Characterisation of the thermal performance of a novel roof ridge solar hot water system

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Abstract

The demand for the development of novel systems for the on-site integration of renewable energy in buildings is increasing, in order to reduce the energy consumption resulting from domestic hot water, heating, and cooling usages. Within this context, the development of efficient solar collectors for domestic hot water production that can benefit from being integrated in the architecture of buildings is highly relevant.In this study, a novel solar collector device with a tube-in-tube concept, which integrates domestic hot water storage and an absorber in a single unit, is tested under the standard ISO 9459-5. The thermal performance of the collector is evaluated by means of the so-called DST (Dynamic System Testing) method that allows its annual energy efficiency to be predicted under different climate condition scenarios. The study concluded that three collector modules in series can provide a high annual DHW energy coverage of 62-70 % for Southern European climates and in the range of 30-40% for Central and Northern European climates. Along with its compactness and efficient design, which allow easier architectural integration on roof ridges, an additional advantage of the system is that its cylindrical geometry makes it possible to rely on a significant surface for full diurnal radiation absorption, independently of solar orientation. With the objective for this new development to be technically and economically competitive compared to available solar domestic hot water systems (SDHW), it is currently in pre-production phase and ready to enter the market in 2018.

Keywords

domestic hot water, solar collector, ISO 9459-5, dynamic testing, SDHW, roof ridge

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1 INTRODUCTION

New policies and mandates are being increasingly introduced to implement renewable energy technologies for reducing the carbon footprint derived from energy use, including the introduction of solar thermal systems to meet demands for domestic hot water (CTE-HE4). However, the design of current solar systems is yet to be improved in order to enhance their efficiency and integration in the architectural design of buildings (Munari & Roecker, 2007).

Some of the limitations of current solar thermal cells are that they require a southern orientation on tilted roofs and that they compete for space with photovoltaic (PV) cell installations and areas of roof windows. On the other hand, novel solar systems technologies are needed that are more easily integrated within the architectural design of buildings and that provide higher thermal performance.

This study describes a new design that addresses some of the limitations indicated above. The solar system presented is a ridge-integrated cylindrical solar water heater that is independent of the space orientation, and is therefore suited to both tilted and flat roofs. It is based on a tube-in-tube concept that integrates the solar collector absorber and the water storage tank within the same design. Specially designed for single family houses, the collector has minimal visual impact due to its integration on roof ridges, it does not compete for space with PV cells due to its compact design, and it does not require extra space for water storage.

The current work presents the results from testing the energy performance of a single solar collector module using the DST (Dynamic System Testing) method for rating solar systems as described in the ISO 9459-5 standard (ISO 9459-5). Estimations of annual energy performance were extrapolated to 3 module units, and evaluated under different climatic conditions and DHW tapping profiles using a simulation model in TRNSYS calibrated with the collector model parameters determined from the DST method. According to the results of the present study, the energy provided by 3 modules can meet more than 50% of the energy consumption for a single-family home. The system performance was evaluated with typical profiles, in terms of volumes and draw-off duration, as defined in standards for testing DHW production devices (EN16147). The performance is dependent on the climate, the number of modules, and the tapping profile. High contributions of DHW energy coverage of 62-70% were found for Southern European climates, with lower contributions of 30-40% for Central and Northern European climates.

2 SOLAR SYSTEM DESCRIPTION

The module that was tested is a solar collector in which the absorber and the water storage tank are integrated within the same unit (see Figs. 1 & 2). The system consists of a tube-in-tube design in which one tube is assembled inside the other. The inner tube stores the hot water while the outer tube is provided with a special layer thanks to which the absorbed solar energy is efficiently converted into heat. The space between the tubes is under very low pressure, enabling the water to evaporate and condense in the inner tube, which is filled with tap water. When the outer tube is heated by the solar energy, the water evaporates. The evaporated water condenses and, in this way, transfers the heat from the outer tube to the inner one, where the hot water is stored. The system is installed on the ridge of the dwelling roof, as modules in series (Fig. 2). Depending of the number of modules connected, the storage can reach as much as 130L. Due to the tubular design of the modules, the system performance is almost independent of the orientation of the dwelling. Another advantage of this system is that an additional hot water storage volume in the dwelling is not needed.

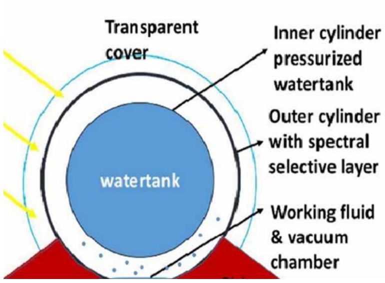

FIG. 1 Cross section schematic of solar collector module

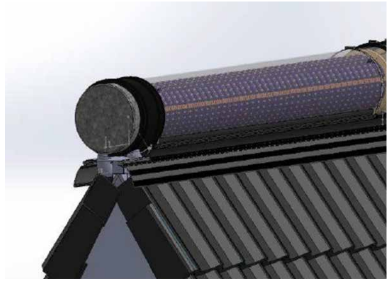

FIG. 2 CAD representation of the installation of solar collector module on a ridge rooftop

FIG. 3 Outdoor installation of the Sunridge module used during testing

The system has been developed within an InnoEnergy innovation project (Knowledge Innovation Community of European Institute of Technology), which supports the developments of products with a relative high TRL (technology readiness level), from about TRL=6. This product has been in development since the end of 2014 and will be introduced to the market in 2018 as a competitive product.

3 SET UP FOR SYSTEM TESTING

The first prototype of the system (so-called Econok system) and the final improved prototype (Sunridge module) were tested following procedures in the ISO 9459-5 standard (ISO 9459-9). Performance test methods for solar domestic hot water (SDHW) systems provide designers, manufacturers, installers, and users the necessary information to compare thermal performance among solar systems. The DST method is used to predict the long-term annual performance from a set of short-term measurements described in the ISO standard. In this study, two prototype versions of the module were tested at the Semi-virtual Energy Integration Laboratory (SEILAB) at the Catalonia Institute for Energy Research (IREC). This laboratory is equipped with facilities that are suitable for testing the dynamic performance of energy components and their optimal integration within the building environment.

A single module of the Econok and Sunridge prototypes with a length of 1.4m and internal water volume of 35L, were tested in Tarragona (North Eastern Spain), in March, 2016 and July, 2017, respectively. These months were chosen for the reason that, at the latitude at which the tests were performed, the requirement for total daily solar radiation levels is met from March to October. Among other improvements related to easier installation and integration, the Sunridge system differs from the first prototype version, Econok, in design characteristics that enhance solar absorption and reduce the overall heat losses.

The collector module (Fig. 3) was attached to a roof test bench that allowed the thermal characterisation of the system by means of the following elements:

- Flowmeter: used to characterise the flow rate through the collector (Cflow)
- 2 PT100 temperature sensors: placed at the inlet of the collector (Tin) and outlet of the collector (Tout), respectively. An additional PT100 sensor was placed on the cold water by-pass line.
- Meteorological information: outdoor temperature (Tamb) and global horizontal solar radiation were measured during the experiments.

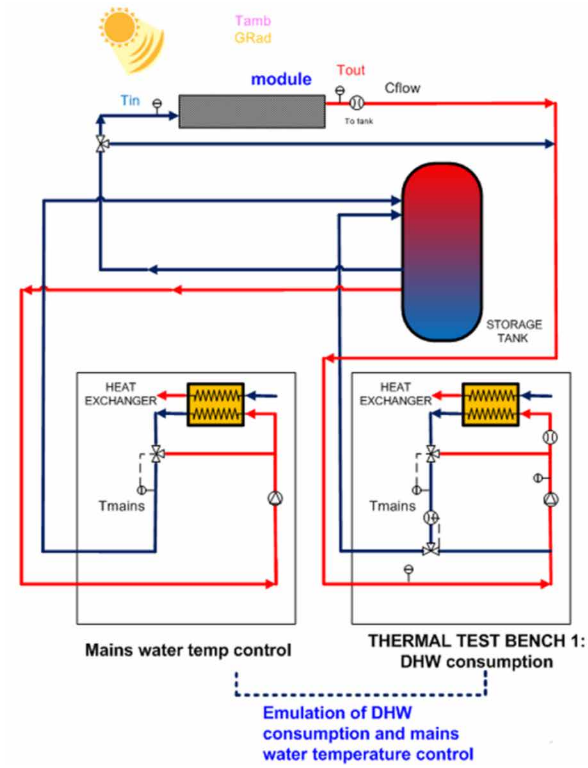

FIG. 4 Laboratory schematic for testing the solar collectors

The inlet and outlet pipes of the collector were connected to the laboratory hydraulic circuits as indicated in the schematic in Fig. 4. The outlet of the collector was connected to a laboratory thermal test bench that controls the flow rate during DHW extractions. A water tank of 1000L was kept at the desired mains water temperature conditions (10°C) by means of the continuous recirculation of cold water provided by an external cooling circuit. A by-pass system was connected to the collector so that the cold water could be diverted to the test bench when there was no need for hot water extraction from the collector. Cold water is circulated through the by-pass line before an extraction event to ensure that the inlet cold water was kept at the required set point temperature at the beginning of each water draw-off.

In the DST method, a mathematical SDHW model is used to predict energy performance from the available experimental data. The measuring data are obtained from a series of short outdoor tests on the SDHW system. The data obtained is used together with the SDHW mathematical model in order to identify model parameters, which characterise the behaviour of the SDHW system tested.

In order to predict the annual thermal performance for a selected climate condition and daily tapping profile, a SDHW computer model configured with the identified parameters was used. Three types of measurement sets comprise the DST testing method: the so-called S-sol tests (A and B sequences) and the S-Store test. The aim of tests A is to obtain information about collector performance at high efficiencies. The aim of tests B is to acquire information about the store heat losses and collector array performance at low efficiencies. The S-store test sequence is intended to identify the overall store losses. Test sequences had to comply with a set of conditions for the test days to be valid. The following table summarises the deviations of the variables to be controlled during the tests, which comply with requirements defined in the ISO standard.

Besides the above, the requirement of a minimum of 12 MJ/m^2 solar radiation per day for a test day was met for the experiments conducted.

MAINS WATER TEMPERATURE		WATER FLOW (2 LPM)		WATER FLOW (10 LPM)	
Standard	Tests	Standard	Tests	Standard	Tests
±3K	-1.5 K/+2.4 K	±0.5	±0.3	±1	±0.35

TABLE 1 Mean deviation of control variables during laboratory tests in comparison with the ISO standard requirements

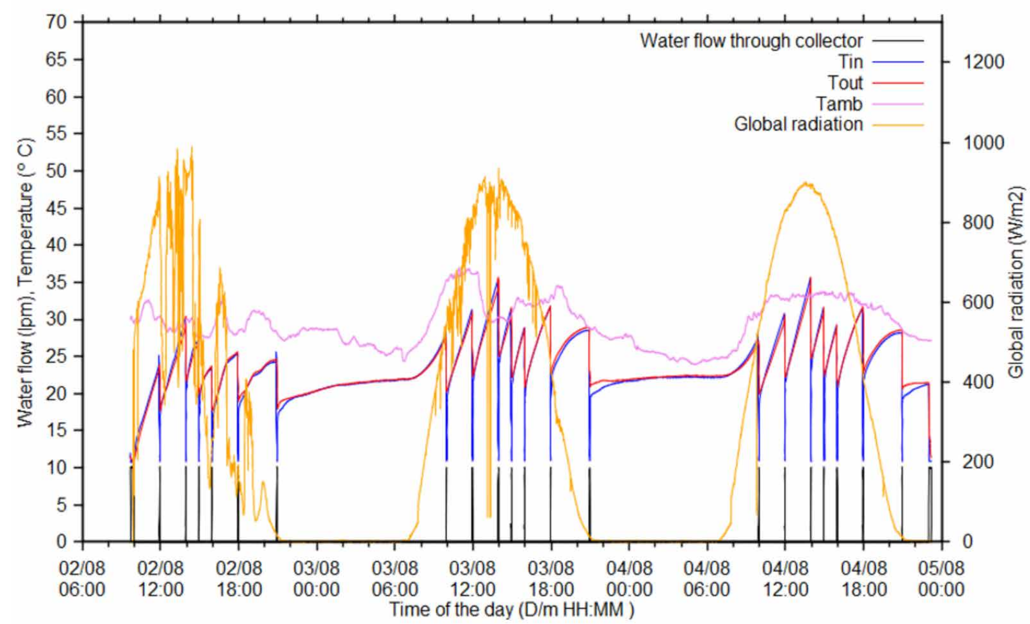

FIG. 5 Evolution of inlet temperature (Tin), outlet temperature (Tout), ambient temperature (Tamb), global radiation and volume flow rate through collector during the A test sequence.

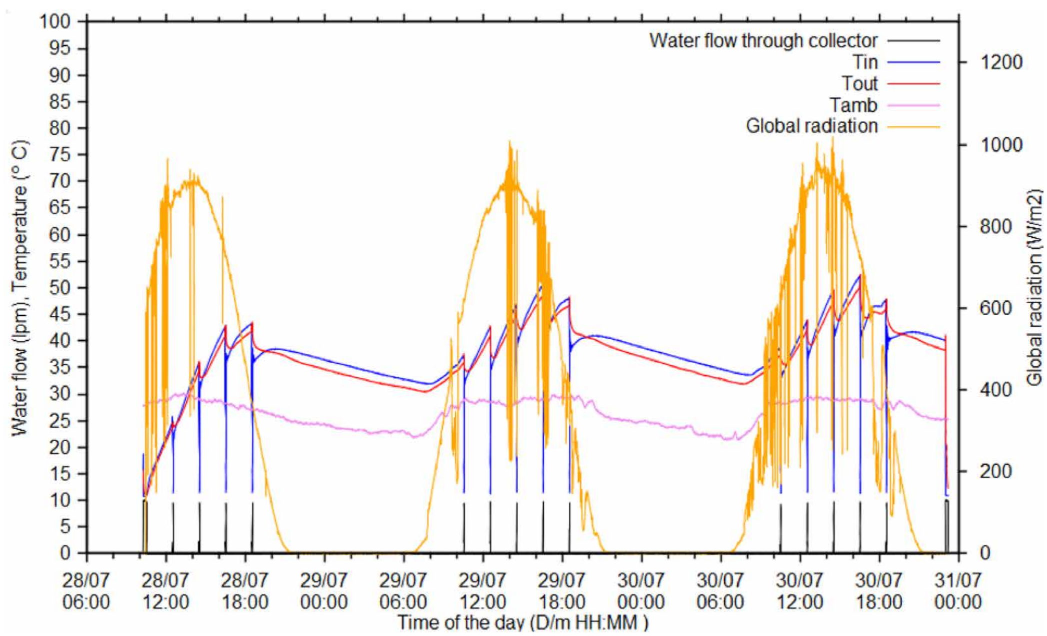

FIG. 6 Evolution of inlet temperature (Tin), outlet temperature (Tout), ambient temperature (Tamb), global radiation and volume flow rate through collector during the B test sequence.

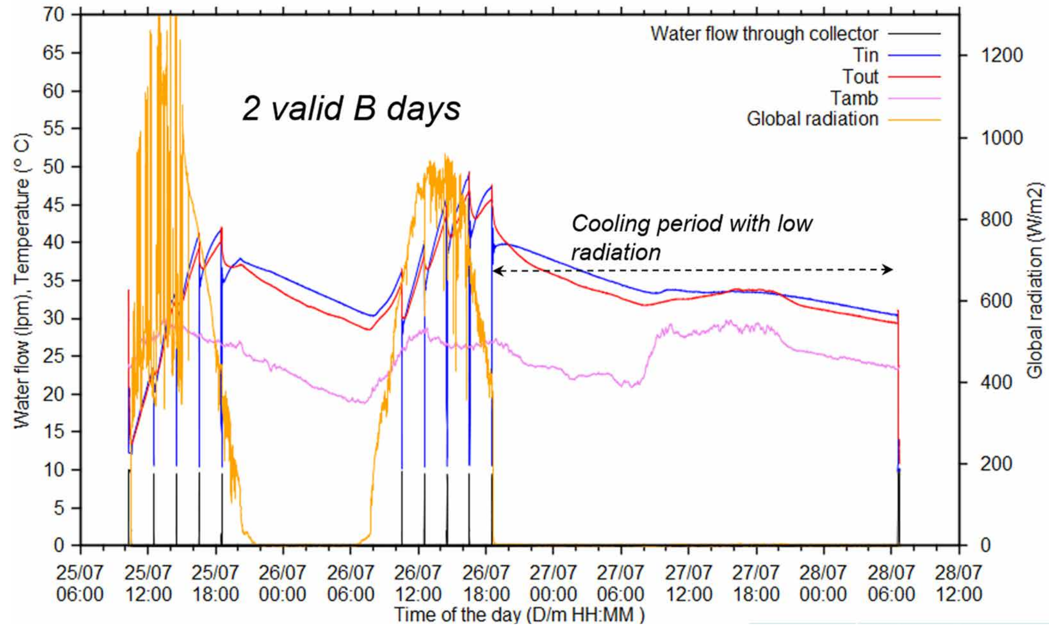

FIG. 7 Evolution of inlet temperature (Tin), outlet temperature (Tout), ambient temperature (Tamb), global radiation and volume flow rate through collector during the S-Store sequence.

4 RESULTS

Figs. 5 and 6 show the evolution of the inlet (Tin) and outlet (Tout) temperatures of the collector, the water flow rate (Cflow), the ambient temperature (Tamb), and the global solar radiation during three valid test A and test B days for the Sunridge prototype. During a water draw-off, a sharp drop in the inlet temperature was observed as a result of the activation of the by-pass and the circulation of cold water through the collector. On the other hand, at the start of each extraction, the outlet temperature increased slightly and then dropped as the cold water circulated through the tubing. Maximum temperatures achieved during water extractions for A type experiments were in the order of 35°C. The highest thermal power obtained correlated with the peak of solar radiation, with a maximum of 14kW. For the B sequence (three valid days), similar behaviour was seen, with higher temperatures achieved than for the A days (maximum of 50°C). Regarding the released heat, a maximum of 25kW at peak radiation conditions was obtained. The test sequence S-Store is illustrated in Fig. 7. This test consisted of two valid B days, after which the collector was covered to cool down for 36 hours. Similar to the B test days above, in the S-store test, the maximum temperatures were close to 50°C. The DST model parameters obtained from the testing were used as inputs for a simulation model that was built in the software TRNSYS in order to evaluate the performance of a set of collectors in different climates and under different tapping profiles. This allowed for estimations of yearly energy production for several modules for both prototypes to be provided. Calculations were done for cycles S (36L), M (100L), L (199L), XL (325L), and XXL (420L) for different European climates. The names S, M, etc. of the cycles represent tapping profiles as defined in testing standards for water heaters and heat pumps, depending on the total daily consumption of standard buildings (EN16147:2011). The climatic conditions used for the calculations were De Bilde, Athens, Stockholm, Wurzburg, and Barcelona, as shown in Fig. 8 (left). As expected, better performance is obtained for the southern latitude countries, where the solar radiation is higher throughout the year.

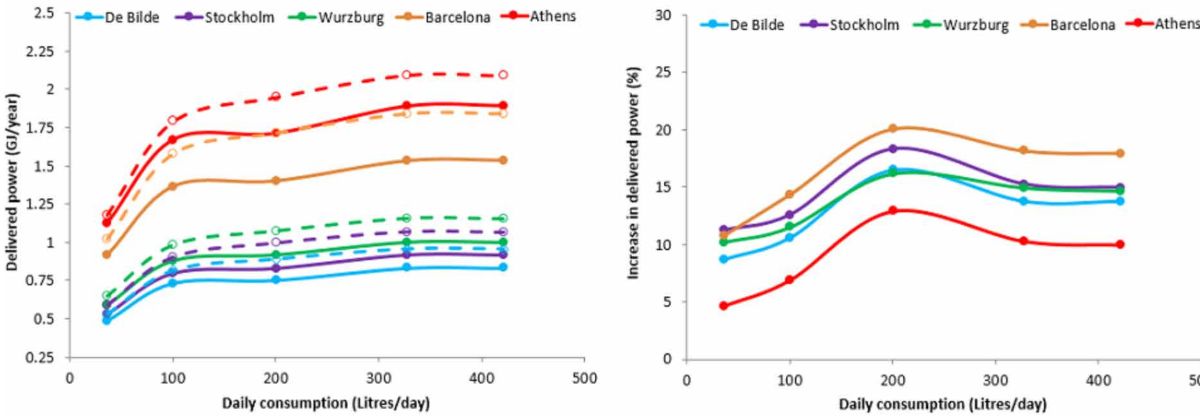

FIG. 8 Left: Annual delivered power for different daily consumption profiles for Econok and Sunridge modules. Right: Increase in the delivered power by the Sunridge prototype with respect to the Econok prototype. Increase in power (%) = (Power Sunridge-Power Econok) x100/((Power Sunridge-Power Econok)/2)

This last figure also illustrates the improvements achieved with the second prototype with respect to the first version, thanks to the lower energy losses achieved in the new prototype. The Sunridge prototype showed an increase in the energy delivered, from 5 – 22%, depending on the climatic conditions and water consumption profile. The design differences between the Econok and the Sunridge module are based on a change in the water circulation design inside the collector and the material of the absorber. In the Econok module, the inlets and outlets for water circulation are on the same side of the tube while in the Sunridge module the inlet and outlet are placed on the opposite edges of the tubing. In addition, the absorption material in the Sunridge module has a spectral selective coating material that was not used in the first prototype.

Table 2 summarises the predictions of the fraction of annual energy that would be covered by 3 solar collectors in series for a single-family home with DHW demand of 100L/day (cycle M), which corresponds to an annual energy demand of 7.62 GJ/year. A significant improvement is achieved with the second prototype in terms of energy coverage thanks to the reduction in the heat losses. For warm climates, the energy coverage can reach values up to 70%, while in higher latitudes the energy coverage can be as high as 39%. The table also includes values of collector performance calculated as the ratio between the annual DHW energy produced and the annual solar radiation in % (parameter Prototype name-Collect). This value of collector performance ranges from 21.7 to 29% for the Sunridge collector, with an improvement of up to 3% with respect to the first prototype version. The results of the study indicate that this novel system can provide significant energy savings, however, an auxiliary heater will still be necessary in order to meet the annual energy requirements and raise the water temperature to the levels required for avoiding legionella issues. No additional water storage will be required with several modules since 3 units provide a storage volume of nearly 100L. The system has successfully passed stagnation tests (with empty and filled storage), demonstrating that it meets the required standards to guarantee good performance under a variety of environmental and usage conditions.

PARAMETER	DE BILDE	STOCKHOLM	WURZBUG	BARCELONA	ATHENS
Econok-DHW	28.9	31.4	34.5	53.8	65.8
Sunridge-DHW	32.2	35.6	38.7	62.1	70.5
Econok-Collect	20.7	19.2	19.8	23.9	27.0
Sunridge-Collect	23.0	21.7	22.2	27.7	29.0

TABLE 2 Fraction of DHW annual energy coverage (%) (Prototype-DHW) and solar collector efficiency (%) (Prototype-Collect) provided by 3 collector modules for a single family home consumption profile (100 L/day, cycle M) at different European climate zones.

5 SUMMARY AND CONCLUSIONS

A new type of solar collector prototype has been tested for energy performance according to guidelines in the standard ISO 9459-5. Long term prediction performance has been compared for 2 prototype versions of the system for different climatic conditions using European standards tapping profiles. The evaluation of the performance of the second version of the prototype indicates an improvement in the thermal energy efficiency of 5-22%, depending on the climatic conditions and water consumption profile. The improved performance is a consequence of lower heat storage losses achieved with design modifications compared to the first prototype version. An annual coverage of the DHW energy demand of 62-70% was found for Southern Europe climates and between 30-40% for Central and Northern European climates. The compactness and the high performance of this system makes it highly competitive as a novel renewable energy technology when compared to other SDHW products on the market, since with a similar cost to current designs it provides good performance and easier integration than standard solar panels.

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