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NUMERICAL SIMULATION AND EXPERIMENTAL VALIDATION OF A SOLAR COOLING SYSTEM IN MEXICO

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Abstract

In this work the numerical simulation and experimental validation of a solar air conditioning to condition a 124 m^2 offices located in Jiutepec, Morelos, Mexico is presented. The model was developed and reported in a previous work, in which, using the software TRNSYS, the system is modeled for the design and sizing in order to reach the demand for air conditioning in comfort conditions for these offices. The system consists in a 8 kW adsorption air conditioning system, a thermal storage tank of 2m^3 and an area of 55.8m^2 of flat solar collectors of high efficiency, which is estimated to reach a solar fraction around 80%. The purpose of a validated model is produce a numerical tool in order to find the best operating conditions of the system and allow the study to any location where the solar cooling system can be implemented.

Keywords: *Solar cooling, TRNSYS, experimental validation, experimental analysis.*

1. Introduction

Mexico is in a privileged position to have high levels of solar radiation throughout most of the year; however this causes high temperatures in several states of Mexico and it is necessary to use cooling systems and air conditioning to have comfortable conditions. Nowadays, there are devices that can generate cold using solar energy, this is very attractive in places where cooling is required due to high ambient temperatures together with high solar radiation.

The advantages of solar cooling systems over conventional systems are mainly in the low electrical power requirement thus contributing to environmental protection, savings in energy costs and can be more easily used in remote locations away from the mains. Within the solar cooling exist two types of applications: absorption and adsorption cooling. For small capacity (<20kW) commercial absorption equipment are the following trademark: AOSOL, Pink GmbH, Robur, Sonnenklima GmbH, EAW, Yazaki, Rotartica and Climatewell. While in adsorption are: SorTech AG, InvenSor GmbH and ECN (IEA SHC-Task 38, 2010).

Among the many technologies for heat with the solar radiation, flat plate solar collectors is an option, they can reached temperatures close to 80°C with good efficiency. This range of temperature and the energy produce can be used in refrigeration equipment operating between 55°C to 95°C, the percentage of energy provided by the solar systems can be calculated (solar fraction).

The simulation program TRNSYS offers the versatility of coupling different independent models to form a solar cooling system under study. It also allows evaluate the system proposed in order to design and dimension its different components (TRNSYS, 2005).

2. Methodology

Through the program TRNSYS, the thermal behavior of offices of 124 m^2 located in Jiutepec, Morelos, Mexico has been simulated in order to show the current comfort conditions and to calculate the capacity of the refrigeration equipment necessary to achieve comfortable conditions inside the offices throughout the year (Lugo et. al., 2014).

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According to the cooling capacity required by the building, it was determined that the most appropriate system was an adsorption system trademark SORTECH model ACS 08 which has a nominal cooling capacity of 8 kW operating under the following conditions: inlet hot water temperature and flow 72°C and 1.6m^3/h, cooling water temperature and flow of 18°C and 2.0m^3/h, and an electric power required of 7W.

With SORTECH operating characteristics curves, this equipment was simulated using the TRNSYS Type 107; in this way, the interaction of this model with other components of the solar cooling system at different operating conditions was modeled.

In a second stage, the solar system was sized to provide at least 80% of the thermal energy required by the adsorption solar cooling equipment. The number and arrangement of solar collectors, size of the thermal storage tank and operating characteristics using a parametric study was obtained.

Solar technology used was flat plate solar collectors manufactured in Mexico by Modulo Solar SA de C.V. The solar collector used for this analysis is the model MS2.5 that has the following characteristics: 2.326 m^2 aperture area, mass flow rate of 3 l/min and efficiency curve according to Ec. 1 (Módulo Solar, 2013).

$$\eta = 0.7535 - 2.9132\frac{(T_{in}-T_a)}{H} - 0.0099\frac{(T_{in}-T_a)^2}{H} \tag{1}$$

The model validation is performed by comparing the results obtained using the TRNSYS simulation and experimental data collected for several days. The comparative error is expressed by the percentage mean absolute error (see Ec. 2) between the simulated and experimental data in the following form (Ayompe et. al., 2011):

$$PMAE = \frac{100}{N}\sum_{i=1}^{N}\frac{|C_i-M_i|}{M_i} \tag{2}$$

Where: *C* is the result of the value in each interval of TRNSYS

M is the result of experimentally measurement values in each interval

N is the number of data points used

In order to determine the thermal comfort in the space under study, the thermal sensation scale established by Fanger was taking account; it is based on the PMV and PPD indices divided into the levels shown in Table 1 (Fanger, 1972).

Table 1. Thermal sensation scale proposed by Fanger (Fanger, 1972)

PMV	PPD	Sensation
+3	99%	Hot
+2	77%	Warm
+1	26%	Slightly warm
0	5%	Confort (neutral)
-1	26%	Slightly cool
-2	77%	Cool
-3	99%	Cold

3. Numerical and experimental results

Daily monthly average weather conditions (Table 2) were obtained from the database generated by the UNAM, it contains meteorological information for populations in Mexico of more than 10,000 inhabitants (UNAM, 2013). These data were introduced to METEONORM software to generate a TMY format file that allows read the data in TRNSYS for short time intervals, in this case each hour (METEONORM, 2009).

Table 2. Weather conditions to Jiutepec, Morelos

Month	H MJ/m^2 day	Ht (20°) MJ/m^2 day	Ta °C	Ta_min °C	Ta_max °C	RH %
Jan	16.5	20.2	20.2	11.9	28.6	52.9
Feb	19.3	22.2	21.5	13.0	30.1	48.4
Mar	22.1	23.7	23.6	14.9	32.4	44.2
Apr	22.8	22.5	25.2	16.8	33.6	46.2
May	19.5	18.2	25.6	17.9	33.4	56.6
Jun	19.2	17.4	24.1	17.7	30.5	71.8
Jul	22.2	20.2	22.8	16.5	29.2	68.9
Aug	20.0	19.2	22.8	16.5	29.1	68.6
Sep	15.3	15.5	22.3	16.4	28.2	73.6
Oct	18.7	20.9	21.9	15.1	28.6	67.8
Nov	17.1	20.4	21.1	13.5	28.8	61.0
Dec	15.1	18.8	20.2	12.3	28.2	56.3
Average	**19.0**	**19.9**	**22.6**	**15.2**	**30.1**	**59.7**

Parametric study of solar thermal energy system was performed to obtain the area of solar collectors, the operating angle and the size of the thermal storage tank more appropriate for this case. The following conditions were considered for TRNSYS simulation: set point temperature (Tset = 72°C), difference for starting hydraulic pump (ΔT_on = 8°C) and difference to stop hydraulic pump (ΔT_off = 4°C).

Figure 1 shows the behavior of the solar fraction is shown against the area of solar collectors, with this results an area of 55.8m^2 (24 collector in an array of 4 series and 6 parallel 4Sx6P) was found in order to reach a solar fraction of around 80%.

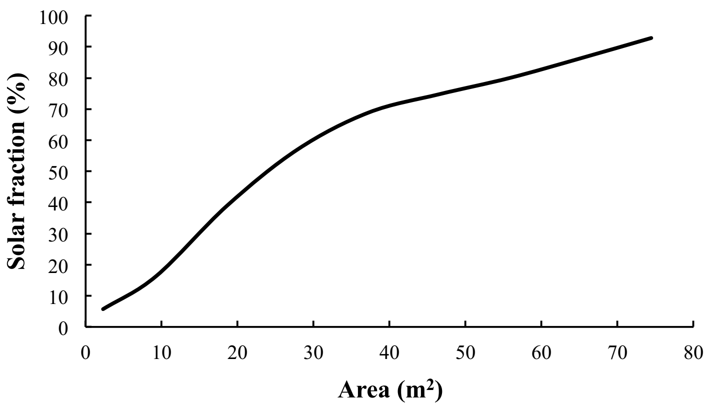

Figure 1. Sizing of flat plate solar collector arrangement

With the above arrangement (4SX6P), the solar fraction at different solar collector angles in order to find the optimum slope angle was simulated. It was obtained that 20° to the South was the best option (see Figure 2).

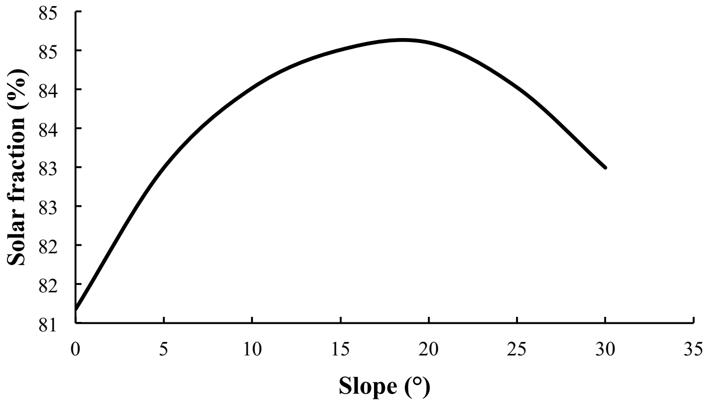

Figure 2. Slope of flat plate solar collectors

Taking into account the values found in the previous figures, the volume of the thermal storage tank was analyzed to find the better option (see Figure 3). The optimal volume of the tank found was 5 m^3, however considering the costs of it and that using a tank of 2 m^3 decreases only 1.8% the solar fraction, it was decided to use the latter one in the system installation.

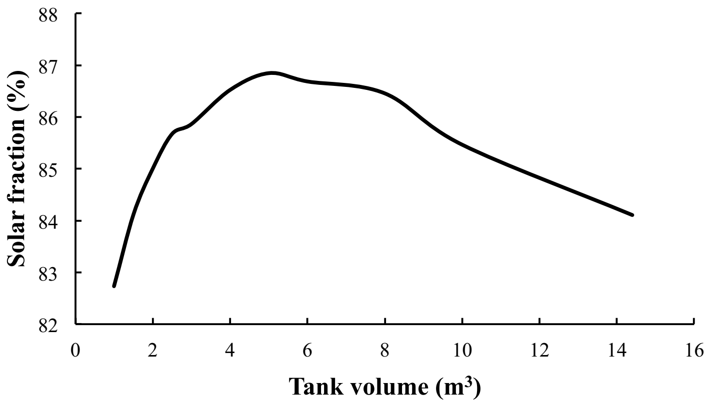

Figure 3. Volume of the thermal storage tank

According to the values obtained by the TRNSYS simulation, the final solar cooling system was designed and the selecting components are shown in Table 3 and Figure 4 shows the real components installed in the place of study in Jiutepec, Morelos.

Table 3. Components of solar cooling system

System	Trademark	Model	Quantity	Capacity
Solar cooling equipment	SORTECH	ACS08	1	8 kW
Solar collectors	Módulo Solar	MS2.5	24 (4Sx6P)	55.8 m^2
Thermal storage tank	MASS	THN-2	1	2 m^3

Figure 4. Installing components of solar cooling system

With the TRNSYS simulation of the solar cooling system, average monthly values of PMV and PPD were obtained throughout the typical year inside the offices, these range are from -0.6 to 0.07 and a maximum of 20%, respectively (see Figure 5). Therefore, according to the thermal sensation scale developed by Fanger (see Table 1), the offices under study will be in thermal comfort throughout the year.

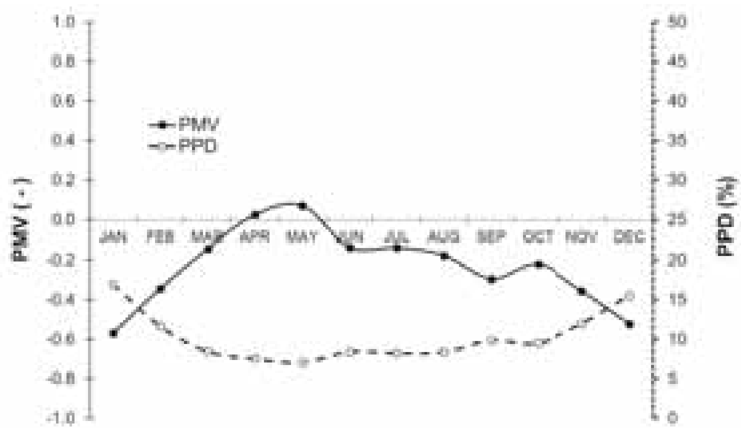

Figure 5. Comfort indices inside offices

Monthly theoretical results of this system (Figure 6) show that an annual average solar fraction of 85% is reached, surpassing the initial request. In addition, the proper functioning of equipment and comfort conditions in the offices are reached with this configuration according to the TRNSYS simulated data.

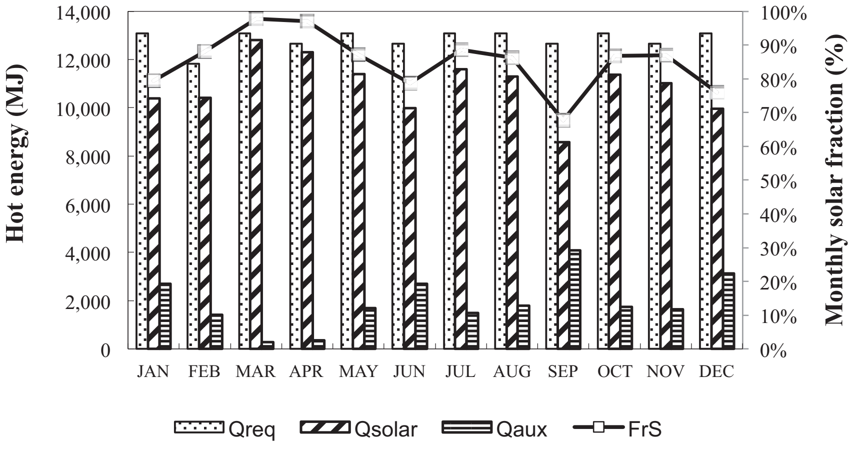

Figure 6. Thermal and energy monthly solar fraction in the solar heating system

The comparative results between the theoretical values obtained in TRNSYS and the experimental values for the outlet water temperature of the solar collector arrangement of 4Sx6P are shown in Figure 7 for a test of one day (May 25th, 2015).

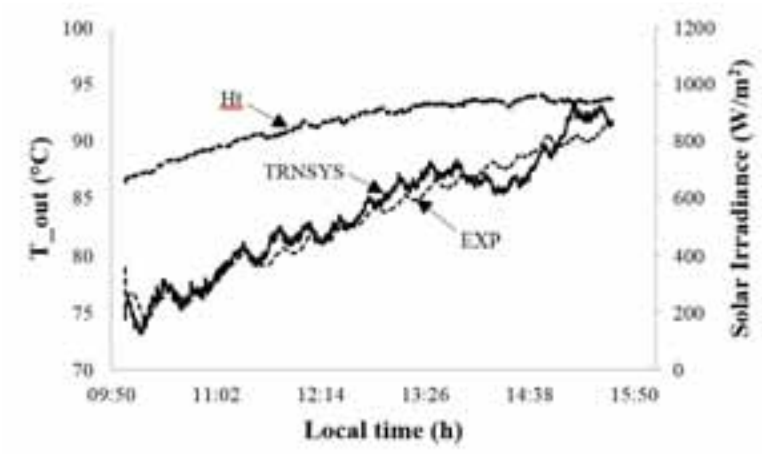

Figure 7. Comparison of outlet water temperature of the solar collector arrangement

The percentage mean absolute error (PMAE) in 10 days of testing performed for the outlet water temperature of the arrangement of flat plate solar collectors in °C is 2.75%, equivalent to ± 2.34°C. These values are within the range of uncertainty cited by Ayompe (Ayompe et. al., 2011). Due to this, the model can be considered in a good agreement with experimental data for the solar collector arrangement.

Validation of the whole solar adsorption cooling system model will be made in the near future when the coupling between the solar collector arrangement and the solar air conditioning system can be completed and experimental data can be obtained for different working conditions.

4. Conclusions

A designed solar cooling system is required to comfortably condition an office of 124 m^2 located in Jiutepec, Morelos, Mexico. The system consists in an 8 kW air conditioning system, 55.8 m^2 of flat plate solar collectors and 2 m^3 of a thermal storage tank. The annual solar fraction reached with this system is 85%, in addition the proper functioning of equipment and comfort conditions in the offices are reached with this configuration according to the TRNSYS simulated data.

This work was carried out modeling in TRNSYS a solar air conditioning system in Mexico. The solar collector arrangement (4Sx6P) has been validated with experimental data obtained for 10 days. The percentage mean absolute error of these days of testing performed for the outlet water temperature of the arrangement of flat plate solar collectors in °C is 2.75%, equivalent to ± 2.34°C. Due to this, the model can be considered in a good agreement with experimental data for the solar collector arrangement.

Validation of the whole solar adsorption cooling system model will be made in the near future when the coupling between the solar collector arrangement and the solar air conditioning system can be completed and experimental data can be obtained for different working conditions.

The validation of this complete system provides the opportunity to have a reliable tool for the design, dimensioning and analysis of solar cooling systems in other Mexican regions with different weather and working conditions.

5. Acknowledgements

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6. References

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7. Nomenclature and symbols

C	Calculated values
EXP	Experimental
η	Efficiency [-]
FrS	Solar fraction [%]
H	Monthly average daily horizontal irradiation [MJ/m^2 day]
M	Measured values
P	Parallel
PMAE	Percentage Mean Absolute Error [%]
PMV	Predicted Mean Vote index [-]
PPD	Predicted Percentage Dissatisfied [%]
Q	Heat energy [J]
RH	Relative humidity [%]
S	Series
T	Temperature [°C]
TMY	Typical Meteorological Year
TRNSYS	Transient Systems Simulation

Subscripts

a	Ambient
aux	Auxiliary
i	i^{th} value
in	input
off	off
on	on
out	output
req	Required
set	Set point
t	Tilted