Modeling of a solar absoprtion cooling system for Guayaquil, Ecuador

C. Naranjo-Mendoza, D. R. Rousse, G. Quesada
t3e, Industrial Research Chair, Department of Mechanical Engineering
École de Technologie Supérieure, ETS
Montreal, Canada

Abstract—**This paper shows the results of the TRNSYS modeling and simulation of a solar absorption cooling system under the weather conditions of Guayaquil, Ecuador in order to partially satisfy the thermal demand of an office building. The maximum hourly thermal load reaches 153 kW. The proposed model utilizes evacuated tube collectors, a LiBr-H_2O single effect absorption chiller, hot water storage and an auxiliary external boiler. As part of this study, the results of the system optimization by varying the dimensions of their main components are indicated. These results show that the optimal system could achieve a yearly solar fraction of 0.6.**

***Keywords-** Solar absorption cooling, TRNSYS, evacuated-tube collectors, building air-conditioning, LiBr-H_2O*

I. INTRODUCTION

Guayaquil is a city near the Pacific coast in the southwest of Ecuador, South America. This city is known for being warm all year round where the temperature oscillates around 27 °C (Fig.1). It also has a strong solar irradiation for which the average insolation is 4574 Wh/m^2-day (1856 kWh/m^2-year) [1]. These factors create the need for air conditioning during all year, primarily in commercial and office buildings. However, the vast majority of air conditioning systems employs vapor compression equipments generating significant economic losses for the Government considering that electricity is subsidized. For this reason, different alternatives to reduce consumption of electricity should be analyzed and with this respect solar absorption cooling becomes an interesting alternative to be studied due to the tremendous solar potential in Guayaquil city and the fact that the thermal cooling load increases when the solar radiation is maximum.

Several simulation models and experimental installations have been studied over the past 10 years showing the systems performances at many different locations around the world. These studies have demonstrated that the most efficient (cost and performance) collector type in solar cooling systems is the evacuated tube collector which allows reducing in 50 % the collector surface compared to the use of flat plate collectors [2]. Moreover, the utilization of hot water storage is recommended as well as the use of an auxiliary heater [3].

The purpose of this study is to develop a TRNSYS model of a solar absorption cooling system for a real building located in Guayaquil. The system, based on the most performing systems available in the literature [4,5,6], consists in a single effect absorption LiBr-H_2O machine; evacuated tubes solar collectors, a hot water storage tank and an external auxiliary boiler.

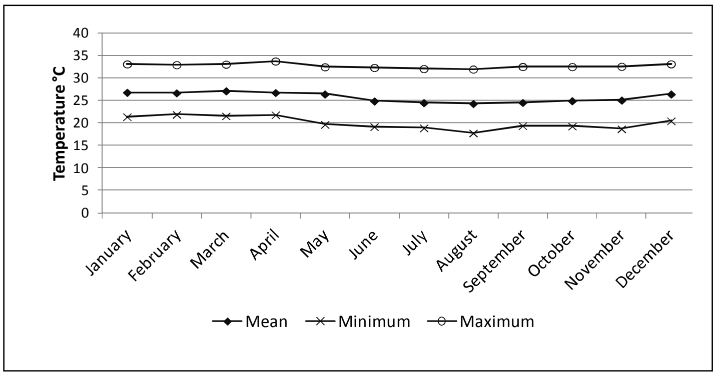

Figure 1. Monthly temperature in Guayaquil

An optimization of the main components is carried out in order to determine the optimum model without oversizing the whole system.

II. BRIEF SYSTEM DESCRIPTION

The system modeled in this study consists of two subsystems: the solar heating subsystem and the absorption cooling subsystem. These are interconnected through a hot water storage tank as shown in Fig. 2. The system has a controller which activates the solar field pump when the outer collector temperature is higher than the bottom storage tank temperature in more than 5 °C and deactivates when that temperature difference is less than 2 °C. The hot water flows into the auxiliary system that is activated when the temperature is less than 85 °C and heated up to 88 °C. Then, the hot water flows to the absorption machine generator to perform the cooling process. Cold water from a cooling tower flows through the absorption machine to condenser the refrigerant. Then, the refrigerant flows, through an expansion valve, into the evaporator producing the cooling effect. Finally, the hot water goes back to the bottom of the tank to restart the process.

A. Thermal loads calculation

The thermal load calculation was done considering a detailed thermal zoning using the software SIMEB (building energy simulation) [7] developed by Hydro-Québec. SIMEB uses the calculation engine DOE-2.2 of the Department of

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Energy. The surface to be conditioned in this study is 1296 m^2 and corresponds to the top floor of a 15-story building. This floor is the most critical mainly for the heat gains by radiation through the roof of the building. The cooling loads were calculated for one year round with one hour steps considering the weather variation provided by the software Meteonorm [8].

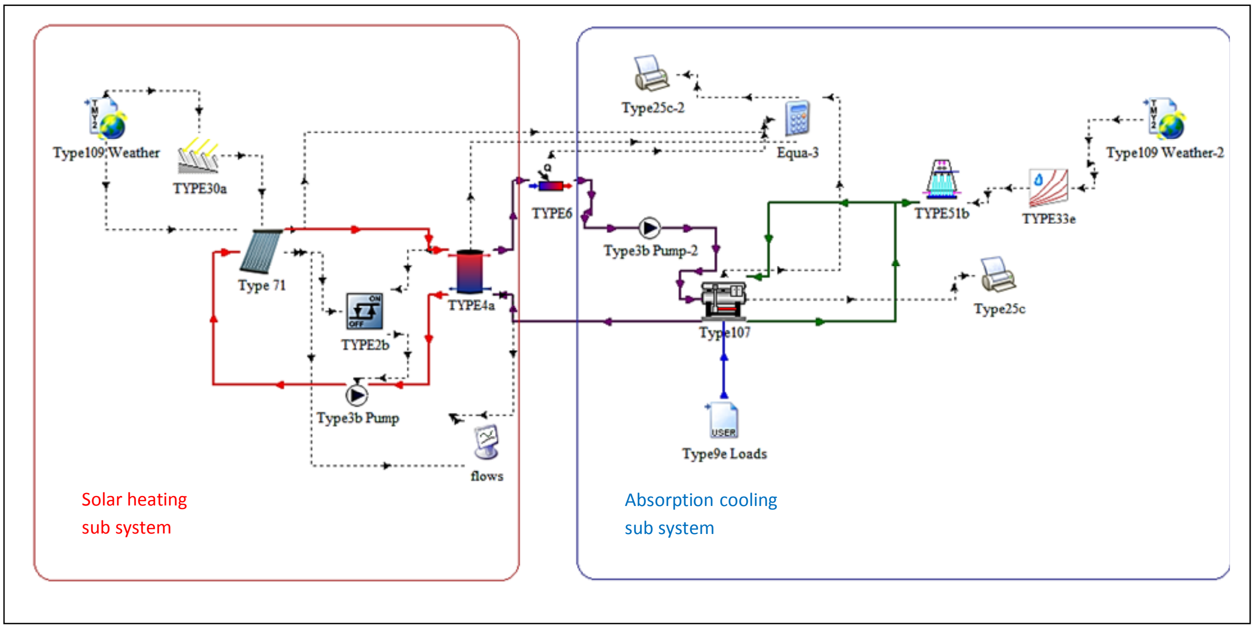

Figure 2. Trnsys model of the solar absorption cooling system

B. *System modeling*

For the system modeling and simulation the software TRNSYS (Transient Systems Simulation Program) [9] was used. TRNSYS is the most used software by researchers to develop models of solar absorption cooling systems. The TRNSYS component "Type 9" (Fig.2) was used in order to read an external file with the hourly thermal loads previously calculated on SIMEB.

The evacuated-tubes solar collectors used were the Sunstar Olymp HP 65/20 [10] represented by the "Type 71" in TRNSYS. The absorption machine was a Yazaki WFC SC 50 with 175 kW of nominal power represented by the "Type 107". Finally, the meteorological data used was in the TMY2 format (Typical Meteorological Year) for Guayaquil city and this data are read by the "Type 109".

III. RESULTS AND DISCUSIONS

Through SIMEB it was determined that the maximum load is 153 kW and it occurs in March. In addition, it was determined that the monthly variation of the cooling energy demand is not very strong as seen in Fig. 3. This monthly energy oscillates around 25 and 32 MWh. For the loads calculation, the occupancy schedule of an office building from 7am to 7 pm only in working days was considered.

A. *System Optimization*

The optimization was performed in order to determine the collector's surface, the storage tank volume and the collector mass flow rate at which the system achieves the highest yearly solar fraction without oversizing.

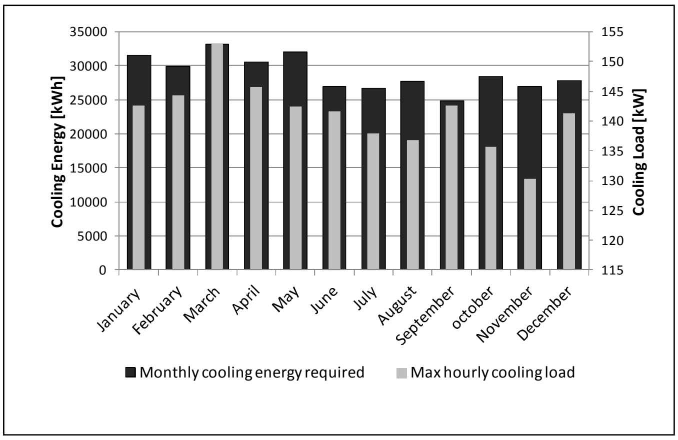

Figure 3. Monthly cooling energy demand and maximal hourly cooling load

The results of the optimization indicate that increasing solar collector area above 600 m^2 does not significantly increases the solar fraction (Fig. 4); consequently this value is regarded as optimum for the this building. With this surface value, a yearly solar fraction of 0.6 could be achieved.

Similarly, the change in the storage tank volume does not cause a severe increase in solar fraction as we can see in Fig. 5; however through the TRNSYS simulation, it was determined that the minimum required volume is 16 m^3 to supply the adequate water volume to the absorption machine so, that value is used as the optimum.

Finally, it can be observed in Fig. 6 that a water flow in the collectors of 15000 kg/h maximizes the solar fraction up to 0.62; therefore it is regarded as the optimum value, however, it is important to mention that a variation in the water flow rate from 5000 to 30000 kg/h doesn't represent a big variation on the yearly solar fraction which has a variation between 0.59 to 0.62.

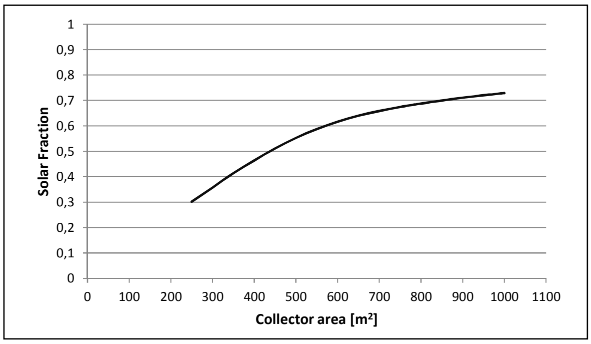

Figure 4. Solar fraction at different collector's surfaces

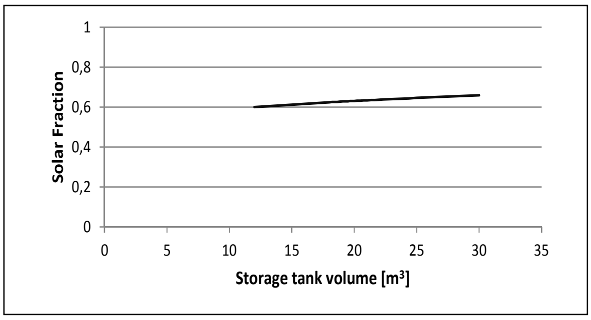

Figure 5. Solar fraction at different storage tank volume

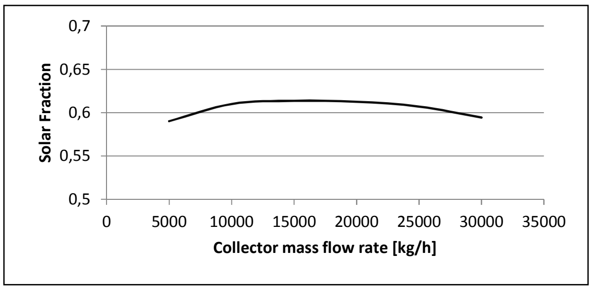

Figure 6. Solar fraction at different collector mass flow rate

B. System performance

With the optimum values previously established, a monthly analysis of the system performance was done in order to determine the months where the solar fraction is maximized and minimized. These results indicate that the system could achieve the highest monthly solar fraction of 0.73 in August and September. In contrast, in December and January, the solar fraction is less than 0.5 as shown in Fig.7. This behaviour is related to the relatively low irradiation in these months that are characterized by their cloudiness, so the system is less efficient and would rely on the auxiliary system 50% of the time.

In order to analyse the hourly performance of the system, the results of the peak week where the cooling loads are maximum where studied. This analysis consists in a comparison between the heat supplied to the generator from the tank (solar heat) and that from the auxiliary heater. It can be distinguished that the supply of heat from the tank is proportional to the incident solar radiation. In the same way, it can be noted that the heat contribution by the auxiliary system is maximized in times of low solar radiation (Fig. 8). Also, it is noted that in the first hour of the first working day, even if the solar radiation is zero the auxiliary system does not supply energy, this is because the system stores hot water during the weekend when the cooling system is no operating.

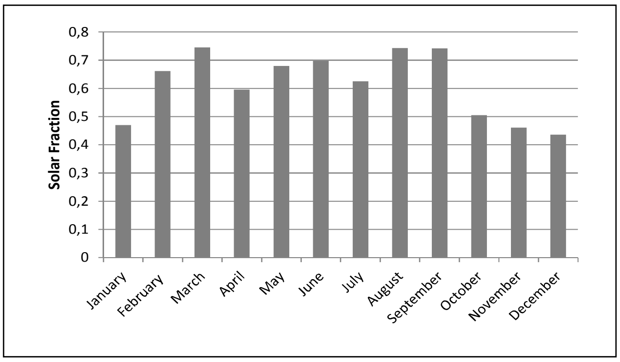

Figure 7. Monthly variation of the system solar fraction

In addition, the optimum slope for the solar collectors in Guayaquil was determined. To this end, the yearly energy captured by a single collector Sunstar Olymp HP 65/20 of 2.92 m^2 successively inclined at different slopes was calculated and results are reported in Fig. 9. It is observed that the most favorable slope angles are 0° and 10° facing north. The reason for having a slope so low is because of the proximity of Guayaquil to the equator line. For this study, it was considered an optimum angle of 10° because having an inclination in the collectors is favorable for self-cleaning.

IV. CONCLUSIONS

The application of solar absorption cooling in Guayaquil, Ecuador has been shown to be quite promising due to its high solar potential and the fact that the system works all year round. This later fact is very important when it comes to reduce the payback period of a project of this type.

The model proposed in this study works correctly and shows that an yearly solar fraction of up to 60 % could be reached considering the optimal collector slope and surface, hot water storage tank and collector mass flow rate. Also, through the optimization of the system, it could be determined that the hot water tank volume does not strongly affect the solar fraction of the system, however, it is necessary to maintain the minimum volume for supply the water required in the absorption chiller during its operation.

Similarly, the optimization is very important to determine the best operating conditions of the system and avoid oversizing. It is also important to analyse the hourly performance of the system during the peak week to make sure that the system will work properly during the whole year.

For the system proposed in this work, due to the high cooling load imposed by the building, it is indispensable to use an auxiliary system which allows to supply the cooling energy during the time of low radiation. For smaller systems, the auxiliary heater could be avoided provided that the designer increases the size of the storage tank, collector's surface or even using a second storage tank for the chilled water.

As a future work, a validation of this model comparing its performance with a real system should be a great contribution. By this way, the model can be adjusted and improved to save time in the study of other projects of this type in Guayaquil.

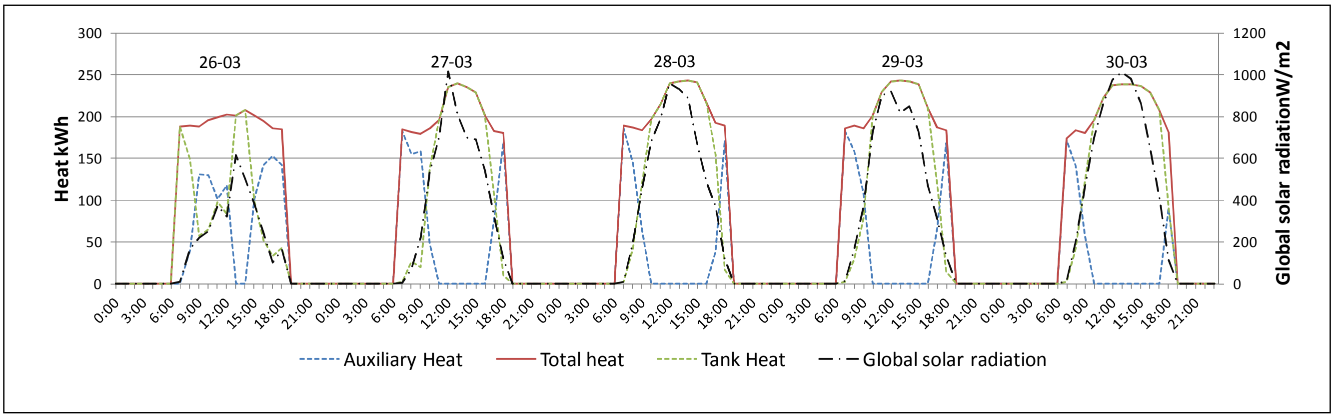

Figure 8. System performance in the peak week

Figure 9. Heat collected at different collector slope

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