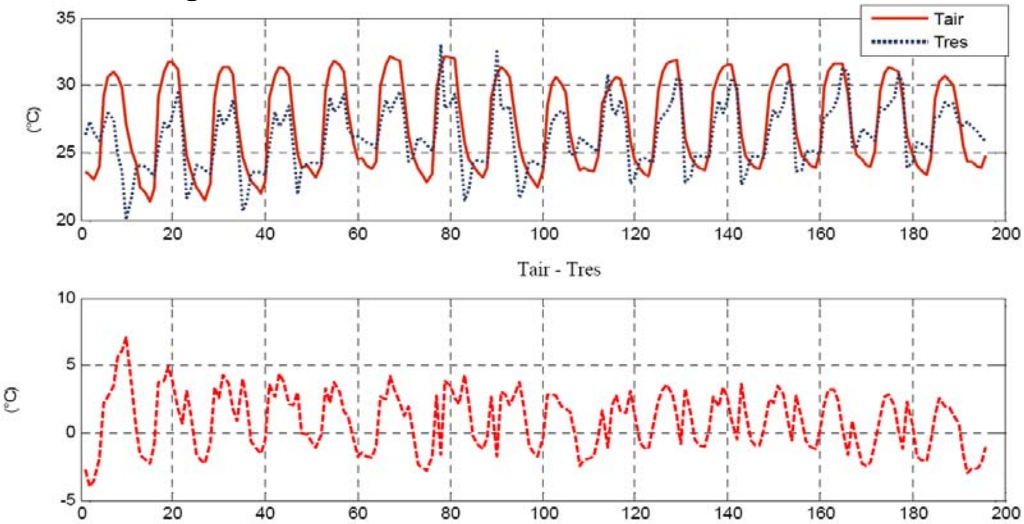

Figure 9. Comparison between resultant temperature (Tres) in classroom and outside temperature (Tair).

The average temperature in classroom is 27°C during the day. There is difference about 4°C between inside and outside air temperature.

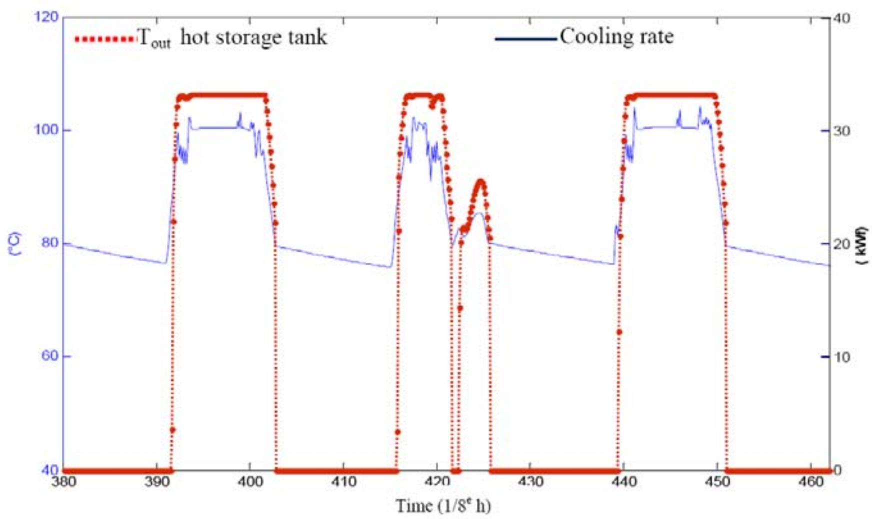

Figure 10. Evolution of cooling rate of the absorption chiller and outlet temperature of hot water storage tank.

The absorption chiller works without additional contribution of a contribution of auxiliary heat. As we can see on Figure 10, the 60 m² of ETC is enough to meet the minimum temperature of 80°C for the generator.
One of the most important points from an economic point of view of a solar cooling plant is the solar loop. The field of solar collectors accounts for approximately 60% of the total investment (in particular if it is vacuum collector). So it is important to dimension in a first place the needs for the building then the total surface of the field of solar collectors. Three points go in general to the decision of the field of solar collectors:
Ec onomic constraint: Budget dedicated to the project
Spa ce constraint: surface available for the solar field
Weather constraint: averag e numbers of good days during the hot period.
Also, it is important to quantify the influence of the elements of the solar loop, of as much we are in the case of an operation of solar cooling, without auxiliary contribution.

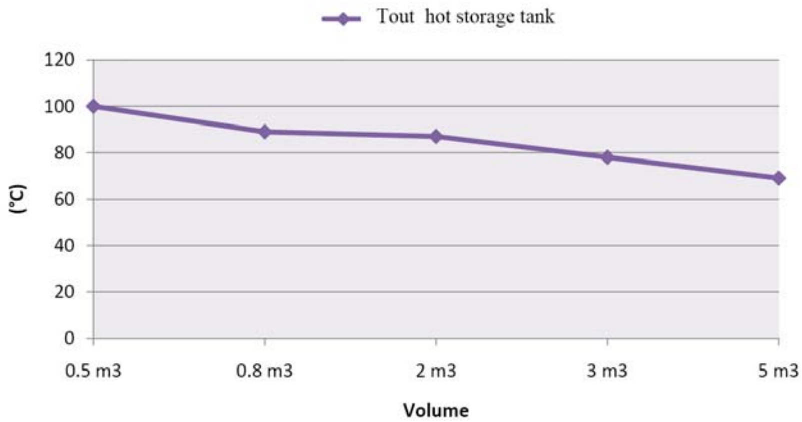

Figure 11. Effect of volume tank on the outlet of hot water temperature.

Many tests have been investigated to evaluate the sensitivity of the machine performance for different volume of storage tank, see Figure 11. For a volume superior than 2.5 m^3, the outlet temperature is lower than 80°C, thus the cold production will stop. Storage volume plays a dominating part because it has a buffering effect to the abrupt weather variations and makes possible to continue the hot water supply of absorption chiller The total solar collector area is the most important point (performance and economy). Several area of solar collectors have been tested (Figure 12.)

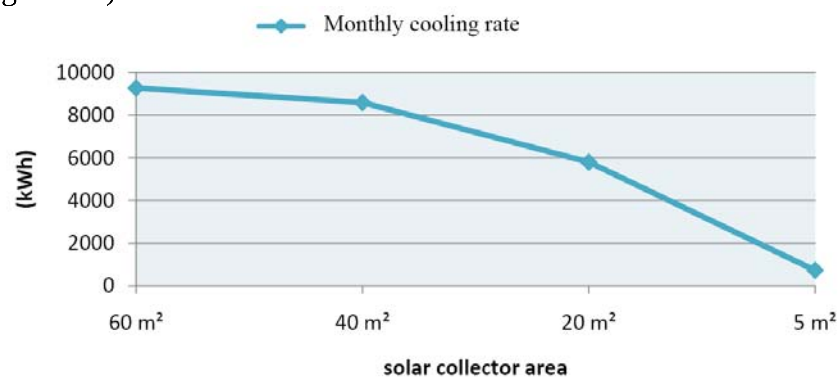

Figure 12. Energy production for different solar collector areas.

The effect of solar collector is evaluated against the energy from absorption chiller. The cooling rate from 60 m² to 40 m² is near. This production reaches to low value for a solar area less than 20 m². Thus, to have continuous condition for cold production a collector area of 60 m² is required.

CONCLUSION

The aim of the current work was to present a method of using solar energy for the air-conditioning. The system is modeled with the TRNSYS program. For the requirements in cooling for our classrooms, an optimum of the components consists of the use of 60m ² of vacuum solar collectors associated a storage tank of 0.8 m^3. We also fixed the nominal capacity of the absorption chiller with 33 kWf. The final objective of this work was to set up a simulation tool representing a solar cooling plant. This environment will be used as basic support with the simulation of various configurations. Theses simulations have been used to dimensioning an installation in our university. The cooling plant will be setup on may June 2007, in order to be in function at the beginning of summer in November 2007.

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