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Research Paper

Simulation of solar air conditioning systems in coastal zones of Mexico

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HIGHLIGHTS

- A parametric studio using TRNSYS of the solar absorption cooling system in coastal zones is presented.
- A technical-economic study of the solar cooling system is presented.
- Comfort conditions are obtained in 8 houses grouped in two duplex houses and connected to a single SACS.
- A COP solar combined value of 0.33 was obtained.

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ABSTRACT

The objective of the present study is to simulate and evaluate a H_2O-LiBr absorption cooling system driven with solar energy, and liquefied petroleum gas (LPG), to air condition low income houses in coastal areas of Mexico. To this end, an analysis of the behavior of the solar absorption cooling systems (*SACS*) was made using TRNSYS 17 with the purpose of obtaining an integrated system that meets the needs of air conditioning, with the smallest area of solar collection, and greater than 50% solar fraction. Two representative places of the predominant climates of the Mexican coast were selected for the study. These are the cities of Campeche and Acapulco. The results show that the *SACS* favors the air conditioning requirements of eight low-income households, generating favorable climate conditions between comfortable and slightly warm in extreme conditions, according to the standard norm ISO 7730 (2005). This is achieved through the use of a solar field of evacuated tube collectors with an area ranging from 207 to 220 m^2 according to the climatic region concerned (warm and dry vs. warm and humid climate), providing 60% of the power required by the system. This solar contribution was determined based on the results of the economic evaluation. Even though the area available on the roof of the houses allows a larger area of collection, the economic parameters as well as the return of investment period and the cost-benefit ratio, favored this proposal. Providing the houses with the service of hot water for sanitary use is also being considered, which makes the project more profitable.

1. Introduction

Mexico, due to its geographical location, has a great diversity of climates as well as an extensive coastal area dominated by warm-humid and warm-dry climate. Millions of people live in these areas and require air conditioning for the spaces they inhabit. The consumption of electrical energy for domestic use for air conditioning in a Mexican house in the North of the country and coastal areas corresponds to 44%.

Mechanical vapor compression air conditioning systems are the most frequently used due to their low initial cost compared to absorption or adsorption cooling technologies; however, operating costs for the compression systems, especially during the summer, are high. The average price for electric power in Mexico has registered annual increments of 3.7% during the period from 2003 to 2013 [1]. Furthermore, the emissions of pollutants discharged into the atmosphere from the electric power plants must also be considered. In 2013, the GHG Mexico program reported an average emission factor of the national electricity system of 0.50 tCO_2e/MWh [2].

Absorption cooling technology can be used in air conditioning and refrigeration for the residential sector; it is also a more environmentally-friendly option since the system uses thermal energy to produce cold which allows the use of solar thermal energy, waste heat and other sources of low enthalpy heat.

Absorption cooling is one of the first and oldest forms of cooling; however, it was scarcely researched since the non-renewable energy resources were abundant, cheap and the environmental impact of their use had not been considered. The 1960s witnessed a

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resurgence of absorption technology with application in air conditioning with the development of systems that used ammonia-water ($NH_3 – H_2O$) and water-lithium bromide (H_2O-LiBr) as working fluids. The vast majority of these units were designed to operate with direct heat and steam. These units had a coefficient of operation (COP) in cooling mode of about 0.5. Recently a new generation of advanced absorption cycles have been developed that are even available commercially in large capacities, including multiple-effect cycles (commercially even triple-effect). There are other advanced cycles that are based on the possibility of recovering internal heat during the basic absorption cycle, in a wide range of concentrations of absorbent solution, a principle developed by the German scientist Altenkich (1913). This research laid the foundation for the development of a new generation of advanced absorption cycles [3].

Currently, the majority of solar absorption cooling systems, SACS, commonly use LiBr-H_2O as working fluids. Research, involving simulation analysis and experimental research, has been reported [4–10] With regard to simulation analysis, the TRNSYS program has been generally used to analyze these SACS [11]. Florides et al. modeled a SACS for a typical house in Cyprus using the TRNSYS simulation program and the weather conditions in Nicosia, Cyprus. The optimum system consisted of 15 m^2 of parabolic collectors with an inclination of 30° on the horizontal, a 600 l hot water storage tank and a LiBr-H_2O absorption cooler which could cover the load of a typical house throughout the year [12]. Assilzadeh et al. conducted a simulation and optimization of a solar absorption cooling system with evacuated tubes which will be designed for Malaysia and other similar tropical regions by using the TRNSYS program. To operate the system continuously and to increase its profitability, the system required a storage tank of 0.8 m^3 and 35 m^2 of evacuated tube collectors with an inclination of 20° [4].

Luna presented the modeling and simulation of an integrated system that provides heating, cooling and hot water for domestic use from a system activated with a hybrid solar/natural gas power source and using a Yazaki 35 kW absorption cooler for a housing project located in Mexicali, BC, Mexico. The system was simulated in TRNSYS together with the values of a file of the typical meteorological year (TMY) for the city of Mexicali. With the optimization of the system came the determination of the area of 104 m^2 and the inclination angle of the collectors, the volume of 6 m^3 for the storage tank, and the optimal temperature set point ($Tsp = 75$ °C) of the auxiliary heater thermostat. The reduction of emissions to the atmosphere was estimated at 9 tCO_2 per year with respect to a vapor compression cooling system [13].

It has been proven that solar absorption cooling systems are technically feasible. This is a particularly attractive application of solar energy since the cooling demand peaks coincide with the availability of solar radiation.

The objective of this work is to propose a solar absorption cooling system that meets the requirements of air conditioning of low-income houses located on the coastal areas of Mexico so that the SACS is technically viable and economically profitable. Analysis and optimization of the components of the system are carried out with the TRNSYS program version 17 [14].

2. Description of the low-income houses

For this study, 8 duplex-type low-income houses located on the development Prado Norte and built by the construction company SADASI were selected. The graphical interface TRNBuil, provided by TRNSYS, was used to determine the thermal gains due to the house envelope, taking into account its thermal inertia. Time variations per week of the internal heat demands of the house are taken into account (number of occupants, hours of use of appliances, fixtures, and others). These data are needed to establish the internal heat gains by equipment and fixtures; some patterns of use and the number of occupants were allocated according to the study by GIZ "*Determination of Typology and Basic Information Survey-Housing Financed by INFONAVIT*" [15], such as:

Number of occupants per house: two adults and two infants
Metabolic rate (MET): 1
Summer clothing (CLO): 0.5
Internal lighting load (per house): 5 W/m^2
Internal equipment load: 20 W/m^2

These duplex houses have a construction area of almost 40 m^2 and consist of one bedroom, a bathroom, kitchen, living room and laundry room. This house shares the mezzanine made of reinforced concrete. The duplex house to simulate presents a West wall with no adjacent houses, and without solar protection, main facade towards the South, rear facade to the North and borders with the following module houses to the East. Fig. 1 shows the plans of a duplex house.

For the purposes of dynamic thermal simulation, two duplex type house modules with four houses each and all connected to one SACS was simulated. The houses of the ground and first floor are considered as independent thermal zones that share the wall of the laundry room with the following block of houses (ground and first floor) towards the East.

The thermal characteristics of the building materials of the houses were obtained from information provided by the construction company SADASI to GIZ in the "*Study of Optimization of Energy Efficiency in Low-Income Housing*" [15], and the calculation of the gain of the envelope for residential buildings was based on the standard norm NOM-020-ENER-2011 of energy efficiency in buildings [16].

Two coastal areas of Mexico were chosen for this study as the most representative of the coastal climate based on the guide "*Design of green areas in housing developments*" of Conafovi [17]. In this way, the city of Campeche was chosen as the entity representative of the warm-humid climate, and Acapulco as the representative of the warm-dry climate.

3. Description of the solar absorption cooling system (SACS)

The absorption cooling unit used for this study was a Yazaki 35.2 kW (126,720 kJ/h) simple effect model WFCSC10 that uses LiBr-H_2O solution as a working fluid [18].

The subsystems and circuits that make up the SACS shown in Fig. 2 are:

1) *Solar Collector and Hot Water Storage Subsystem* where using an RZ Solartecknick model DF-120-6 evacuated tube collector field, pressurized water (as temperatures in the collector field can reach more than 100 °C) is heated and stored in a horizontally stratified tank. The DF-120-6 evacuated solar collectors were selected and proved to be efficient and reached the required temperatures to drive the Yazaki cooling system [19].
2) *Auxiliary Subsystem* consisting of a gas heater (LPG), which operates when the hot water stored in the tank does not meet the temperature specifications (Tsp) between 75 °C and 95 °C required to drive the Yazaki chiller.
3) *Water Cooling Circuit.* Yazaki absorption machines must be connected to a circuit of cool water to dissipate the heat from the absorber and the condenser, being necessary to maintain the entering temperature to the Yazaki chiller at a value between 24 °C and 31 °C. A water-cooling tower was employed for this purpose.