SIMULATION AND OPTIMIZATION OF A SOLAR DRIVEN AIR CONDITIONING SYSTEM FOR A HOUSE IN SOUTH ALGERIA (BECHAR)

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Abstract – *The main objective of this work is to develop a computational model that allows the simulation of an hourly basis for an absorption refrigeration system assisted by solar energy and natural gas as auxiliary fuel. This model was developed using the dynamic simulation program TRNSYS. The results of the optimization process of the absorption refrigeration system assisted by solar energy, indicate that an area of 12 m^2 of flat plate collectors with an inclination of 23° and 0.5 m^3 storage tank were enough to cover the demand of air conditioning in a house of 20m^2 located in Bechar (South Algeria).*

Keywords *: Solar Energy, Building, Absorption System, Cooling, Trnsys.*

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INTRODUCTION

The energy demand for refrigeration and air-conditioning to control temperature and humidity has increased continuously during the last few decades. This increase is caused amongst other reasons by increased thermal loads, occupant comfort demands, and architectural trends. This has been responsible for the escalation of electricity demand.
Absorption refrigeration technology has been used for cooling purposes for over 100 years. The increase of electricity cost and environmental problems has made this heat-operated cycle more attractive for both residential and industrial applications. In this case, renewable energy sources will become important.
Ghaddar et al. (1997) presented modeling and simulation of a solar absorption cooling system for Beirut. The results showed that for each ton of refrigeration, it is required to have a minimum collector area of 23.3m^2 with an optimal water storage tank capacity ranging from 1000 to 1500 liters for a system to operate solely on solar energy for about seven hours a day [1].
Florides et al. (2002) used TRNSYS simulation program to model a complete system which comprised of a solar collector, a storage tank, an auxiliary boiler and a LiBr-water absorption system to provide load of a typical house for the whole year in Nicosia, Cyprus. Three types of compound parabolic, evacuated tube and flat plate collectors were used, the final optimum system consisted of 15m^2 compound parabolic collector tilted 30˚ and a 600 liters hot water storage tank when auxiliary boiler thermostat is set at 87˚C. The results indicated that solar absorption cooling system is not economical to provide any amount of cooling and heating load by heat collected from collector systems but recent increase in the fuel price will change this result [2].
Vidal et al. (2005) simulated and optimized a LiBr-water solar absorption refrigeration system considering as a study region the city of Santiago. It is a summer dwelling with a 149 m^2 area and consists of three bedrooms, two bathrooms, a living room, a dining

room and a hall, which contains a lounge area and an office. This model will be developed using the dynamic simulation program TRNSYS. The results of the optimization process of the absorption refrigeration system assisted by solar energy, indicate that an area of 110m^2 of flat plate collectors with an inclination of 33° and 7 m^3 storage tank provides an annual solar fraction of 70%, getting to cover the demand of air conditioning in a house of 149 m^2 located in Santiago, maximizing the gain of useful energy of the system and minimizing the consumption of auxiliary energy [3].

SYSTEM DESCRIPTION

A. Building description

For this research, a typical house area was about 20m^2 and the average height is about 3m with double walls with parping of 10cm and blade of air of 5cm.

B. Internal loads

The house is occupied by four (4) persons. Most of the occupant arrived between 12AM and 21PM and left the building between 08AM and 12AM. The total heat gain is 300W.

C. Model approach

The software program selected to model the house and its solar driven cooling system is TRNSYS (The transient systems simulation program). This software was developed by the Solar Energy Laboratory of the University of Wisconsin. It supports detailed simulations of multi zone buildings and their energy supply equipment [4]. Thus, a thermal balance on the site will determine the amount of energy that needs to be removed hourly in order to maintain the comfort conditions inside the building.

MODEL ASSUMPTIONS

A. Weather

Bechar is one of the sweltering cities with latitude of 31˚38' and longitude of 2°15'. Its climate can be classified like desert heat and dryness. To simulate the solar cooling system, an accurate climatic data base TMY2 file (TYPE 109) is used to get the solar radiation, the temperature and the relative humidity of the outside air in Bechar. The solar radiation on a horizontal surface is between 8.11kWh/day in July and about 5.516kWh/day in January. The maximum load of cooling is 3.8 kw in July.

A computer program is written to simulate and design a solar single effect lithium bromide-water cooling absorption system to supply demand of cooling for sunshine hours [5].

B. Solar collectors

There are many types of solar collectors, which are used in air-conditioning applications. These can be flat plate collectors, evacuated tube collectors or compound parabolic collectors. In our case, the solar collector used is the flat plate with parameters of the efficiency curve: F_R U_L= 3, 33 W/ m^{2}K, and FR ($\tau\alpha$)n = 0.72 and incidence angle modifier 0.2. The outputs are: the useful energy gain, the temperature of the fluid on the outlet side of sensor and the flow rate. Type 1b in TRNSYS 16 is designed to do this computation.

C. Absorption chiller

Among all kind of thermally driven chiller available on the market, most solar-powered absorption cooling projects to-date have utilized single-effect systems, with low-temperature solar collectors.

Comparaison of the performance of several multi-effect chillers, typical single, double- and triple-effect chillers with the same component size and under the same operating conditions show that the single-effect system gives best results in the temperature range 80–100°C; for a higher supply temperature, it is worth switching to a double effect system, up to about 160°C, and then to a triple-effect. Absorption chillers are available from various manufacturers, in large capacities up to several thousand kilowatts [6].

Wilbur and Mitchell compared the coefficient of performance (COP) of absorption systems with different working fluids. Of the various continuous solar air-conditioning systems, LiBr-H2O and H2O-NH3 are the major working pairs employed in these systems. It is reported that LiBr-H2O has a higher COP than for the other working fluids [7].

An absorption chiller, single effect, trademark YAZAKY, model WFC-SC10 employing LiBr-H2O solution as working fluid and it is energized by a flow of hot water between 75 and 105°C. It has a nominal capacity of 35 kW, and a nominal COP equal to 0.7, which is sufficient for the load requirements of the system. A typical water bromide absorption chiller was chosen. This type of machine is mostly used in existing offices solar air conditioning installations Absorption chiller behavior has been implemented in a TRNSYS by type 107 [8].

D. Thermal storage tank

The availability of solar energy doesn't often accord with the required energy of applications, so the thermal storage tank can coordinate them. It stocks solar energy when the recovered quantity is more than the condition for the application and it discharges when the recovered quantity is unsatisfactory; consequently, the solar system operates steadily. Thermal storage tank may operate with significant degree of thermal stratification, where liquid temperature increases from the bottom to the top of tank. This situation depends mainly on the volume of the tank, the size, the location and design of the inlets and outlets and flow rates of entering and leaving streams.

Type 4a is modeled from TRNSYS component library. [DUFFIE, 1980] has given the expression of the heat balance to node i [9]:

$$M_i C_p \frac{dT_i}{dt} = UA_i(T_a - T_i) + \alpha_i \dot{m}_h C_p (T_h - T_i) + \beta_i \dot{m}_L C_p (T_L - T_i)$$

$$+\begin{cases} |\gamma_i (T_{i-1} - T_i) C_p \text{.......................} si\gamma_i \rangle 0 \\ |\gamma_i (T_i - T_{i+1}) C_p \text{.......................} si\gamma_i \langle 0 \end{cases} \qquad (1)$$

with: $\gamma_i = \dot{m}_h \sum_{j=1}^{i-1} \alpha_i - \dot{m}_L \sum_{J=i+1}^{N} \beta_j$

The gas fired auxiliary heater is used to elevate or maintain the fluid medium temperature of an auxiliary heater with natural gas as fuel, which has a maximum capacity of 125 kW, with an average efficiency of 85% and a setting temperature of 80°C to supply the energy deficit. The auxiliary heater is modeled by type 6 of TRNSYS.

E. Solar Pump

The solar pump is used to circulate the fluid in the closed loop. Type 3, in the TRNSYS Component Libraries is modeled; with a maximum flow capacity having a value of 50 kg/hr m^2.

F. Controller ON-OFF

The controller of the circulating pump is modeled with type 2 of TRNSYS. It is acting on the pump to control the ON-OFF circuit. It has a high cutting temperature, which is activated if the inlet collector temperature is greater than 98°C. Values of 2°C and 0.15°C were considered for upper dead band and lower dead band, respectively.

SYSTEM SIMULATION

The final system is assembled by connecting all inputs and outputs to simulate the real solar absorption system. The resulting model with the main TRNSYS components and all the interconnections of the system are shown in Figure 1.

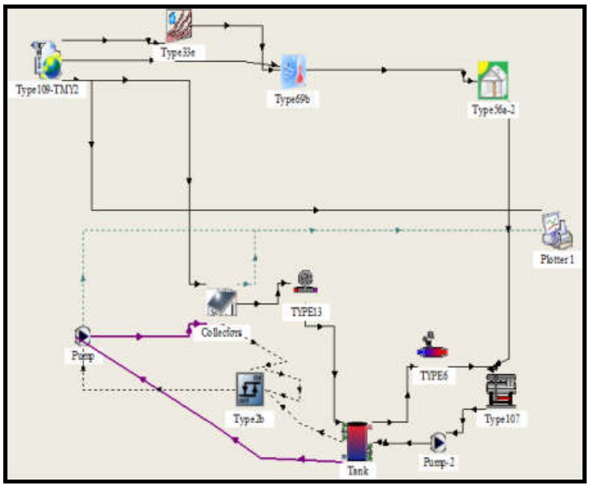

Fig. 1: TRNSYS Model of the Solar Absorption Refrigeration System

In Figure 2, it can be seen that an increase of ambient temperature results in the increase of collector fluid temperature. The temperature of fluid will increase to obtain the operating temperature of 98°C. When the temperature of collector decrease under 98°C, the pump stops and the collector does not provide more energy. Also it shows that a progressive increase in the area of the collector results in an increase in the gain of useful energy.

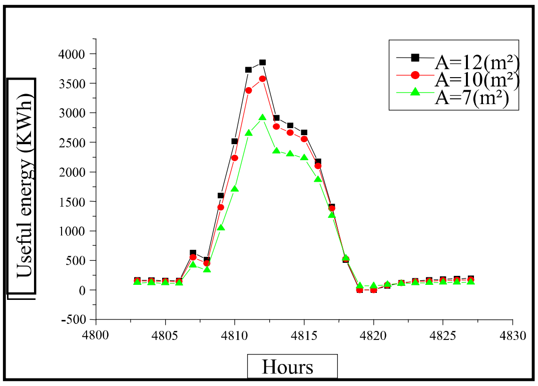

Fig. 2: Power Extracted from the Collector

Figure 3 shows the influence of the solar collection area on the auxiliary energy of the system. It is observed that an increase in the collection area leads to a decrease in the solar energy requirements on the auxiliary heater.

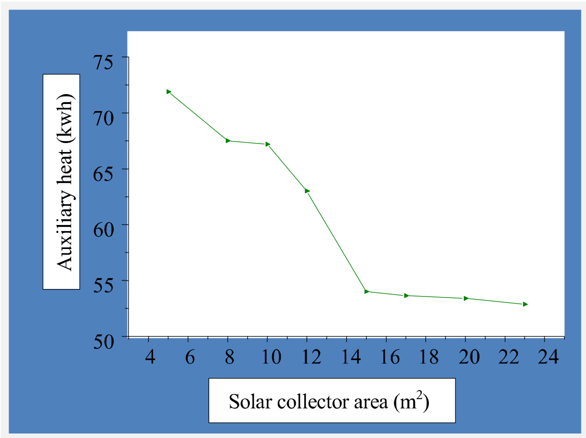

Fig. 3: Effect of the collector area on the auxiliary heat of the system

The gain of useful heat in the solar collector for different volumes of reservoir is shown in Figure 4. This shows that progressive increase in the size of the tank results in a slight increase in the gain of useful energy collector.

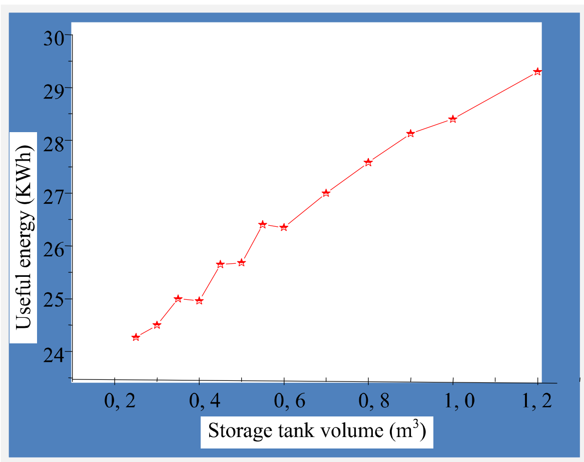

Fig. 4: Effect of the reservoir size on the useful heat of the collector

OPTIMISATION OF THE SYSTEM

A sensitivity analysis on design and operation parameters is performed to improve the base case. TRNSYS simulations were performed for three different operational configurations. Design parameters (collector area and storage tank volume) were varied to determine optimal settings for each operational configuration. Results were compared to define the optimum design and operation for the house.
To optimize this system, it is chosen to investigate the effect of the volume of the storage tank on the consumption of auxiliary energy. We can see that the auxiliary energy used reaches a minimum value for a reservoir volume of 0.5 m^3.

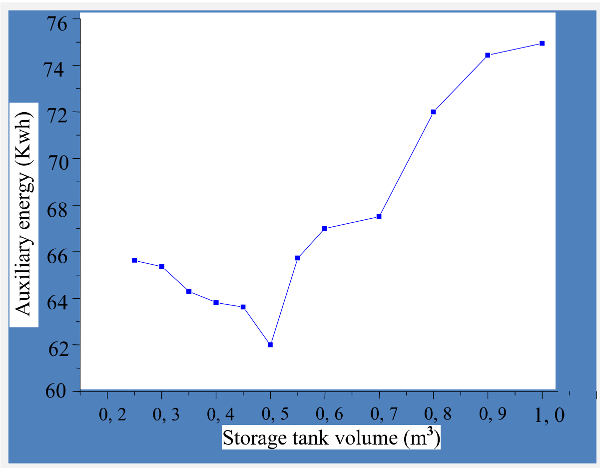

Fig. 5: Effect of tank volume on the consumption of auxiliary energy

Another parameter that affects the system performance is the angle of inclination of the collecting surface with respect to the horizontal. In figure 6, it is shown the influence of the inclination of the collector plate on the useful energy gain of the system, which is maximized for an angle of 23°.

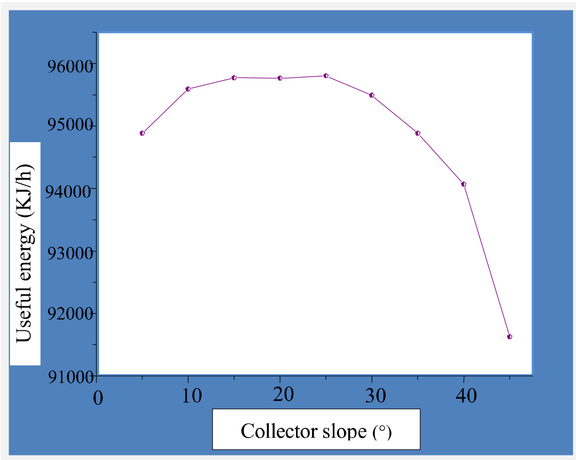

Fig. 6: Effect of the inclination angle of the collector on the useful energy

CONCLUSION

The results of the parametric optimization of an absorption refrigeration system assisted by solar energy indicate that with an area of 12 m^2 of plat collector area sloped at 23° and of 0.5m^3 hot water storage tank, is achieved to cover the demand of air conditioning of a dwelling of 20m^2 located in Bechar. Finally, the model developed can be used in future works to perform a thermo economic optimization of different systems (different sizes of absorption chiller, variable flow pumps, different climates), which will allow evaluating the performance and economic viability of the system on a long term.

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NOMENCLATURE

A_i [m²]	Surface area of the ith tank segment
C_p [j/Kg. K]	Specific heat of the tank fluid
M_i [g]	Mass of fluid in the ith section
m_h [Kg/h]	Fluid mass flow rate to tank from the heat source
m_l [Kg/h]	Fluid mass flow rate to the load and/or of the makeup fluid
T_a [°C]	Temperature of the environment surrounding the tank
T_k [°C]	Temperature of the fluid entering the storage tank from the heat source
T_l [°C]	Temperature of the fluid replacing that extracted to supply the load
U_l [-]	Loss coefficient between the tank and its environment
αi , βi [-]	Control functions