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ScienceDirect
Energy Procedia 91 (2016) 477 – 485
Energy Procedia

SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry

Economic feasibility of flat plate vs evacuated tube solar collectors in a combisystem

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Abstract

The aim of this research is to determine the economic feasibility of a solar thermal system used for Domestic Hot Water and Radiant Floor Heating. A two floor house is modeled to create a thermal load. The system design and thermal analysis is studied using TRNSYS. The technical-economic analysis is performed using Microsoft Excel. The optimal type/number of solar thermal collectors and thermal storage size were determined based on the economic figures. The optimum system configuration for the case of evacuated tube system resulted in 8 collectors using a storage relation of 40 L/m^2 whereas flat plate system resulted in 12 collectors using a storage relation of 50 L/m^2. The return on investment for the flat plate system was calculated in 9 years and the evacuated tube system resulted in approximately 11 years.

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Keywords: Solar Energy; TRNSYS; Combisystem; Radiant Floor; Hot Water; Economic feasibility.

1. Introduction

The National energy balance indicates that the residential sector consumes about 16% of the total energy [1]. However, around half of that energy it is consumed in terms of space and water heating.

Due to economic and technological development higher comfort levels in buildings are constantly being demanded. Although human comfort involves many inputs influenced by physical, physiological, psychological, and other processes, thermal comfort in buildings is a primary objective. As a consequence temperature is an important

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Peer-review by the scientific conference committee of SHC 2015 under responsibility of PSE AG
doi:10.1016/j.egypro.2016.06.181

variable for thermal comfort inside a building. Since there are wide temperature variations in weather conditions in the northwest region in Mexico, designing a well-insulated building with an adequate HVAC system represents a challenging work [2].

Radiant floor heating is not a new concept; moreover, it has been used since the very first moments of human reason, when heated rocks were buried below the ground in order to create a comfort condition. Although it is a well-known concept, it is still being studied and discussed all around the world getting more and more popularity for its great number of advantages over the most commonly used heating systems.

The Water council assures that 96.1L of hot water are consumed daily by person. This consume represent the 47% of the total energy used by an entire building [3]. Since water and space heating represents a significant part of house daily energy consumption and moreover the solar radiation over the analyzed region is among the best of the world, an economic analysis is needed to determine the optimum combisystem configuration for this specific application.

Solar thermal behavior of several systems under different thermal loads for heating and domestic hot water has been studied. Leckner and Zmeureanu, presented the performance of a base case solar combisystem, focuses on the search for the optimal configurations of a residential solar combisystem for minimum life cycle cost, life cycle energy use, and life cycle exergy destroyed in Montreal [4].

In 2012 an analysis was performed using 4 different types of construction in two different locations. TRNSYS was used in order to model and simulate the buildings with different thermal loads. The results show that these systems are more cost effective when there is a greater solar availability and are applied in buildings with higher energy demands [5].

Ampatzi and Knight analyzed the importance and consequent complexity of gaining a reliable estimate of the temporal energy demands made of active domestic solar systems. TRNSYS was used to study the influence of weather data, thermal comfort operating schedule, lighting and plug loads, on the predicted thermal energy demands that are to be met by solar thermal combisystems with heat storage. The study demonstrates also that dynamic system simulation tools like TRNSYS can handle the complexity of elaborate building modelling descriptions but highlights the need for more suitable modelling methods which incorporate comprehensive, building-focused interfaces [6].

Nomenclature

DHW	Domestic Hot Water
RFH	Radiant Floor Heating
PEX	Crosslinked Polyethylene
PW	Present Worth
SPWF	Series Present Worth Factor
GPWF	Gradient Present Worth Factor
i	Inflation
G	Gradient
R	Uniform Amount
Aux	Auxiliary amount of energy
Eff	Tank-less heater efficiency
EC	Energy Cost
ΔEC	LPG Annual Cost Interest
PW	Present Worth
ROI	Return on Investment

2. Methodology

A solar heating system was designed to provide the required amount of energy for DHW and RFH using solar thermal collectors, heat storage and a residential tank-less water heater (boiler) as an auxiliary support. Cold water reposition from the draw was also considered for the hot water daily usage of 4 occupants.

The system description has been divided into two main parts: The solar energy collection and the RFH/DHW (Fig. 1).

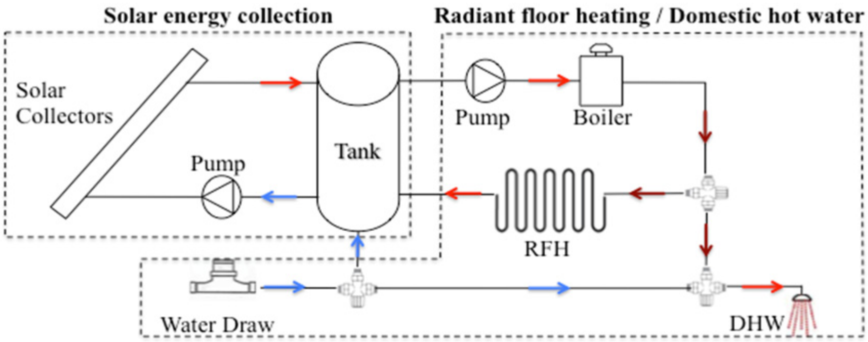

Fig. 1. Proposed system diagram.

2.1. Solar energy collection

Solar Collectors.

Two types of certificated solar collectors were analyzed in this work. A Flat plate solar collector was considered using the technical data of Kioto Clear Energy, FP7.25.0H. On the other hand an evacuated tube solar collector represented by Apricus, AP-30. The slope angle used was 40° in both analysis.

Storage tank.

The storage tank analyzed is a cylindrical-vertical type with three thermal stratification nodes. A maximum height of 2.1 m was considered. The thermal fluid used in the system was water and the tank is a non-pressurized type.

Pump.

An ON/OFF differential controller is used in the solar energy collection. The value of the control signal is chosen as a difference between upper and lower temperatures, which in this case is given by the solar collector outlet temperature and the tank outlet load temperature. This control sets a high limit cut-out of 98°C in the tank.

2.2. RFH/DHW

Building.

The analyzed building is located at latitude 28.65° and longitude -106.15° in Chihuahua, Chihuahua, Mexico. A 32° rotation angle is also being considered for orientation. The first floor was set as one thermal zone of 83.31 m^2 which includes a kitchen, dining room, living room, vestibule and closet. The second floor was divided into two thermal zones, an 87 m^2 which includes 2 bedrooms, 1 bathroom, dress room, TV room and service room, additionally a thermal zone of 33 m^2 which includes the main bedroom and a bathroom as shown in Fig. 2. Materials description is presented in Table 1 and Table 2.

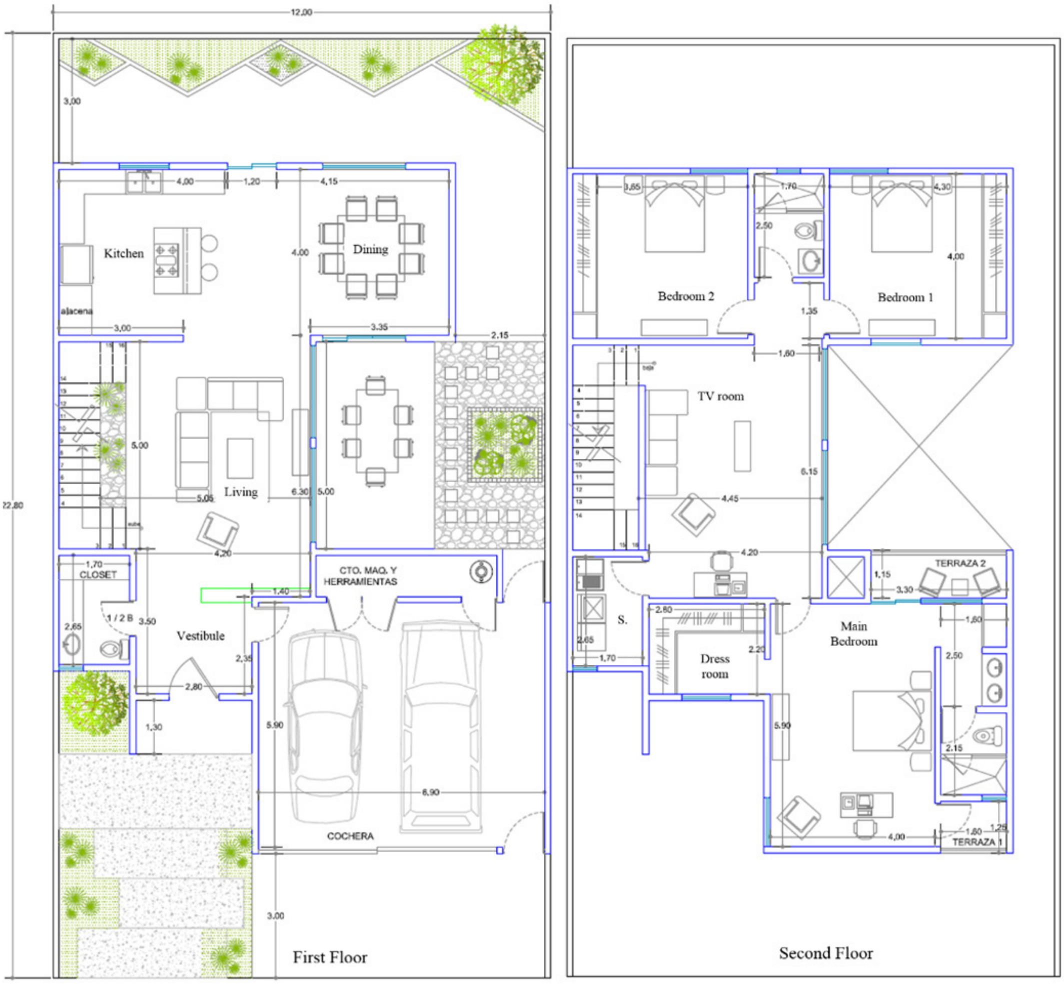

Fig. 2. House distribution

Table 1. Construction Materials and Properties.

	Layer	Thickness (m)	Conductivity (kJ/h m K)	Capacity (kJ/kg K)	Density (kg/m^3)
Walls	Interior Gypsum	0.015	5	1	2000
	Hebel	0.15	0.468	1.36	500
	Exterior Gypsum	0.015	5	1	2000
Floor	Floor	0.005	0.252	1	800
	Concrete C1	0.12	7.56	0.8	2400
	PEX	-	1.368	2.3	951
	Concrete C2	0.12	7.56	0.8	2400
	Isolation	0.3	0.1224	1.4	55
Roof	Polyurethane	0.051	0.13	1.47	40
	Concrete	0.24	7.56	0.8	2400
	Gypsum	0.015	5	1	2000

Table 2. Window properties.

Layer	U Value ($W/m^2 K$)	G Value (%/100)	Frame area (%/100)	Frame U Value ($kJ/h\ m^2\ K$)	Frame Absorptance
Double Glass	1.4	0.589	0.2	8.17	0.65

Radiant floor heating.

The considered habitable surface has been set with radiant floor. The loops under the floor consider PEX tubing filled with water as a thermal fluid. PEX properties are presented in the Table 3. An eight loop manifold it is considered for the first floor, on the other hand the second floor considered an eight loop manifold and an extra four loop manifold due to its bigger floor surface.

Table 3. PEX Properties

Tube	Tube spacing (m)	Tube external diameter (m)	Tube thickness (m)	Tube thermal conductivity (kJ/h m K)
PEX	0.4	0.025	0.0023	1.368

Temperature control is performed by the pump operation and a logical function applied on the diverter valve (first floor/second floor) as shown in the diagram of the Fig. 3. The temperature of both floors is reported to the control. The pump will be in operation while time is between 15:00 to 8:00 hours and any temperature is below 21°C. The diverter will apply the result given by a logical function in order to control which floor need a greater hot water flow.

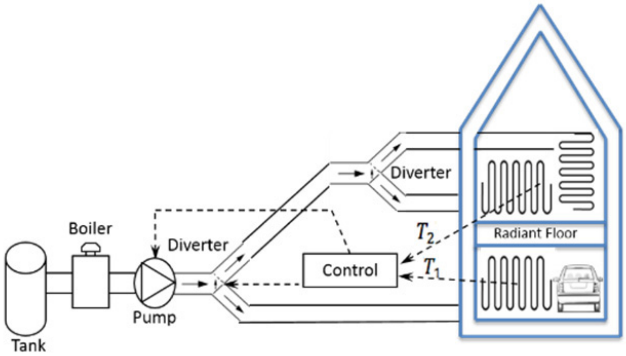

Fig. 3. RFH control diagram

Domestic hot water.

Based on the local water administration (JMAS), the average hot water daily consumption for personal sanitation in Chihuahua is 96.1 L. Four persons are being considered in this analysis, which means a daily consumption of 384.4 L in a draw period between 6:00 and 8:00am every day.

Hot water below 98°C is stored in the tank, nevertheless domestic water temperature is set to 45°C by combining hot water from the storage tank and cold water from the draw. Temperature of the water draw is given by a parabola function which starts from 16°C on January and getting to 23°C in its vertex on the middle of the year.

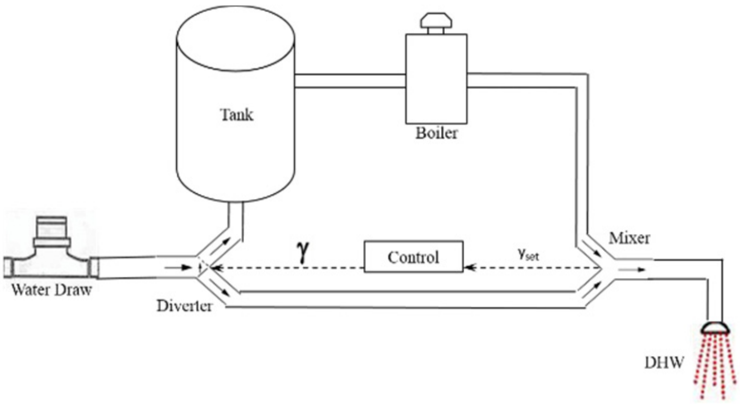

Fig. 4. DHW control diagram

2.3. Dynamic simulation

The natural variability of parameters such as temperature, relative humidity, irradiance and geographical location, which influence the behavior of a solar thermal system through time, makes the use of a computational tool indispensable. The simulation was performed using TRNSYS 16 and the proposed system integrates a considerable number of modules. The main modules in the simulation are presented in Fig. 5.

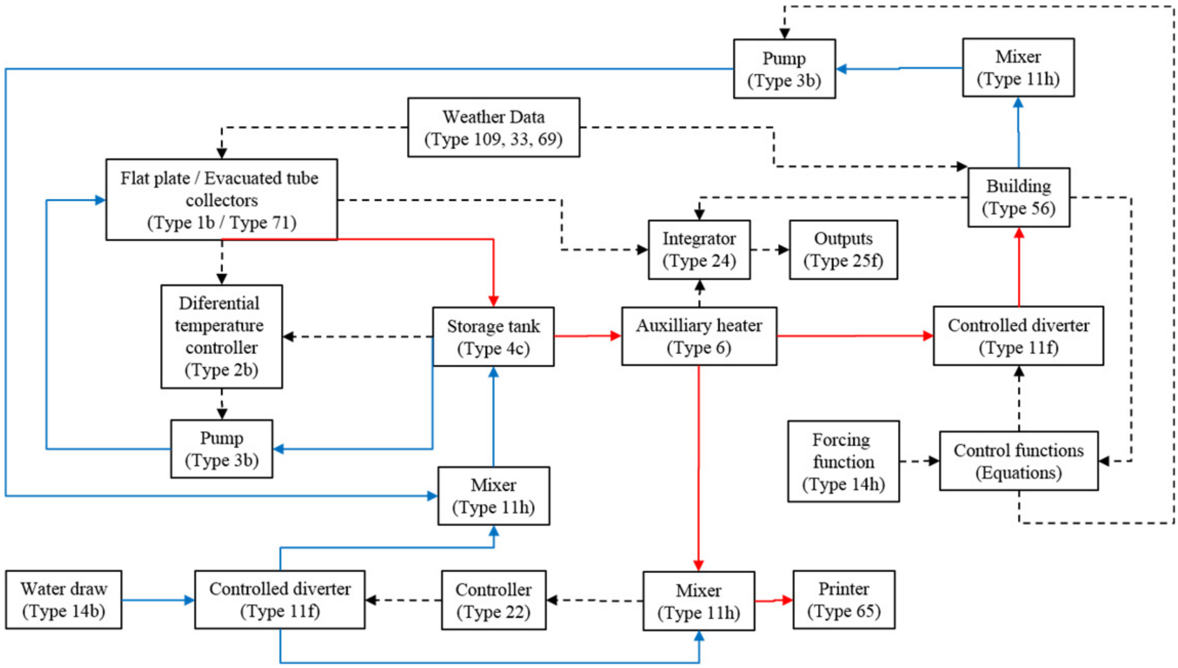

Fig. 5. Proposed simulation diagram.

Variables intervening in the dynamic simulation of a solar thermal system are generally numerous. For this reason it is necessary to perform a parametric analysis in order to evaluate the results and optimize the system performance. TRNEDIT was used to variate the type and number of solar collectors as well as the storage tank capacity in a parametric table.

2.4. Economic analysis

A solar thermal system implementation is generally intended to reduce the operation costs due to the energy consumption. Therefore, the feasibility of these systems is analyzed considering the equipment cost, operation cost and life span of the solar equipment.

Solar Collectors

The cost considered for the solar thermal collectors includes two types: Flat plate solar collectors and evacuated tube solar collectors. Both models present the SRCC certification and are considered as top efficiency in their kind. The model description and costs are presented in the Table 4.

Table 4. Solar collectors cost.

Solar Collector	Company	Model	Cost (USD)
Evacuated Tube	Apricus	AP-30	680.00
Flat Plate	Kioto Clear Energy	FP 7.25.0 H	334.00

Storage tank.

A maximum of 3 storage tanks of 2500 liters of maximum capacity each were considered in the analysis. The costs of several storage capacities were consulted using Swimquip information as a reference. According to this information, the cost estimation is calculated based on a polynomial regression developed using Microsoft Excel showed in Fig. 6.

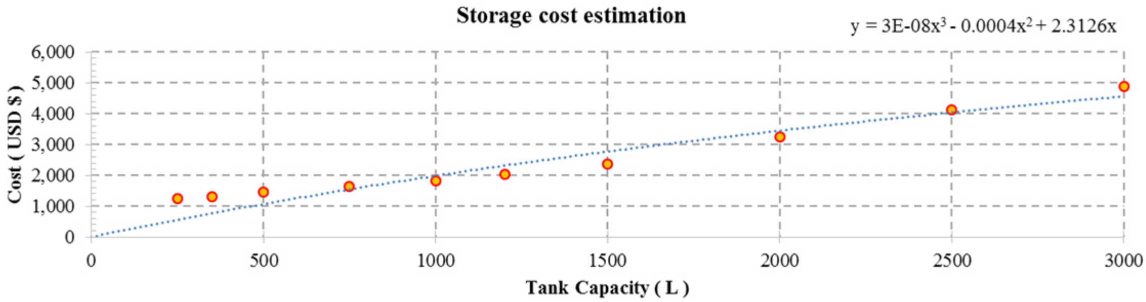

Fig. 6. Storage cost estimation using information from Swimquip Company.

Operation Cost.

Operation cost is calculated by means of the SPWF (1) which multiplied by R (3) yields the present worth and GPWF (2) which is based on the progressive increase of the energy cost as fossil fuels become more expensive [7].

The resulting present worth value is mainly influenced by the Aux (Parametrically obtained by the simulations), nevertheless Eff (91%), EC (USD$16/GJ), ΔEC (9%) [8], i (4%) and n (25 Years) were also considered.

$$SPWF = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{1}$$

$$GPWF = \frac{1}{i}\left[\frac{(1+i)^n - 1}{i(1+i)^n} - \frac{n}{(1+i)^n}\right] \tag{2}$$

$$R = \frac{Aux}{Eff * EC} \tag{3}$$

$$G = R * \Delta EC \tag{4}$$

$$PW = R * SPWF + G * GPWF \tag{5}$$

3. Results

Once the operation cost is at present worth, it was added to the cost of the solar collectors and the cost of the corresponding storage capacity for each parametric result. The results of the parametric analysis were exported to Microsoft Excel in which dynamic graphs were performed in order to observe the optimized technical-economic system configuration for each type of solar collector. The Fig. 7 and Fig. 8 show the results of the parametric analysis for evacuated tube and flat plate solar collectors respectively. It can be observed that the lower cost corresponds to the optimum system configuration which for the case of evacuated tube analysis resulted in 8 collectors using a storage relation of 40 L/m^2 whereas flat plate analysis resulted in 12 collectors using a storage relation of 50 L/m^2.

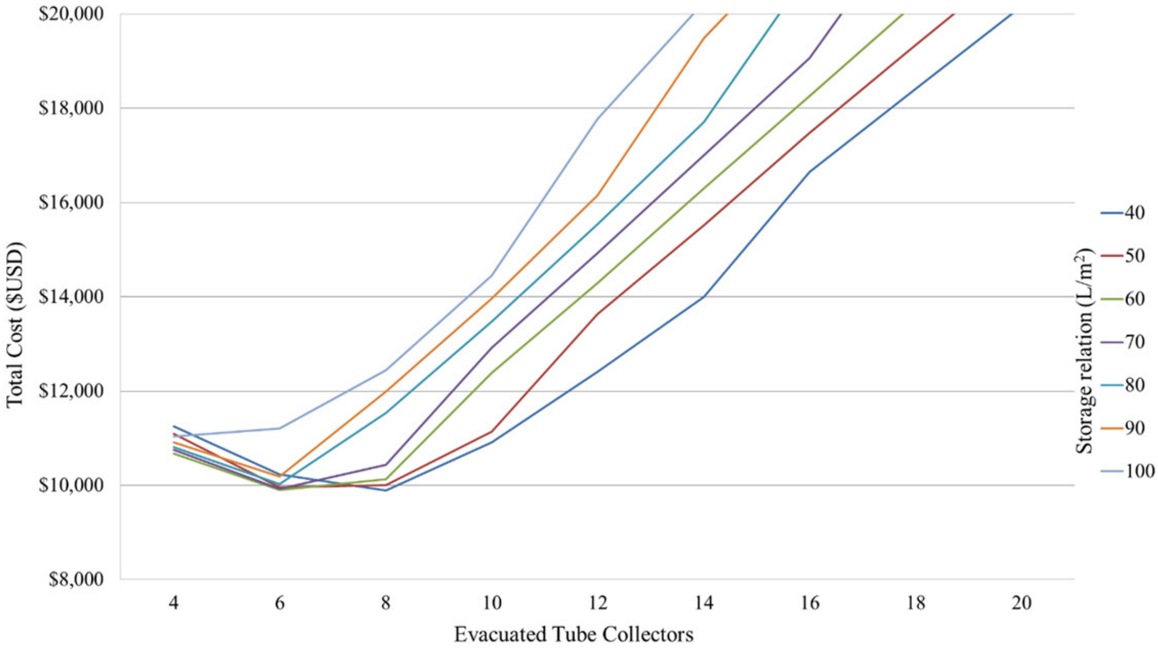

Fig. 7. Results of evacuated tube solar collectors.

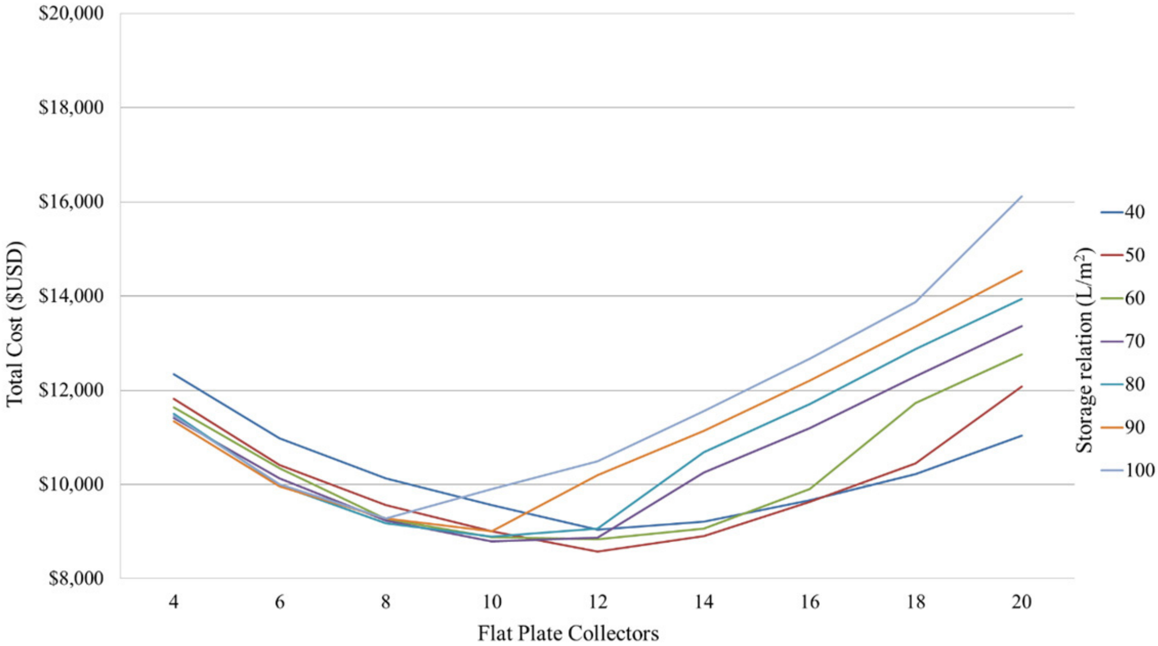

Fig. 8. Results of flat plate solar collectors.

4. Conclusions

It was possible to use TRNSYS as the main tool to determine the optimum technical-economic parameters for a solar heating system used in a combisystem. A summary of Fig. 7 and Fig. 8 for the optimum technical-economic system configuration is presented in the Table 5. The last column corresponds to the results of a simulation performed without the use of solar thermal collectors, nevertheless a 500 L tank is considered for DHW.

Table 5. Optimum technical-economic system configuration

Type	Evacuated Tube	Flat Plate	Non-Solar Collector
Collectors (Quantity)	8	12	0
Tanks (Quantity)	1	1	1
Tank (Capacity)	1408	1543	500
Auxiliary Energy (kJ)	3.19E+06	3.04E+06	4.06E+07
Solar Fraction (%)	92.14	92.51	0
Total Cost ($USD)	$9,895.00	$8,580.00	$23,571.00

The cost calculated for the house heating in a 25 years period with no solar equipment resulted in $USD 23,571.00 which represent 274.7% more compared with the equipment and operation cost of the flat plate project.

Considering the total cost (Equipment plus operation) of a non-solar collector system, the return on investment (ROI) was calculated for both evacuated tube and flat plate systems. Whereas the ROI for the flat plate system was calculated in 9 years, the evacuated tube system resulted in approximately 11 years. Even when the total cost is lower and the ROI is shorter for the flat plate system, it would be convenient to consider installation and maintenance costs in further research.

This simulation can be further used for dimensioning and optimization of a solar combisystem for a different house in a different location.

Acknowledgements.

The authors would like to thank the support given by the project P13 (Laboratorios de pruebas para baja y media temperatura, laboratorio para el diseño e integración de sistemas termo solares asistido por computadora) of the ***Centro Mexicano de Innovación en Energía Solar (CEMIE-Sol)***

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