The development of the Sunridge, an orientation independent thermal solar system

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Abstract

For near zero energy dwellings an easy to integrate and install, efficient thermal solar system is essential. Moreover, the main disadvantage of thermal solar energy systems, i.e. the required south orientation on tilted roofs, needs to be tackled to increase the applicability of such systems. Furthermore, the competition on the roof with PV systems should be avoided. This will be tackled with the Sunridge solar energy system, a ridge integrated solar thermal system. The system characteristics are designed, tested and the blue print for the industrial manufacturing process has been made. The first prototypes are produced and are tested for performance, durability, fail safe overheating and freezing. The system will be ready for market implementation end 2018.

Keywords: ICS, solar thermal system, ridge integration, SDHW system, orientation independent.

1. Introduction

In order to realize Nearly Zero Energy Buildings not only renewable electricity has to be produced, but also the energy consumption needs to be reduced. Moreover, renewable heat needs to be generated and used effectively. The heat demand of existing and new buildings is about 1.5 to 3 times higher than the electricity demand. Thermal solar energy systems can reduce the demand for conventional fuels. On the roof there is competition between solar photo voltaic systems and solar thermal systems. Moreover, if the orientation of the roof is not favorable for solar energy, for instance east-west orientated houses, no economic possibilities for solar energy exists. Solar domestic hot water systems are smaller and can be placed as integrated system on the ridge of the roof. In this way, some of the called disadvantages will be solved.
For this application an easy to integrate and install, efficient thermal solar system is under development (fig 1). In Figures. 2 to 4 CAD views of the Sunridge system are presented.

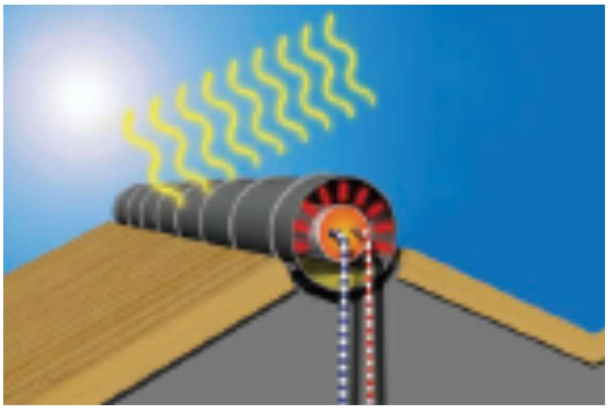

Fig. 1: Schematic presentation Sunridge

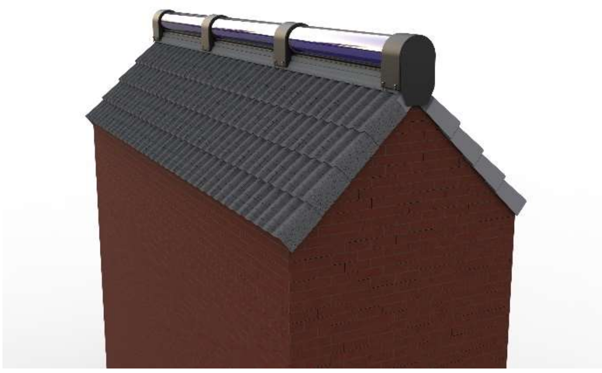

Fig. 2: CAD views of the Sunridge system on the roof.

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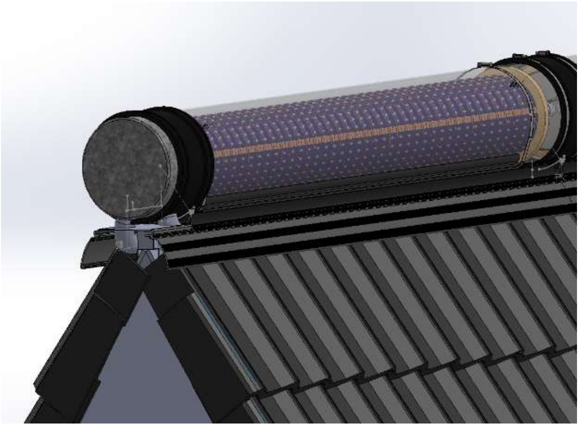

Fig. 3: Detail of the Sunridge system integrated in the ridge.

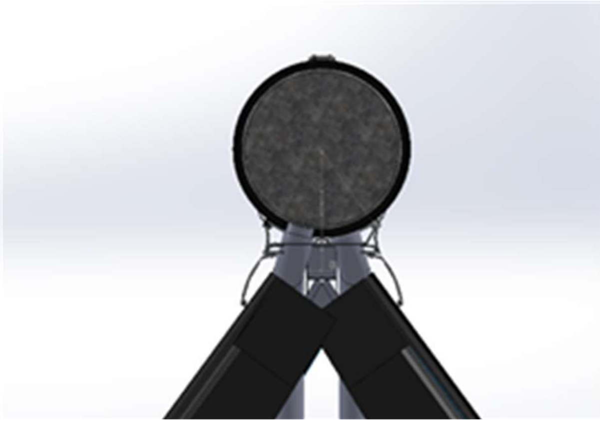

Fig. 4: View at the end of the roof.

This development of the Sunridge system, a ridge integrated solar domestic hot water system is further described in the paper. The Sunridge system offers the integration of a solar product at a place of the building (the ridge) which has a low attention factor (aesthetics), is not in competition with other energy systems at that place, integrates also the water tank (no extra space in the building needed) and is scalable to fit the ridge length. From street level the system is almost invisible. The developed concept is a tube in tube concept placed on the ridge of the roof. (Figure 3.). The Sunridge system will be very well suited for the new to build and the existing one family buildings. For this reason, the market potential is high. There are approximately 120 million existing dwellings across Europe which are suited for the Sunridge. The energy performance measurements show that more than 50% of the energy consumption needed for hot water can be produced by the Sunridge system. This performance will, of course, vary according to the climate.

2. Technology of the Sunridge system

The Sunridge product is an integrated solar domestic hot water system. The absorber for solar energy and the storage tank, for the hot water, have been merged into one unit (see Figure 5). The product consists of two tubes whereby one tube is assembled into the other. The inner tube is the container for (hot) tap water. The outer tube is provided with a spectral selective layer. Demineralized water is placed in the space under low pressure between the inner and outer tube in order to transport the solar heat form the outer tube to the inner tube. When the outer tube is heated by solar energy, the water evaporates. The evaporated water condenses at the inner tube and transfers in this way the heat from the outer tube to the inner tube. The inner tube containing the tap water is heated. The condensed water drips of the inner tube and the whole process of evaporation and condensing starts again. In case of absence of solar energy and during nights the heat transfer from the inner tube to the outer tube is only possible through radiation and some convection. The evaporation/condensing process is not possible then. In this way the heat losses are low.

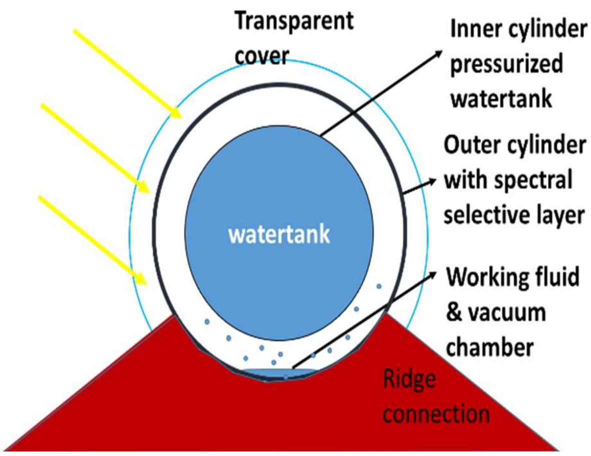

Fig. 5: Scheme of the Sunridge system.

The inner tube serves as storage tank for the hot water. In this way the solar heat is efficiently transported to the storage tank.

The Sunridge product is placed on the ridge of the dwelling and several modules can be connected in series in order to reach the required volume for storing the hot water. The modules have a length of 1,8 m and can store 35l of hot tap water. Up to 5 modules can be connected together, which gives 175l of hot tap water. For a typical Dutch single one family house three modules are connected and placed of the ridge of the roof. Due to the characteristic of the tubular Sunridge system and the placement of the system at the ridge of the roof, the system performance is almost independent of the orientation of the dwelling. Another advantage of the integrated system is the fact that in this concept an extra storage tank for hot water is not needed inside the dwelling, but is integrated at the roof. In this way a large market for SDHW systems now becomes available especially in refurbishment sector.

3. The Industrial Design

The previous version of the Sunridge system, the so-called Econok, was for a short time on the market around 2004. This working and set-up of the Econok was based on the same working principles, but experienced some draw-backs. The system did not have a spectral selective layer, was time consuming to install and the transparent outer tube was a polymeric material deteriorating quicker than foreseen. This resulted in a lower performance and higher installation costs than designed. At that point of time there was not market party interested in further product development.

With the help of InnoEnergy (Knowledge Innovation Community of European Institute of Technology) the redevelopment was supported through an innovation project. The Sunridge product is since end 2014 under development to realize a competitive product for the market by 2019.

Furthermore, the goal of the development in this InnoEnergy innovation project is to develop the pilot prototype production line, showing the manufacturing process at small scale, proving the realistic end price of the system and showing the high performance under realistic conditions.

The program of requirements for the redesign of the old Econok system looks as follows:

- Price / performance of the systems market conform;
- Esthetic, simple and scalable ridge integration for new and existing dwellings;
- Inherent safe product for overheating and freezing;
- The product has to withstand all the tests according to the standard and internal Monier standards for roofing product, such as wind, ventilation, hail, durability and safety.
- The product must be easy adaptable to different widths of the roof.
- Product should be easy to install by roofing companies
- Robust and quick connection for the modules.
- Installation process: only at one place of the roof connection through the roof for connection the water pipes to the auxiliary heater and the mains water supply.

Based on these requirements the industrial design of the Sunridge system was made, leading to the following important systems parts to be further developed and tested. These are:

- The transparent outer cover. The choice has been made to use glass tubes.
- Stainless steel as the material for the inner tank containing the drinking water.
- Copper as material for the outer tank
- Spectral selective layer applied on the outer copper tank.
- Water under low pressure between the outer and inner tank enabling the boiling condensation process for heat transfer from the outer to the inner tube.
- Supporting construction for quick installation between the ridge and the system, in the form of dedicated aluminum profiles.

In the following Figures 6 to 10 the results of the industrial design are showed.

Besides the solar and thermal performance, the durability, safety and ecological performance must be excellent. And of course, last but not least the price performance ratio must be competing with normal solar domestic hot water system.

The roofing company Monier is participant in this project and has the rights for the first market introduction. For this reason, the systems overall performance and the integration in the roof should fulfill all the requirement of the quality of products which are standard at Monier. For this reason, the durability and safety tests will be performed by Monier in their roof testing center in Heusenstamm, Germany.

Fig. 6: Spectral layer on copper tube

Fig. 7: Mock-up of the Sunridge

Fig. 8: Ridge profile, upper for the system, under profile to the beam of the ridge

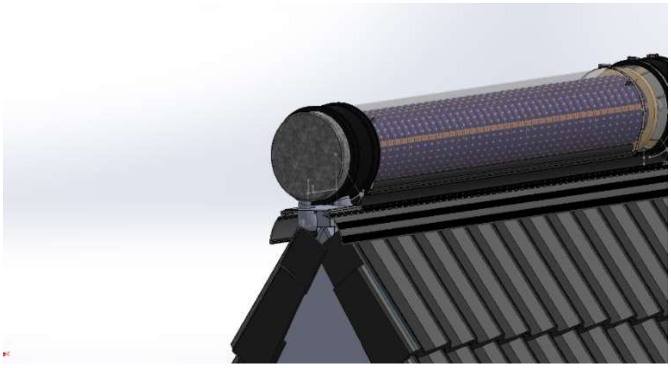

Fig. 9: End cap for the module

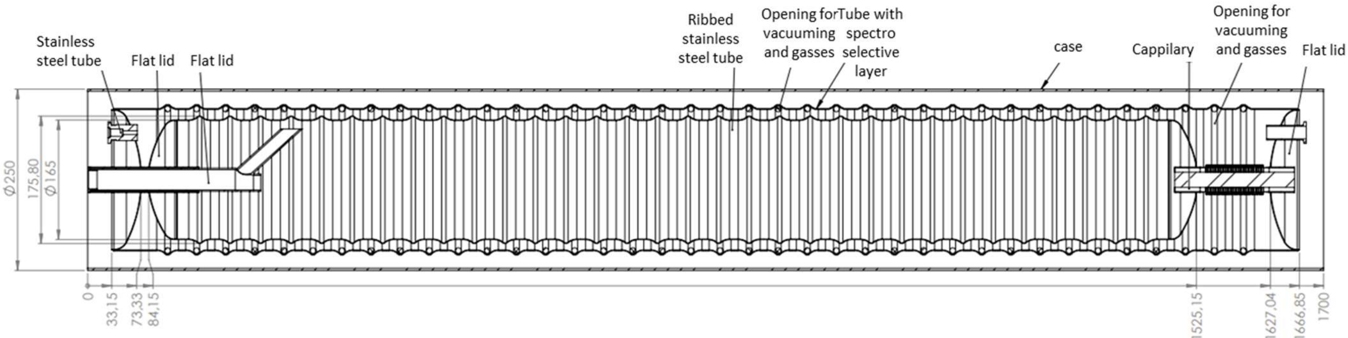

Fig. 10: Designed module with end caps.

4. First tests results with the Sunridge system

4.1 Performance test

In the spring of 2017 one module of the Sunridge system consisting of the spectral selective layer and glass transparent layer was delivered at IREC, for outdoor performance testing. In Figure 11 the system placed at the testing roof at IREC is shown. The system was tested according to the Dynamic System Test method (DST method). In Figure 12 the outcome of the new module is presented and compared to the old module (Econok). The results shown are for one module. For typical one family conditions about 3-4 modules will be used.

Fig. 11: The Sunridge system at test facility at IREC (Taragona Spain)

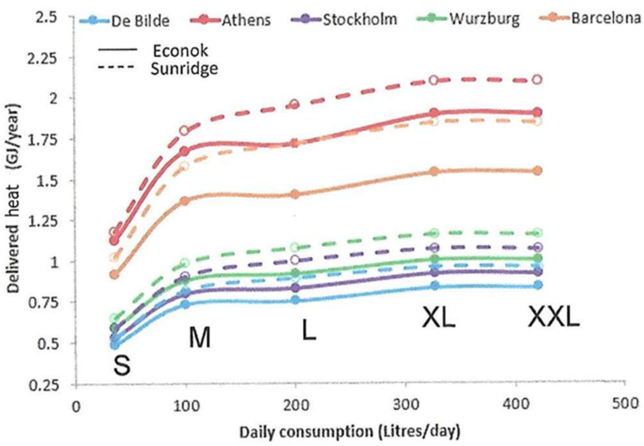

Fig. 12: Results from the DST test. Yearly energy output for one module for various climatic zones and different daily hot water consumptions. Comparison between the old Econok module and the new Sunridge module.

4.2 Overheating and freezing test

In the case of long period of absence (holiday) and high solar radiation the temperature in the tank of the Sunridge system can be very high, even higher than 100 °C. for this reason, a safety control will always be a part of the installed installation.

Since the complete system is place outside freezing during winter conditions can occur. For this reason, the Sunridge will be equipped with an electrical tracer. The typical vulnerable aspects in the design are in the inlet and outlet tap water piping and the connecting pipes between the modules (see Figure 13 and 14).

Fig. 13: Tracer on the connection pipe between the modules

Fig. 14: Electrical tracer to the inlet and outlet pipe of the module.

In a freezing cabinet at TNO the Sunridge system including the installed electrical tracers were tested according the requirements of EN 12976-2. The complete system has to withstand an outdoor temperature of -20°C during a period of 12 hours with a start temperature of the tap water of 5 °C. In Figure 15 the location of the temperature sensors is shown and in Figure 16 the test results.

The system was tested under -20°C for more than 30 hours. The temperatures of T203, T204 and T205 are around 0°C, but the more critical temperatures of the connecting pipes are above 15°C. The temperatures T deep and T shallow drop to a still safe level of slightly below 3°C.

The conclusion from the test was that the Sunridge system equipped with the electrical traces and the temperature sensor placed on the right position, fulfills the EN12975-2 requirements with respect to withstanding freezing. Moreover, the freezing tests have made clear that the highest energy losses are at the beginning and the end of the Sunridge module. This cold bridge can be avoided by changing the hydraulic connections.

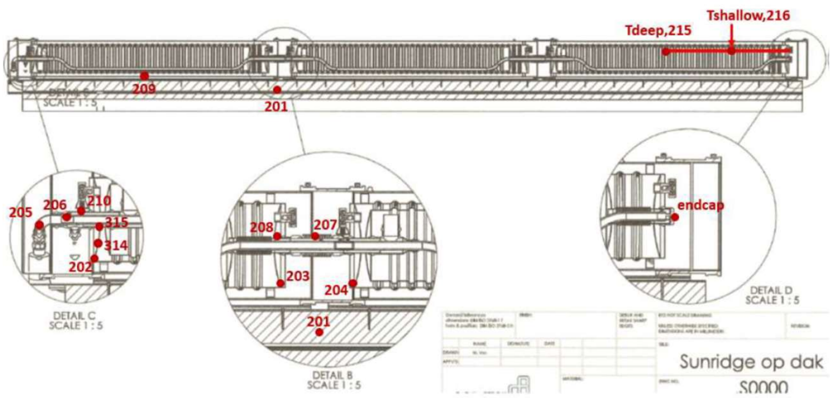

Fig. 15: The location of the temperature sensors in and around the Sunridge system.

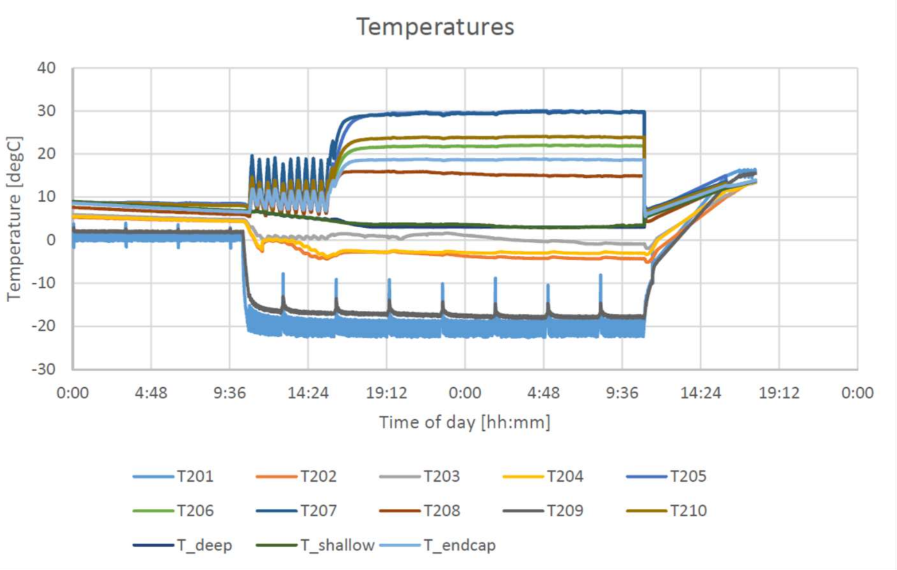

Fig. 16. Temperatures in the and around the Sunridge water tank during the freeze testing

4.3 Heat loss test

As part of the freezing tests carried out the heat loss coefficient of the module was measured and calculated with the detailed model. As follow up, a thermal loss test was performed by first heating the water in the module, and subsequently measuring the water temperature during free cooling down to ambient temperature. The normalized cooling curve is shown in Figure 17 (red line), together with a fit based on a theoretical cooling curve (blue line). The resulting loss coefficient equals 1,5 W/m^{2}K. During the DTS test the heat loss coefficient was determined as 1,37 W/m^{2}K. Based on the test results and calculations, it was concluded that the thermal loss coefficient is mainly determined by the connections to the modules, and not by the modules themselves

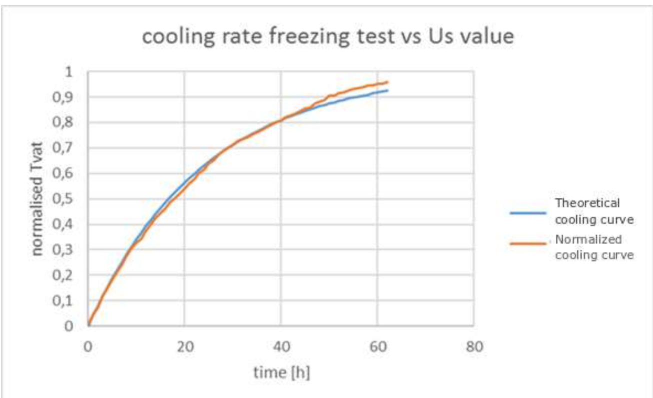

Fig. 17: Normalized cooling curve as measured (red) and calculated (blue).

From the results shown in Figure 17 it is concluded that the thermal loss coefficient is a system parameter, rather than a module parameter: the loss coefficient will depend on the number of modules in a system. Therefore, a calculation can be made of the loss coefficient as a function of the number of modules. The result is shown in Figure 18.

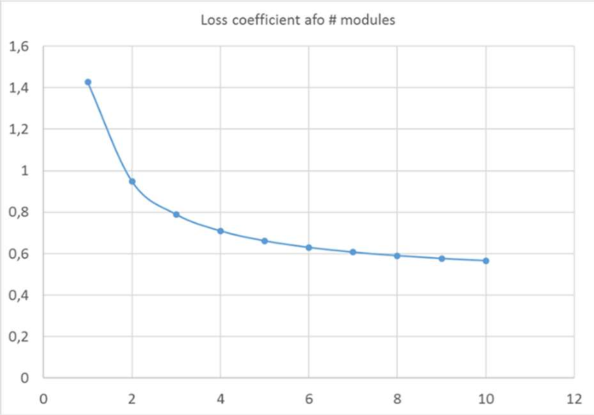

Figure 18 shows that the loss coefficient decreases with an increasing number of modules in a system, ranging from approx. 1,4 W/m2K for a single module to approx. 0,6 W/m2K for large systems. Improvement in the heat loss coefficient can be obtained by redesigning the inlet and outlet connection to the modules and a better insulation of the end of the first and last module.

Fig. 18:. Calculated loss coefficient as a function of the number of modules, based on the DST test result (one module) and additional data and calculations from the freezing test

4.4 Wind load design

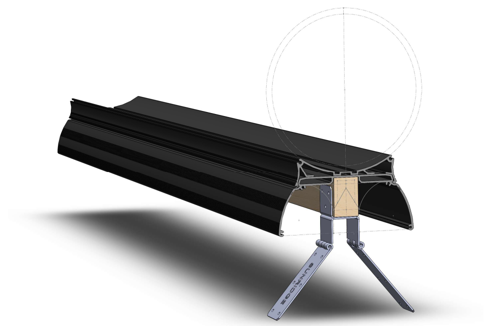

Fig.19:. The aluminum profile connected to the beam and the clamp for holding the wooden beam for connection to the roof plates.

The Sunridge system is mounted on an aluminum profile. This profile clicks into a profile that is connected to the ridge. The wooden beam for the ridge is connected to the roof plates by means of a number of clamps. Wind loads will come on the glass tube of the Sunridge system. These forces will generate momentum to the roof. The connection from the system to the roof plates have to withstand severe wind loads. For this the most severe conditions from the standards are taken. In this case that is the British Standard for wind loads on roofs. The glass tube is mounted on the aluminum support profile. The profile is screwed on the beam of the ridge. This is a new wooden beam mounted with ridge batten holders on the roof plates. A dedicated design has been made for the ridge batten because they form a constructive unit with profiles. In order to withstand the extreme wind load, the place and thickness of the screws was calculated. Moreover, this was also carried out for the clamps and ridge batten holder. Hereafter this was manually tested at the test roof set-up at Monier. A first quite simple tests showed that the steel support for the beam were not strong enough. Redesign for strengthening the steel support is needed

5. Redesign

Based on the outcome of the testing and the cost price analysis a number of improvements were taken into account. These are:

- Improvement of the heat loss coefficient of the modules
- Reducing the mixing during draw-off
- Cost reduction for the outer copper tube
- Redesign of the end caps and intermediate caps
- Redesign of the steel ridge support

5.1 Improving the heat loss of the Sunridge system

Based on the analysis of the heat loss of the Sunridge modules a redesign of the hydraulic connections of the modules was carried out. In Figure 20 and 21 the solution for this is presented. Based on the outdoor testing at IREC and the heat loss test at TNO, it was concluded that the heat losses were much lower than in the old version. Analysis showed room for improvement. The heat losses at the end caps could be further reduced. The improvement given in the redesign of the hydraulic connections reduces the cold bridge at the end /beginning of

a 3-module system. Furthermore, well insulating the end/beginning caps of the system will further reduces the heat losses. Moreover, this also applies for the interconnection between the modules
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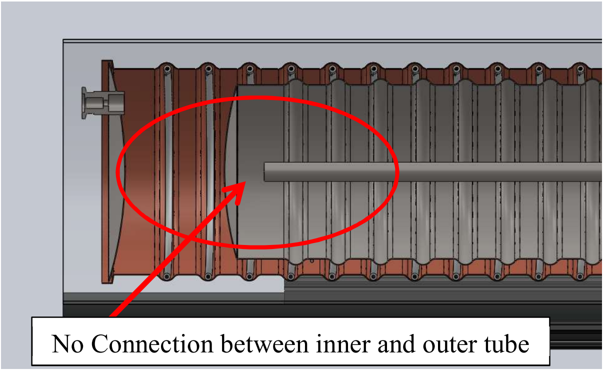

Fig. 20: Redesign absorber tube without cold bridge

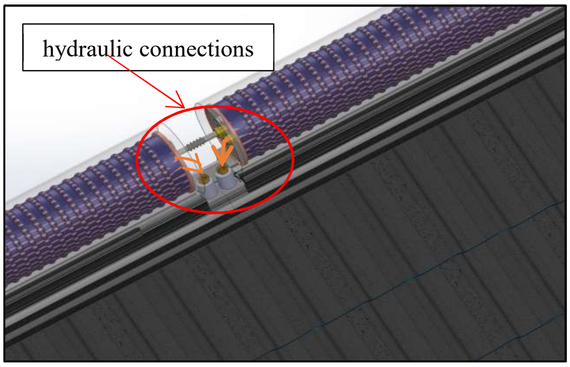

Fig. 21: Hydraulic connections through roof between modules

Fig. 22: Calculated effect of improvements in the insulation of the end caps and connections.

In Figure 22 it is shown, based on simulations, that the heat losses of the Sunridge system can be much lower and that the heat losses are dependent on the number of modules.

5.2 The draw-off mixing

Dynamic System Testing and modeling by IREC indicates an additional improvement in the energy performance of up to 12% in simulations, when the mixing during draw-off is similar to the previous system (Econok), depending on hot water consumption & climate conditions. Experiments have taken place on two types of modules of the Sunridge system, which are foreseen. To be more precise: a middle module and an end module. Various tests are carries out for a number of different flow-stratifiers for both modules. The flow patters are visualized by using a test circuit and inject ink into the pipeline. A transparent tube in combination with a camera allows to visually capture flow profiles over time. For this test a PMMA tube with flanges has been designed. By opening the flanges, the internal configuration can be changed and tested.
The solution which comes the closest to the theoretically ideal block-response will be industrialized to the final solution for Sunridge.The Sunridge system is designed for the so-called highest comfort class. Therefore, the experiments are carried out for a water draw off flow rate of 14 l/min (higher than the best comfort class of 12 l/min in The Netherlands).

Fig. 23: Transparent module with ink injection.

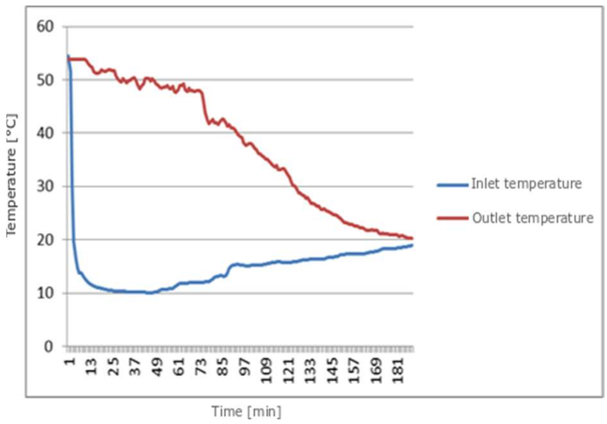

Fig.24: Inlet (blue) and outlet (red)t temperature of the module over time.

Based on the analysis of the measurements and visualization the best configuration is chosen and presented in the following Figures.

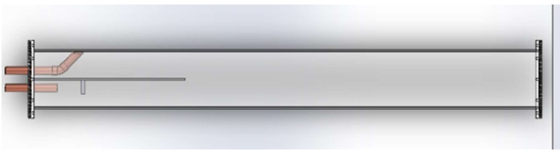

Fig. 25: Inlet-outlet solution end modules

Fig. 26: Flow solution middle module

Combination of the modules leads to the final system set-up as shown the Figure 27.
In this Figure the Sunridge configuration for 3 modules is given, two end-modules and a middle-module.
The solution of applying the two type of modules with different internal flow coupling leads to a situation which comes the closest to the theoretically ideal block-response for tapping of the hot water of the storage tank. In this way the mixing of cold and hot tap water during draw-off is strongly reduced. This solution will be industrialized for the final solution for Sunridge.

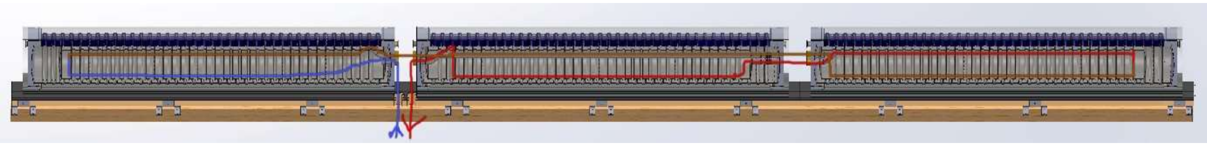

Fig. 27: The Sunridge system coupling of modules

5.3 Cost Reduction

The first prototype of the Sunrise modules consisted of a copper absorber tube, covered with a spectral selective layer on a thin (0,12 or 0,20 mm) copper carrier.
The use of a copper tube has two disadvantages:

- copper is expensive;
- Ensuring vacuum tightness of the copper/ stainless-steel welding at the end-caps of the tube is difficult and requires skilled workers.

For this reason, the use of a stainless- steel absorber tube was proposed by the consortium.
The use of stainless-steel has two advantages:

- A cost reduction in materials of EUR 40 per module, plus a reduction in labour cost;
- Easier to achieve vacuum-tight welding at the end-caps of the tube.

Fig. 28: Two Sunridge prototypes, as-received for testing

The thermal conductivity of stainless-steel however is lower than for copper, which might influence the thermal gain of the solar energy system. Therefore, the thermal performance of a module was investigated in the lab, where a comparison was made between a prototype with a copper absorber tube and a prototype with a stainless-steel absorber tube.
The investigation was performed at the HVAC- and Solar Energy lab of TNO in Delft, using an indoor solar simulator delivering close to 1000 W/m2 of power.
Both the prototype with the copper absorber tube and the prototype with the stainless-steel absorber tube were tested using the solar simulator. The tests were done simultaneously.
In Figure 28 the two different prototypes are shown, as-received int he lab. In Figure 29, the prototypes are shown, mounted in the solar simulator. Four Tests were carried out in to determine difference in the performance of the modules.
Type 1: Static heating test. In this test, both prototypes are filled with cold water. All valves are closed, and the solar simulation is switched on.
Type 2: Dynamic heating test. In this test, both prototypes are filled with cold water. The valves are adjusted, to apply a flow (e.g. 1 dm3/min) to the system. The flows are measured by Q1 and Q2. The temperature differences T4 - T1 and T5 - T1 are measured. The thermal power is calculated from the flow and the temperature difference.

Type 3: Static cooling test. This test usually follows a Type 1 test. All valves are closed, and the solar simulation is switched off.
Type 4: Stagnation test. This test closely resembles a Type 1 test. All valves are closed, and the solar simulation is switched on. The temperatures in the inner tube with the tap water is measured by T2 and T3.
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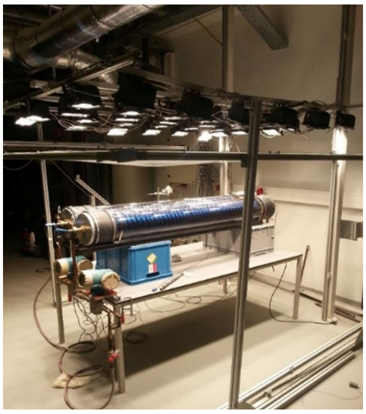

Fig. 29: Two Sunridge prototypes, mounted in the solar simulator

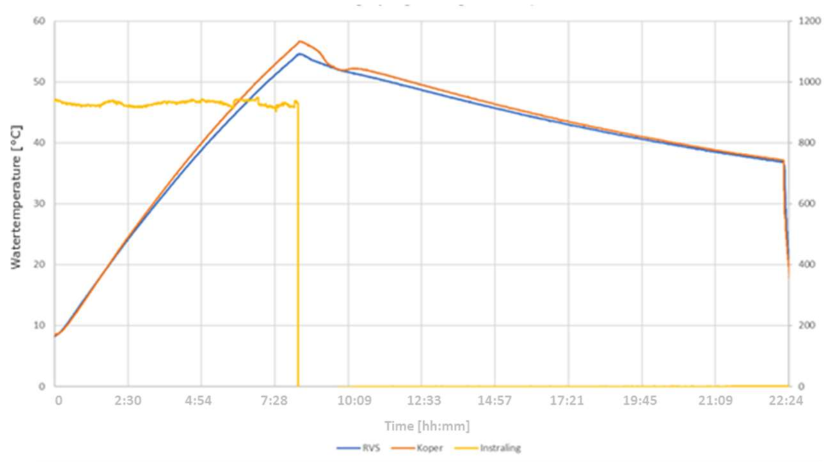

Fig. 30: Measurement results of the copper and stainless-steel tube

Tab. 1: Comparison of the prototypes using a dynamic measurement

	stainless-steel outer tube	copper outer tube
Supply temperature [°C]	9,8	9,8
Delivery temperature [°C]	13,5	15,0
Measured flow [dm3/min]	1,39	0,90
Measured irradiation [W/m2]	928	
Thermal power [W]	363	330
Difference	+9%	

The thermal performance (gains and losses) of both prototypes were measured.
In static measurements, differences of 5% or less were measured in the advantage of the stainless-steel outer tube. The measured difference is comparable with the overall accuracy of the measurement, which is determined as 4%. In a dynamic measurement, the thermal gain of the prototype with the stainless-steel outer tube was 9% higher. This result seems to be significant.
In a stagnation test, the stagnation temperature of the prototype with the stainless-steel absorber tube was 103 °C, while the stagnation temperature of the prototype with the copper absorber tube was 106 °C. This difference is within the accuracy of the measurement.
In view of the different test results, the thermal performance of the prototype with the stainless-steel absorber tube was not significantly lower than the thermal performance of the prototype with the copper absorber tube. Since the stainless-steel absorber tube is significantly cheaper as compared to the copper absorber tube, it is concluded that using a stainless-steel absorber tube will result in a better business case: lower production costs at the same energy (cost) savings.
The prototype with the stainless-steel absorber tube will therefore be produced for the field test

6. Conclusions

In this paper the development of the ridge integrated solar water heating system, Sunridge is described. The Sunridge system consist of a number of modules coupled and placed on the ridge of the roof. With this flexible design for the system, the solar energy contribution to the hot tap water can be tuned to the demand, the climate and the dwelling. The first development started during 2015-2016. Test results and production analysis showed a competitive performance. Based on the test a number of improvements are carried out. The inlet and outlet configuration for the tap water was changed from the beginning and end of the Sunridge system to the middle of the system. This change reduces the heat losses considerably. Moreover, the installation costs will be

reduced by this measure. Next the mixing of the tap water during draw-off is prevented by designing a so-called stratifier in the modules.
An important step in the design is the replacement of the expensive copper tube by a tube of stainless-steel. Experiments showed little difference between the materials. The big advantage of using the stainless-steel tube is first a reduction in the material cost and secondly a reduction in the manufacturing cost. Welding copper with stainless steel is more complicated than only stainless steel.
The energy performance of the ridge integrated system can be about 50% of the energy demand for hot tap water and most important this is orientation independent. Moreover, the ridge integration enables the roof of the dwelling being used for other purposes, such as photo voltaic panels and/or roof windows.
The Sunridge system is a preheater for hot tap water with the tap water storage tank placed outside the dwelling, on the roof. The design of the system enables an inherent safe product, easy to install and to connect to the hot water system in the dwelling.
The industrial production process is designed in order to produce the system at high quality in a professional way. The overall cost price including installation is expected to be competitive with the standard solar thermal domestic hot water systems. In 2019 the Sunridge product will be introduced in the market in The Netherlands.

7. Acknowledgements

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- Monier roof and tiles manufacturer,
- TNO research Institute in The Netherlands,
- IREC Renewable Energy laboratories,
- RTB de Beijer bv innovative SME company
- ArtEnergy bv SME company

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