Performance of a solar thermal collector prototype designed for architectural integration

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Abstract

This article presents a novel solar thermal collector prototype designed for architectural integration. Its main characteristic is a curved absorber, which allows more flexible positioning on facades and roofs.

The main objective of the work is to compare the performance of the prototype's absorber with the one of a conventional solar collector. The curved geometry of the prototype precludes to estimate its characteristic curve, so it is obtained in an experimental facility. In this way, the prototype's absorber has been tested in a solar test set-up, where climate conditions (solar radiation, ambient temperature and wind velocity) are measured, and fluid flow and inlet and outlet temperatures are controlled.

The facades where the prototype is going to be integrated will not be always the optimal features for positioning the collectors in the best inclination. Aspects like position or inclination are much more relevant in the prototype designed for architectural integration purposes, than in conventional collectors. Thus, a key parameter to determine is the prototype's efficiency for different inclinations and positions, due to its looses will not increase linearly, like in a conventional flat collector.

Finally, different improvements in the prototype design in order to increase its efficiency during winter period and offer a more linear response along the year are tested.

1. Introduction

In the recent years different countries are going for the use of clean energies in order to decrease the greenhouse gases leaks and fight the climate change. Thus, many countries are promoting the installation of solar collectors in buildings for domestic water heating. Nevertheless, the roof integrated systems are a topic of discussion for architects because of the visual impact of solar collectors and the necessity of occupy almost the whole roof surface of the building.

There have been attempts to integrate conventional solar collectors in facades and roofs [1], but the results show that not all architects agree with the final building configuration and neither engineers do. Other solution could be the construction of specially designed solar collectors to achieve a reasonable performance and to be easily integrated in the building. The most common solution is to integrate the solar collector with the inclined roof, although this alternative is not possible in horizontal roofs.

In this way, this article presents a new prototype that consists in a collector whose main characteristic is its curved absorber, which increases the possibilities of integration in facades and roofs. The reason of this study is to compare the performance of this new curved collector with the results obtained with a conventional flat collector under the same ambient conditions.

2. Prototype description

As commented previously , this solar collector design tries to offer a pleasant and aesthetic solution to integrate the collector in facades and roofs. In addition, the prototype has been designed for being easily manufactured and offers several installation configurations, with a compromise between its aesthetic aspects and a reasonable efficiency. Figure 1 shows a scheme of the curved absorber and Figure 2 a simulation of a possible integration solution.

Fig 1. Bottom view of the curved absorber prototype.

Fig 2. Photographic scheme of an integrated solar installation on a real facade .

The proposed solution is a curved absorber, in a quarter-cylinder shape, that allows integration solutions in horizontal or vertical positions and columns in a quarter or a half-cylinder shape, what would have a low or even positive visual impact. Another possibility is to use it as a cornice trimmer or also to camouflage the collector, making it nearly “invisible”, in the roof interior. As an additional advantage, the wind resistance of the prototype is lower than the one of a conventional collector, leading to decrease the installation costs and difficulties. The installation of the collector has to be complemented with non active elements (‘dummies’) with a similar appearance to the collector. These elements give an architectural coherence to the building and are usually used in architectural integration designed elements [1].

Once the problem and the prototype are defined, it is necessary to check its performance in comparison with a conventional flat collector. In this way, a serie of experiments have been carried out, comparing two absorbers of the same size, one flat absorber and the curved absorber prototype. Due to the difficulties in manufacturing a complete curved collector, the first tests have been carried out comparing two identical naked absorbers. The only difference between them is that one absorber is curved, forming a quarter of cylinder, while the other one is flat.

The flat plane absorber dimensions are 360 x 1900 mm and consists of four cupper pipes welded to a selective aluminium 0.5 mm thickness sheet. The absorbers are provided with sunstrip and their main characteristics are summarised in Table 1.

Table 1. Parameters of the Aluminium/Copper absorber.

Flange efficiency at 20 L/min	0.938
Flange efficiency at 60 L/min	0.975
Emissions values/ratios	5% ± 2%
Absorption value	94% ± 2%
Surface tested to IEA Task X	OK

3. Experimental facility

In order to analyse the prototype performance, an experimental set-up was designed where the collectors can be orientated in different positions. The facilities are placed in the roof of the Renewable Energy Research Institute of Albacete (39º N, 1.52º W), so the experiments were made in ambient conditions.

There are multitude of possible experimental set-ups for thermal solar collectors facilities [2,3,4]. In this work an experimental set-up similar to the one used by [2] was chosen due to its simplicity, including a room temperature and an humidity sensor. A program written in LabView permits to control the water pump and choose the limits of wind velocity, solar radiation and room temperature and humidity where the experimental results are considered valid. The program also permits to select the length of the recording intervals and determines the mean, maximum and minimum values of the recording variables during each period. The data acquisition system that commands all these actions consists of two real time controllers that acquire the signals and computes the instantaneous performance of the collectors. Finally, the data acquisition system is completed with a user-friendly control panel that permits to command the whole installation during an experiment.

The data acquisition system acquires values of solar radiation and inlet, outlet and room temperatures three times per second and storages these data in memory during an user-defined period, of ten minutes typically. When that period ends, the program computes the mean values of the measured data and storage them in a data file. The user can define the room temperature, wind velocity and humidity ranges where the test is considered valid. If any of the mean values is not in the user defined limits, the program will record an advice in order to discard the data.

In addition to the data acquisition routine, two security routines have been implemented in the program. The user can define two limit temperatures, a freezing temperature and an overheating temperature. In case any of these temperatures is reached, either during an experiment or when the installation is in stand-by, the software activates a protection routine to stop a possible primary circuit freezing or a dangerous high temperature that could damage the installation. These ranges are important when different thermal fluids are used, especially during winter.

Finally, the installation can be commanded manually by the user. The virtual instrument implemented will always give priority to user orders unless an emergency routine is activated.

4. Experimental results and discussion

As commented previously, the tests consist of a comparison of the results obtained with two absorbers, one flat and one curved, without any other element (glass or box). Obviously, under these conditions their performance will be low, in comparison with typical thermal collector efficiencies. But both absorbers operate under similar conditions and permits to compare the results obtained with a curved geometry with the ones obtained in a flat one, avoiding any other influence.

As the prototype has been designed for architectural integration, which can be combined for making architectural trimmers, different orientations should be studied, trying to simulate different architectural solutions. But first, in order to determine the performance losses, both absorbers have been mounted in an optimal situation: the two collectors south faced. As the curved absorber has a quarter cylinder shape, its optimal position would be horizontal, while the flat absorber was inclined 45º. During all tests, the flat absorber will be in the same position. Thus, we will compare the performance of the curved absorber in an “integrated” position with an absorber in a typical optimal position (Figure 3a). In this way, efficiency losses caused by ‘integrating’ the collectors will be determined.

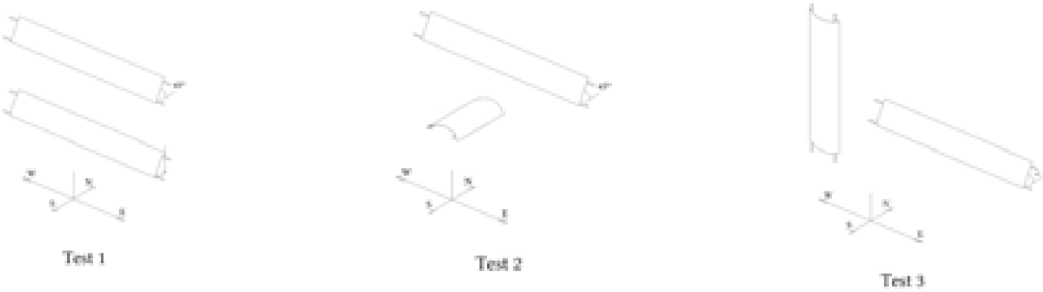

Fig 3. Position schedules of the different exterior configurations.

The first test was carried out during 24 hours of a typical summer day in Spain. Due to the high exterior temperature, it was difficult to maintain constant the absorbers inlet temperature. During the higher sunny hours this temperature was controlled between a maximum variation of 7 ºC.

Figure 4a shows the results obtained in the first test. The flat absorber presents a small increment in its outlet temperature in comparison with the curved absorber in the middle of the day, although they have similar outlets temperature during the rest of the day This is caused because the flat absorber has is optimal position during the central sunny hours and the curved absorber will have an opening area smaller than its real area and 45º tilted.

The performance curves, represented in Figure 4b, show a similar behaviour to outlet temperature curves, i.e. during central hours the performance of the flat absorber is higher than the one of curved absorber, being the difference significant. The instantaneous performance is calculated as:

$$Eff = \frac{\dot{m}\, c_p \left(T_{out} - T_{in} \right)}{I\ A} \quad (1)$$

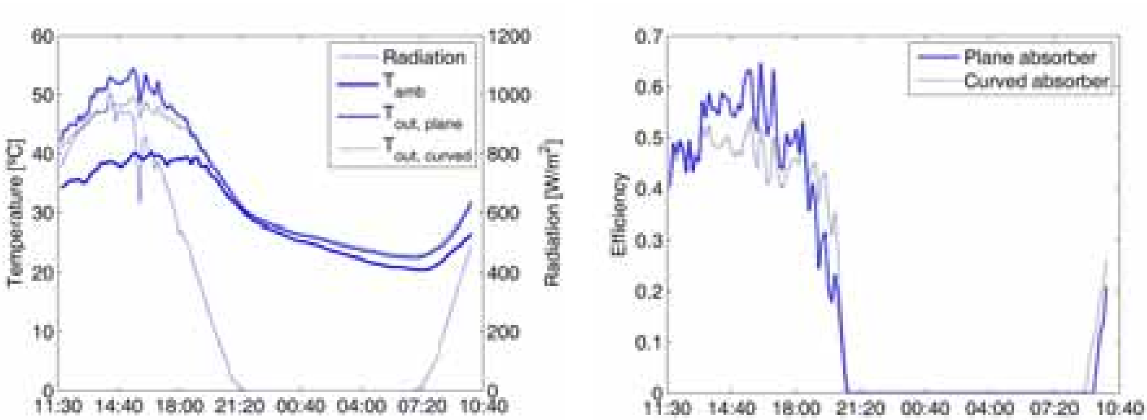

Fig 4. (a) Radiation, ambient temperature and oulet temperatures for the curved and the flat absorber in test 1 and (b) instantaneus efficiency

The maximum difference in the performance of both absorbers is 14%, which results in a difference of 5ºC in the outlet temperatures. As the solar radiation decreases, the curved absorber shows a better performance than the flat one because the projected area of the curved one receives more solar radiation during the sunrise and the sundown. At optimal positions, the curved absorber gives a maximum performance difference of 15%. The mean global efficiency during the period showed in Figure 4 is 0.43 for the flat absorber and 0.41 for the curved one.

Once both absorbers have been compared in the "optimal" position, we are going to vary the position of the curved absorber. Two different configurations have been analysed: in a horizontal position, being its largest length north-south oriented, and in a vertical position, being the projected area of the absorber oriented to the south. The flat absorber is maintained with the same orientation.

In the horizontal position, due to its geometry, the curved absorber will receive very low sun rays, thus we can expect a higher thermal performance during the sunrise and the sundown. Figure 5 shows this phenomenon. The flat absorber has the same heat capacity as the curved one at central hours, but the second is able to achieve higher temperatures on extreme hours. In the horizontal north-south position the curved absorber offers a more linear and higher performance along the day than in its optimal position, being even higher than the one of the flat collector. Nevertheless, note that the tests have been carried out during summer period and the curved absorber is horizontally positioned, where as the flat absorber is 45º tilted. The performance of the flat absorber will be higher if it were horizontally situated. The global performance in this case were 0.24 for the flat absorber and 0.40 for the curved one.

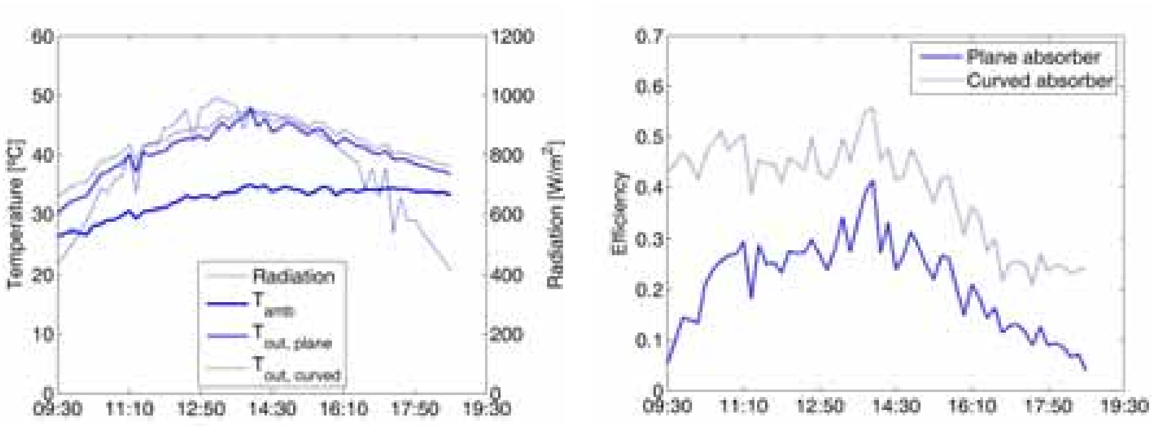

Fig 5. (a) Radiation, ambient temperature and oulet temperatures for the curved and the flat absorber in test 2 and (b) instantaneus efficiency

The vertical position configuration could be more interesting from an architectural integration point of view, due to in this position the collector could be integrated in form of columns. In this way we have 5 interesting positions where the curved absorber has to be tested. With its center south faced (where it will need two 'dummies' to complete the column). With South-West and South-East positions, where combined will form a South faced position and North-West and North-East positions, which are the worst positions for the panel but it were studied for possible combinations in facade position, instead perhaps a 'dummie' would be better solution for these positions.

Initially, in this configuration, we can not expect high performance of the curved absorber due to its orientation.

Figure 6 shows the results obtained with the curved absorber in the vertical position with its projected area oriented to the south. During the day, the curved absorber has a minimum performance due the azimuth angle, the flat collector offers a global performance of 0.37 while the vertical curved absorber had a performance of 0.11. Thus, this vertical position does not seem to be suitable for using in an individual installation, but it could be used as winter complements, specially that ones that are not used in summer months, preventing them from overheatings and not needing other elements like dynamic disipators.

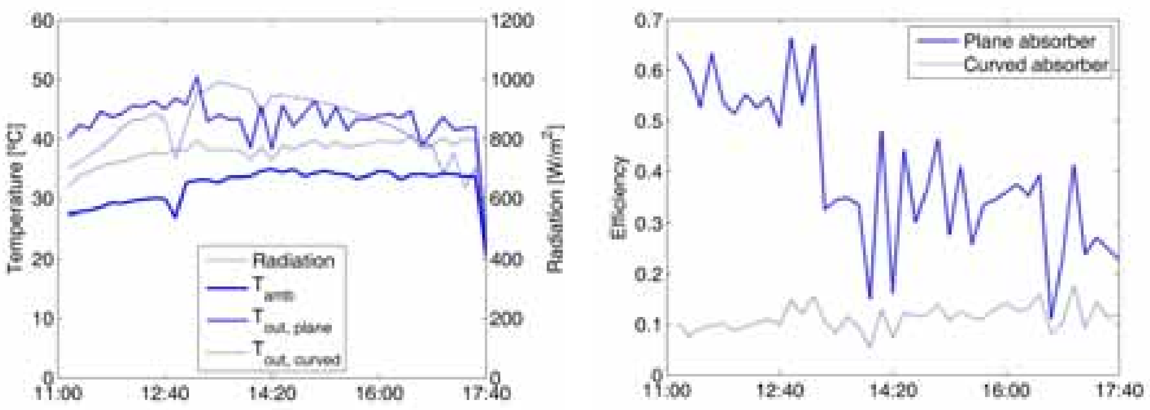

Fig 6. (a) Radiation, ambient temperature and oulet temperatures for the curved and the flat absorber in test 3 and (b) instantaneus efficiency

5. Conclusions and future works

The preliminary results obtained in this work have shown that a curved thermal collector, which can be easily integrated in buildings, could be competitive in comparison with flat collectors, depending on the collector orientation. The results obtained during the summer period comparing both absorbers how that the curved absorber only losing a 2 % of efficiency when both absorbers are in their standard positions. In contrast, it shows better results when it is horizontally positioned and south-north oriented, because it receives more solar radiation during the firsts and the lasts hours of the day, and it shows a worse results when it is vertically positioned.

To complete the analysis of this work seems necessary to complete experiments during different periods of the year (winter and spring or autumn) for accepting or discarding possible integration solution, specially when we are talking about forming vertical columns. This configuration, that could be very attractive for architectural integration, could have high thermal losses. Horizontal north-south configuration has shown interesting results during summer tests and it seems to be the "integrable" solution that offers a better performance.

In future developments we want to change the regular cylindrical shape to different curves due to increasing thermal performance at winter trying to offer a more linear thermal response along the year. As top part of the cylinder curve, when the collector is in a horizontal position, will receive much more radiation in summer than in winter, it is possible to change geometrical topologies to do the collector receiving less radiation in summer, when thermal demands will be lesser, to getting a increasing of received radiation in winter, when thermal demand will increase.

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