SOLAR SPACE HEATING SYSTEM USING HIGH EFFICIENCY FLAT PLATE COLLECTORS: EXPERIMENTAL RESULTS

J. D. Marcos[1,*], M. Izquierdo[2,3], D. Parra[3] and M.E. Palacios[4]

[1] Escuela Técnica Superior Ingeniería Industrial, UNED, c/ Juan del Rosal 12, 28040 Madrid, Spain.

[2] Instituto de Ciencias de la Construcción Eduardo Torroja (CSIC) c/ Serrano Galvache 4, 28033 Madrid, Spain.

[3] Escuela Politécnica Superior, UCIIIM, Av. de la Universidad 30, 28911, Leganés, Madrid, Spain.

[4]Escuela Universitaria Ingeniería Técnica Industrial, UPM, C/ Ronda de Valencia 3, 28012, Madrid, Spain.

[*] Corresponding Author, jdmarcos@ind.uned.es

Abstract

An experimental solar energy facility has been designed in order to contribute to the coverage of cooling and space heating demand for the typical Spanish housing. This work focuses on the experimental evaluation of this facility working in *solar space heating* mode during the winter months (November 2008- April 2009). To that purpose a new type of solar vacuum plate collectors with a higher efficiency than conventional ones has been used. The solar facility comprises a solar collector field of 48 m^2 (42 m^2 useful area), a plate heat exchanger, a 1500 liters storage tank, an absorption machine and several fan-coils. The facility has been tested while heating an 80 m^2 building located in Madrid. The results show that the solar facility is able to meet 65 % of the space heating demand. As the average floor size of Spanish homes is 80 m^2, these results can be extrapolated. This research is supported by the PSA INVISO 2007-2008 Research Project (SP3-Sustainable Power Generation for Housing).

1. Introduction

The main problem in the design of solar installations concerns the mismatch between the energy demand and the energy supply. This problem is usually solved through the integration of storage and an auxiliary energy source. It must determine all the parameters that affect the performance of the solar system in order to optimize this integration.

The recent literature analyzes the performance of domestic hot water (DHW) and space heating systems. Lund [1] proposes a daily averaging sizing method for a solar combisystem (DHW and space heating). The space heating generally uses radiant floor for the heat transfer. Other researchers studied the storage tank [2] and others analyzed the auxiliary sources to increase their efficiency as much as possible [3].

An experimental solar energy installation is designed in order to contribute to the coverage of cooling and space heating demand for the typical Spanish housing. The present work reports on some of the results of experiments conducted at the Spanish National Research Council's Experimental Solar Energy Plant at La Poveda, Arganda del Rey, Madrid, in the winter of 2008-2009. This experimental facility consists of a new type of vacuum flat plate collectors that provides a higher efficiency than conventional flat plate collectors. A plate heat exchanger (PHE) conveys the solar energy from the collector field to the storage tank.

2. Description of the solar heating system

Fig. 1 contains a simplified diagram of the solar cooling/heating system, which consists of three circuits:

1. Primary circuit: comprising a field of flat plate vacuum solar collectors, a pump and the hot side of a plate heat exchanger. The thermal fluid id pumped through the collectors, where it is heated by the incident solar radiation. In the exchanger, this heat is subsequently transferred to the secondary circuit fluid.

2. Secondary circuit: comprising the cold side of the plate heat exchanger, a pump and an insulated storage tank. The fluid heated in the exchanger is pumped to the storage tank where it is stored for use.

3. Tertiary circuit: comprising the circuit that feeds the absorption unit (solar cooling mode) and the fan-coil installed in the laboratory (solar space heating mode). When operating conditions are reached (demand in the premises and tank temperature), the water is pumped from the storage tank to the generator to the fan-coil.

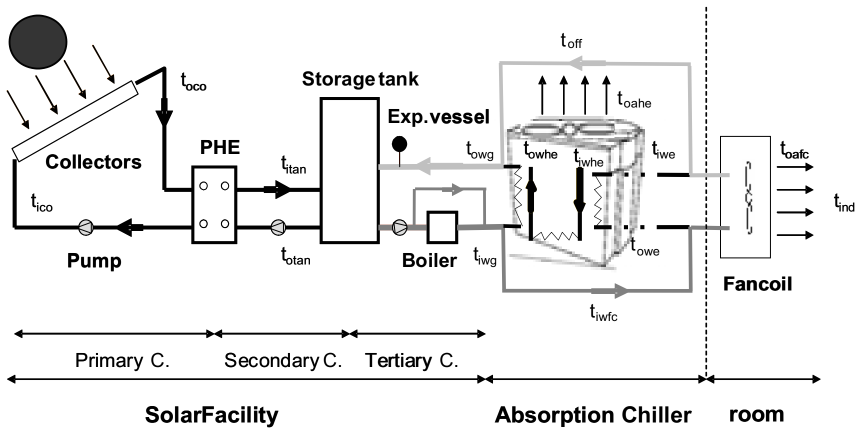


Fig. 1. Diagram of the solar facility - mode "space heating" (by-passing absorption machine).

Next the different components of the solar facility are described.

2.1 Solar collectors field

The solar field consists of a new type of vacuum flat plate collectors, fig. 2, that present a higher efficiency than conventional ones. The reason is that vacuum has been created inside the collector, what eliminates the convection losses. The total area of the solar field is 48 m^2 (42 m^2 useful area) and each collector has an optical efficiency of 0.81, a first order loss coefficient of 2.61 W/m^2K and a second order loss coefficient of 0.008 W/m^2K. The collectors, which are tilted on a 30º angle over the horizontal and arranged in four groups of six, face south. Circuit pressure balancing takes account of the thermal fluid flow distribution.

Fig. 2. Solar vacuum flat plate collectors in the Solar Experimental Plant (CSIC).

2.2. Plate heat exchanger

A plate heat exchanger (PHE) conveys the solar energy from the collector field to the storage tank. The PHE is a 25-kW exchanger and connects the primary circuit with the secondary circuit.

2.3. Storage tank

The 1500-liter storage tank (figure 3) is insulated with 0.06 m polyurethane foam. The primary, secondary and tertiary circuit boosters, with power demands of 395W, 175W and 110W, respectively, pump the flow at rates of 29, 22 and 18 l/min. Each circuit has its respective expansion vessel. Pressure is kept upward of 2 bar in all three circuits. All pipes are insulated with 0.02m polyurethane foam.

Fig 3. Storage tank.

2.4. Heat Pump Laboratory (thermal load)

The premises to be heated have a net area of 80 m^2 and a volume of 240 m^3. The UA factor for these premises, which are occupied by three people for 8 hours daily, was 460 W/K. The coincidence factor was assumed to be 0.75.

3. Environmental variables

Fig. 4 shows the environmental variables prevailing on December 23rd , 2008 (very cold day) and February 16th , 2009(cold day), outdoor dry bulb temperature, T_dbo and wind velocity, v_w. Theses days have been chosen because they are representative of the space heating season. The lowest temperatures were -2.5 ºC (23/12/08) and 0 ºC (16/02/09); and the highest 16 ºC (23/12/08) and 13.9 ºC (16/02/09). The wind velocity was variable along the day, being higher on 23/12/08 than on 16/02/09, where a peak of 10.5 km/h was reached at 21 hours.

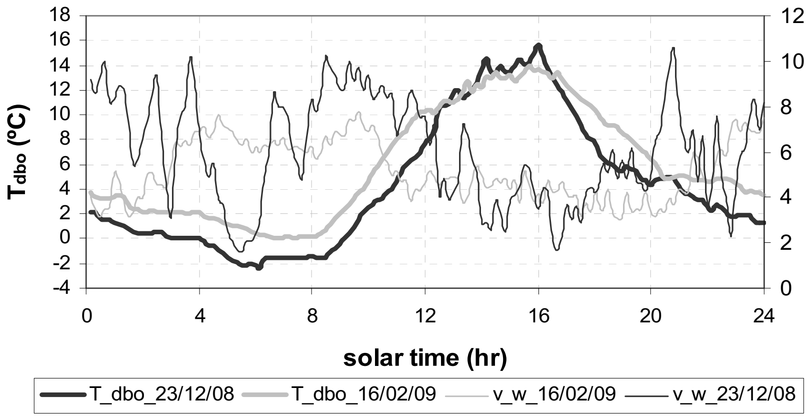


Fig.4. Outdoor dry bulb temperature and wind velocity (23/12/08 and 16/02/09)

Fig. 5 shows the daily distribution of solar radiation on the collector surface on 23/12/08 and on 16/02/09. The maximum, 917 W/m^2, was reached at 12:50 hours on 16/02/09. Sunrise was at 07:10 and sunset around 18 hours. The solar energy intercepted (tilted at 30º) was 5.5 kWh/m^2·day.

The maximum value on the 23/12/08 was 804 W/m^2, and it was reached at 12:40 hours. Sunrise was at 08:00 and sunset at 17:10 hours. In this case, the solar energy intercepted was 4,3 kWh/m^2·day.

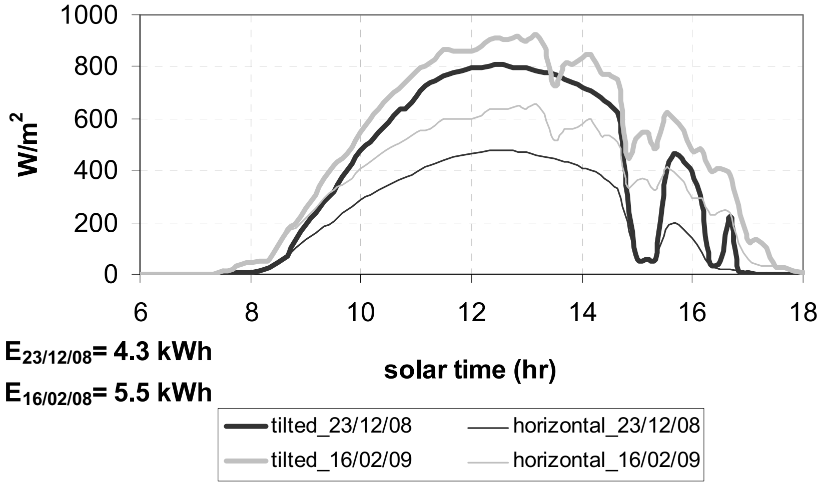


Figure 5. Daily tilted and horizontal solar radiation (23/12/08 and 16/02/2009).

4. Data reduction

The heat stored in the tank is directly provided to the fan-coil as long as the inlet water temperature coming from the tank is above 40 ºC. The indoor air is heated up to reach a reference temperature (T_{inref}) of 21 ºC.

In these experiments a housing heating period has been chosen. The highest thermal loads were 10.8 kW (16/02/09) and 10.4 kW (23/12/08), being the total demand 40 kWh and 53.8 kWh, respectively.

The lab thermal load is calculated as follows,

$$\dot{Q}_{thL} = U \cdot A \cdot \left(T_{inref} - T_{outdoor}\right) \tag{1}$$

On the other hand, the solar heating capacity is calculated with eq. (2):

$$\dot{Q}_{sh} = \dot{m}_{fc} C_p \left(T_{ifc} - T_{ofc}\right) \tag{2}$$

In eq. (7) $\dot{m}_{fc}$ is the water mass flow rate in the fan-coil; T_{ifc} the water inlet temperature in the fan-coil and T_{ofc}, the water outlet temperature.

The solar coefficient of performance (SCOP) of the solar space heating facility is a system efficiency parameter and was evaluated from the ratio of heating produced and the solar radiation incident on the tilted plane, G_T, of the collectors field given by the following relation,

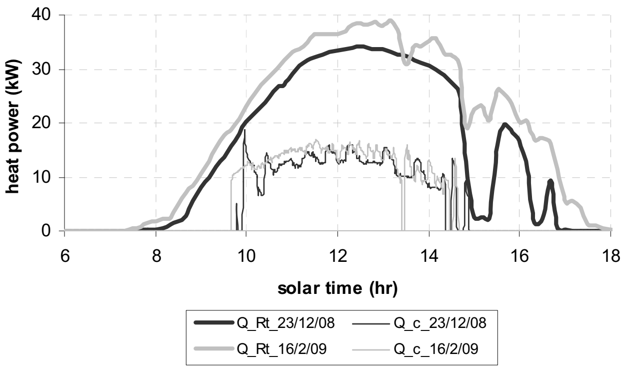
$$SCOP = \frac{\dot{Q}_{sh}}{G_T} \tag{3}$$

5. Experimental results

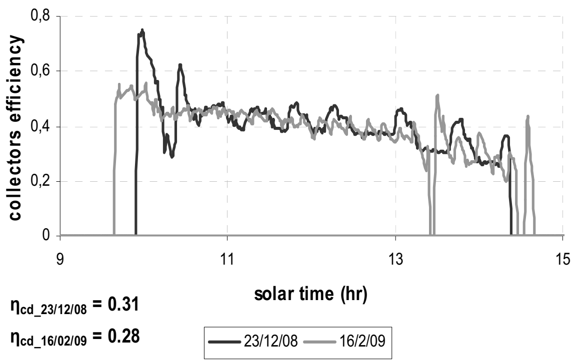
The experimental period ran from November 2008 to April 2009. The main objective of this work was to analyze the performance of the solar collector field. To that purpose two representative winter days were chosen to check the yield of the system in variable conditions: cold and very cold.

The highest values of the solar power received by the tilted collectors ($\dot{Q}_{RT}$) during the 16/02/09 and 23/12/08 were 38.9 kW and 34 kW, respectively (fig. 6a). At 09:42 hours on 16/02/09, 9.7 kW of useful power, Q_c, was delivered to the storage tank and by 11:33 hours this figure had climbed to its maximum value 16.6 kW, practically the same as the reached during the 23/12/08.

On the other hand, Fig. 6b shows the solar collectors efficiency for both days. The highest values were 0.55 and 0.63 on 16/02/09 and on 23/12/08, respectively. Daily yields, η_{cd} , were 0.28 and 0.31.



(a)



(b)

Fig. 6. Solar energy received and transferred from the solar collector field to the tank (a) and collectors efficiency (b)

Fig.7 and 8 show the experimental results corresponding to the whole heating period. The tilted solar radiation (Q_{RT}), the enery stored in the tank (Q_{ST}) and the energy provided by the fan coil (Q_{fc}) for each day are shown in Figure 7. The global results for this period are: solar energy intercepted, 16636.7 kWh; solar energy stored in the tank, 4173.6 kWh; and heating energy transferred in the fan-coil, 2128.4 kWh.

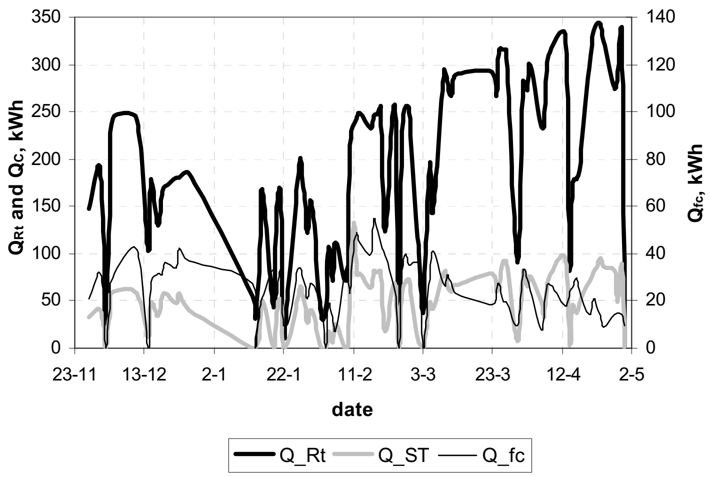


Figure 7. Daily energy balance

Fig. 8 displays the solar fraction (SF) and the collectors and global efficiency (SCOP) for the total experiments carried out during the heating period.

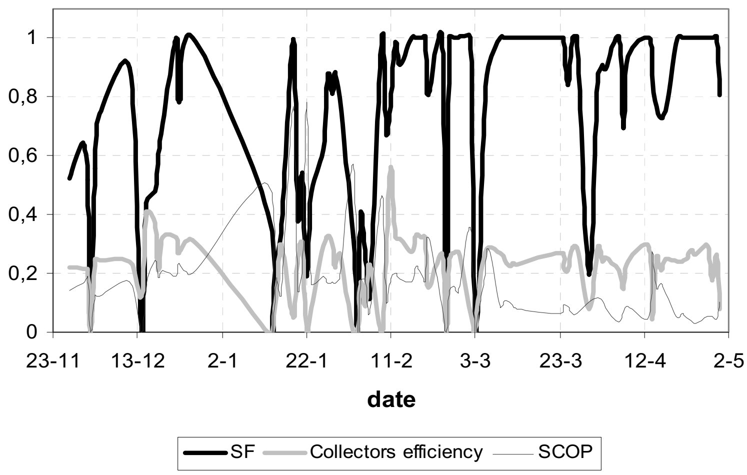


Figure 8. Daily efficiency

The efficiency of the system was obtained from the analysis of the results provided by the experiments for the whole heating season. This global efficiency was 0.18 and the seasonal collector efficency 0.28. It was also calculated that the solar fraction reached 65 %.

5. Conclusions

In this work experimental results of a solar space heating facility that uses a new type of solar vacuum flat plate collectors are presented. Two days representative of the winter season were chosen to analyze in detail the performance of the facility: a cold and a very cold day. Daily collectors efficiency, η_{cd} , on these days were 0.31 and 0.28, respectively. On the other hand, it is also shown the performance of the main parameters of the facility for the whole season: the global efficiency was 0.18, the seasonal collectors efficiency 0.28 and the solar fraction 65 %.

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