# SUstainable solutions for affordable REtroFIT of domestic buildings

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| **Other authors** | **University of Nottingham (UNOTT)** |

# WP4 - Deliverable D 4.7

# Solar thermal/PV unit

### Dissemination Level

| | | |
|---|---|---|
| **PU** | Public | **X** |
| **CO** | **Confidential, only for members of the consortium (including the Commission Services)** | |
| **CI** | Classified, as referred to in Commission Decision 2001/844/EC | |

### Document History

| Version | Date | Authors | Description |
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| 1 | 28/01/2022 | UNOTT | Draft for reviewers |
| 2 | 02/02/2022 | ISQ | Coordinator Review |
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| 4 | 19/04/2022 | UNOTT and ISQ | Final version |



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# Abbreviations

*Aeff* Effective area, $m^2$
*C* Specific heat
*Di* inner diameter of heat exchanger tube, m
*Do* outer diameter of heat exchanger tube, m
*e* percent deviation
*F* Fin efficiency
*F’* Flat plate collector efficiency factor
*g* gravitational acceleration, $m/s^2$
*h* heat transfer coefficient, $W/m^2K$
*I* incident solar radiation, $W/m^2$
*K* Thermal conductivity, W/mK
*L* cubic root of dwelling volume, $m^3$
*m* variable defined to solve differential equations
*M* Mass, kg
ے Mass flow rate, m/s
*Q* Energy, W
*T* Temperature, °C
*U* Thermal transfer coefficient, $W/m^2K$
*W* Distance between tubes, m
*V* Wind speed, m/s

*Greek Letters*
Į absorption
ùp temperature coefficient for PV efficiency, °C-
ùs tilt-angle of PV panels, °
į thickness, m
ڗ emissivity
Ș efficiency, %
ى Stefan-Boltzmann constant, $W/m^2K^4$
ڱ transmittance
v kinematic viscosity, $m^2/s$
ȡ density, kg/m³
ħ packing factor

3 thermal conductivity, W/mK

*Subscripts*
*a* air
*abs* absorber layer (PV cell)
*c* cover layer
*cv*convective
*db* dry bulb
*dp* dew point
*e* electrical
*f* fluid
*hein* inner wall of heat exchanger
*heo* outer wall of heat exchanger
*heo, hein* outer wall to inner wall of heat exchanger
*hein, w* inner wall of heat exchanger to water
*in* inlet
*l* loss
*o* overall
*p* pipe
*pl* EVA plastic back of a PV module
*pv, heo* PV cell layer to outer wall of heat
*rd* radiative
*rs* reference situation
*s* sky
*sa* supply air
*t* thermal
*tl, heo* tile to outer wall of heat exchanger
*v* vapour
*w* water
*wb* wet bulb

# Publishable summary

This document reports the work developed regarding the use and test of Solar Thermal PV unit as the heat source to supply the regeneration heat. A hybrid PVT collector, which is a combined collector from a PV module for the generation of electrical energy with a highly efficient solar flat collector for the production of heat energy, is detailed in this report. Importantly, the different components are thoroughly explained, as well as recommendations and solutions to potential problems are pointed out. Finally, the report documents the construction of the prototype for the SUREFIT project.

This research will be published in the future with integration of liquid desiccant cooling technologies, and solar assisted heat pump, with paper title of "A polymer hollow fibre liquid desiccant unit: Experimental, numerical, and building performance analysis."

# Introduction

**Leading Beneficiary: SOLIMPEKS**

**Participants: University of Nottingham (UNOTT)**

**Task description:**

The work package involves fabricating and testing the key components and assembling the components into complete prototypes of technologies. The technologies will be tested in the lab to assess their performance under the nominal set conditions. The testing results will be used to modify and improve the design of the final prototypes, if necessary, which will be used in WP6 (field tests). The availability of this prototype system for field trials will be milestone 3. UNOTT is the work package leader.

Task 4.2: Produce solutions for energy efficient facilities (UNOTT, M7-M17)

- SOLIMPEKS will construct PV vacuum glazing as a type of high performance window for electricity generation, light transmission and thermal insulation. PV Vacuum glazing windows will have a U-value below 1 W/m2K for renovation. In addition to creating a simple vacuum within the casing as in conventional practice, different low-cost manufacturing methods and different types of supporting pillars will be investigated such as aerogel. SOLIMPEKS will also produce novel solar thermal and PV systems for integration into buildings. Advanced evacuated tube solar collectors will be investigated where the absorber is treated with a selective Tinox coating to maximise the solar energy absorbed and minimise heat loss through radiation. Novel (poly exchanger for) solar collectors which could form a component of roofing and facade structure will also be produced by this partner together with UNOTT for heating hot water and as a heat source for heat recovery or solar powered cooling. In addition, research will be carried out to combine solar collectors with a heat pump as a renovation solution to existing buildings and to integrate high performance thin-film PV glued straight onto the roof and monocrystalline PV modules into building envelope.

This deliverable concerns the developments in experimental work related with the Solar thermal PV Unit.

# 1 Summary

The amount of useful energy that can be obtained by a collector depends on several factors. The most important of these factors is the solar energy available. In addition, the types, slopes and directions of the collectors also play an important role. In order to operate the solar system economically, the elements of the system must be carefully dimensioned. Sol-Titan coating copper absorber forms the basis of Solimpeks collectors. This absorber provides a high level of absorption of the sun's rays and thermal radiation emission is low. The heat carrier fluid flows through the copper tube attached to the absorber sheet by laser welding. The heat of the absorber is transmitted through the copper tube to the heat carrier fluid. Absorber is covered with a highly heat insulated collector body. The heat losses of the collector are reduced to a minimum. High quality heat insulation is resistant to heat. Heat insulation is gas-free. Heat insulation consists of glass wool / rock wool. the collector is covered with a special solar-glass. Reflection losses are very low due to the low iron content of the glass used in Solimpeks collectors. The glass collector body is surrounded by EPDM glass edge wick inside and is also fixed on the wick with aluminum lath on the frame. With the system we call flexsibile, the collectors have the opportunity to be easily installed in the solar circuit. A collector temperature sensor can be mounted on the flow of the solar circuit via a set of sensor covers. There are ventilation holes on the collectors. These ventilation holes are opened to prevent condensation inside the collector. Thanks to the existing air holes, it is aimed to discharge the steam and water that may arise from condensation in the collector.

Water based PV/T modules, as shown in Fig. 4, possess absorbers in conjunction with quantity of PV cells that are parallel, or series connected and attached to serpentine or series of parallel tubes underneath in which water is forced to flow through. If the water temperature is kept lower, PV cells will be cooled off which leads to enhanced electrical conversion efficiencies while the water temperature will rise as a result of absorbing heat from the PV cell layer. This heated water can be exploited for various applications including heating, cooling or food drying etc. In comparison to air-based PV/T, systems, the water based systems are able to achieve enhanced efficiencies due to higher thermal mass of water, therefore, both thermal and electrical efficiencies will be improved [1]. Anderson et al. [2] theoretically analysed the design of a building integrated photovoltaic thermal water system (BiPVT/w) in Australia. The proposed system was integrated to the standing seam or toughed sheet roof where passageways formed into trough for thermal cooling flow. The steady-state outdoor thermal testing proved the validity of modified Hottel-Whillier model. The results revealed that prime design factors such as fin efficiency, lamination, thermal conductivity and efficiency had notable impacts on the electrical and thermal efficiencies. It was recommended that the replacement of absorption material like copper or aluminium with a cost effective one such as pre-coated steel as the efficiencies were sufficiently maintained. Moreover, the proposed system was suggested to be integrated 'into' (rather than onto) the roof structure, as the rear air space in the attic could make a good insulation as well as any high insulation material.

A PVT collector is a combined collector from a PV module for the generation of electrical energy with a highly efficient solar flat collector for the production of heat energy. Photovoltaic elements

(PV) are semiconductors and have a disadvantage – the decrease in power with trigender temperature. If you want to get the most out of your PV system on a sunny summer day, the performance decreases significantly due to the rising temperature of the silicon cells. By cooling the cells by means of a solar absorber below the solar cells, a balance between PV efficiency and heat output can be established. Using this principle, it is possible to achieve a higher electrical yield together with enough free heat to meet the annual heat requirement of a low-energy house. Excell Hybrid PVT is a revolutionary technology that maximizes the energy yield of a PV system constituting a finely balanced solution that optimizes efficiency while saving space and money. With an effective PV power/operating temperature. All photovoltaic elements are available under standard test conditions with a radiation output of 1000 W/m2 and a temperature of 24 °C. PV power and temperature are inextricably linked. For every 1 K temperature increase, the electrical power decreases by 0.5%. At direct sunlight can reach the temperature of a standard PV module at 110 °C, resulting in a 43% reduction in efficiency caused by heat alone. Finally, the annual yield and thus also valuable energy decreases.

## 2 System structure

The Solimpeks EXCELL PVT collector is designed to maximize the panel's current yield, making it a better PV collector capable of delivering a reasonable amount of heat in summer, as shown in Figure 1. The maximum power of this collector is 315 watts of electricity and 855 watts thermal. When installed correctly, the collector generates around 30% more electricity than conventional photovoltaics and contributes to meeting the heat requirements of a building. This is the ideal solution for customers who want to take advantage of a maximum energy yield outside the smallest area. Each house with at least 16m$^2$ of available south-facing roof space can use the Excell panel to generate the annual equivalent of 20.8 m$^2$ of conventional monocrystalline photovoltaics. The same area of Excell collectors provides the same amount of heat as 4.2m2 of conventional solar heat collectors, i.e. 25m$^2$ of roof space on separate systems would be required to generate the same thermal and electrical energy. In addition, the Excell collector has numerous commercial applications and can achieve impressive power performance when cooling is active.

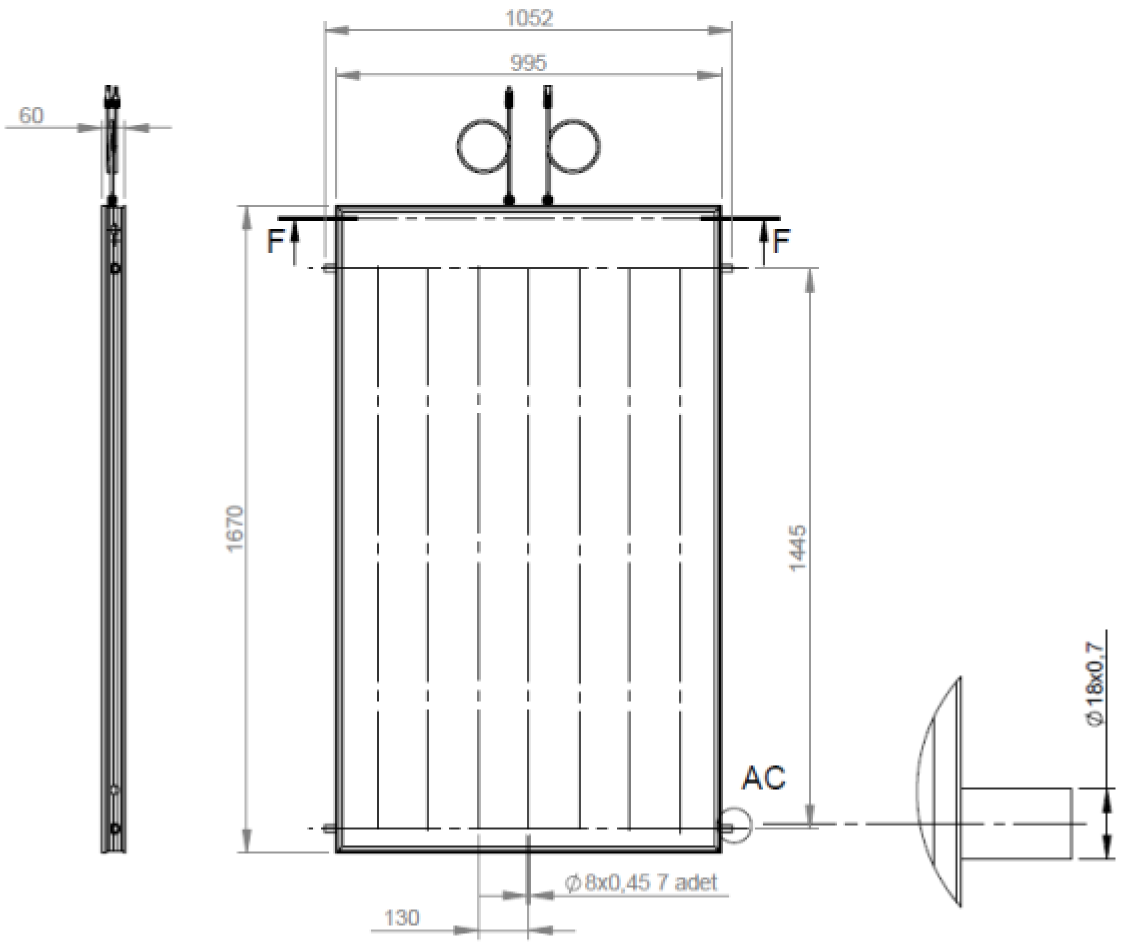


Figure 1 System structure

Due to the intricacies of hybrid PVT, correct system planning, assembly and setup for operation are essential for the efficient operation of the plant and thus ultimately customer satisfaction. Temperature is, of course, a key – a means of limiting the maximum temperature or a plan to use lower heat levels must be considered as a matter of urgency before installing Volther Hybrid PVT. Ideal for maximum yield and best benefit, it is recommended to keep the maximum panel temperatures below 55 °C.

The proposed roof system consists of polyethylene heat exchanger loop underneath PV modules to form a PV/Thermal roof collector. The complete roof structure has several layers, an outer cover; a layer of photovoltaic cells beneath the cover; EVA plastic layer at the back of PV adjacent to the PV cells layer, polyethylene heat exchanger and roof support. Fig. 2 illustrates the build-up for the polyethylene heat exchanger system. As the heat exchanger is loosely contacted with the corrugated roof, any radiative exchange would be miniscule and thus disregarded.

Figure 2 Integration of the poly heat loop underneath PV modules

The PV solar collectors absorb a greater proportion of incoming solar radiation on the PV cell surface, while dissipating remainder to ambient as waste heat. From top to bottom, a transparent and thermally resistant outer cover enables to reduce dissipation and secures that maximum solar radiation reaches the photovoltaic cells. Meanwhile, the temperature of the cell layer needs to be lowered so as to facilitate the solar power conversion efficiency of PV panels. Heat flows from ambient to the photovoltaic cells in case of lower temperature of cell surface. Thus, adjusting circulating water temperature at a lower range helps to reduce the cell surface temperature to some extent. Although first-of-its-kind polyethylene heat exchanger, due to its physical structure, is loosely adhered to the rear surface because of the aluminium frame of the PV modules, less flexible pipes and risers, relatively low temperature difference between the cell surface and circulating water is expected. Furthermore, the physical structure of the poly heat exchanger prevents the use of thermally conductive adhesives due to uneven contact to the rear of PV modules. Consequently, any decrease in the cell temperature will collaterally enhance both power and thermal efficiencies.

## 3 Results and discussion

The test of the PV/T system is conducted in Marmont Laboratory, University of Nottingham. The wind speed was observed over the course of test to detect the heat flow rate through natural convection between the PV panels and ambient air, and was measured as 1.2 m/s in average. Also, average solar radiation data during the day and outside air temperature were found to be 761.5 W/m²and 37.2 °C, respectively. During the series of test sessions, no working fluid leakage was observed both in the roof and cooling units.

Fig. 3a presents the hourly variations of effective PV module temperature (TPV)eff, and water temperature Tw with the ambient temperature, Ta and incident solar radiation, I. It is shown that the PV module temperature throughout the operation remains higher than the water temperature as expected. The increase in water temperature circulating through the heat exchanger reaches up to 16°C throughout the testing. Fig. 3b illustrates the degree of polyethylene heat exchanger influence over the electric power conversion efficiency of the PV modules, Șpv. For with Polyethylene HE case, the increase of cell efficiency as a result of passive cooling off via water circulation would lead to an increase on power conversion efficiency, Șpv. On the other hand, higher cell temperature would cause a substantial decrease on the cell efficiency, Șpv. Nevertheless, it was found that for both cases examined in this study, the cell efficiency, Șpv is always better off with Poly HE case than without Poly HE case. This implies that from the viewpoint of the first law of thermodynamics, the “with Poly HE” case would be a better choice for PV systems to enhance the overall energy output of PV panels. Fig. 3c shows the variation of useful heat through circulating water with a mass flow rate of 0.0493 kg/s. The useful heat generated by the polyethylene heat exchanger roof unit ranges between 2.23 kW and 4.33 kW for the given test period.

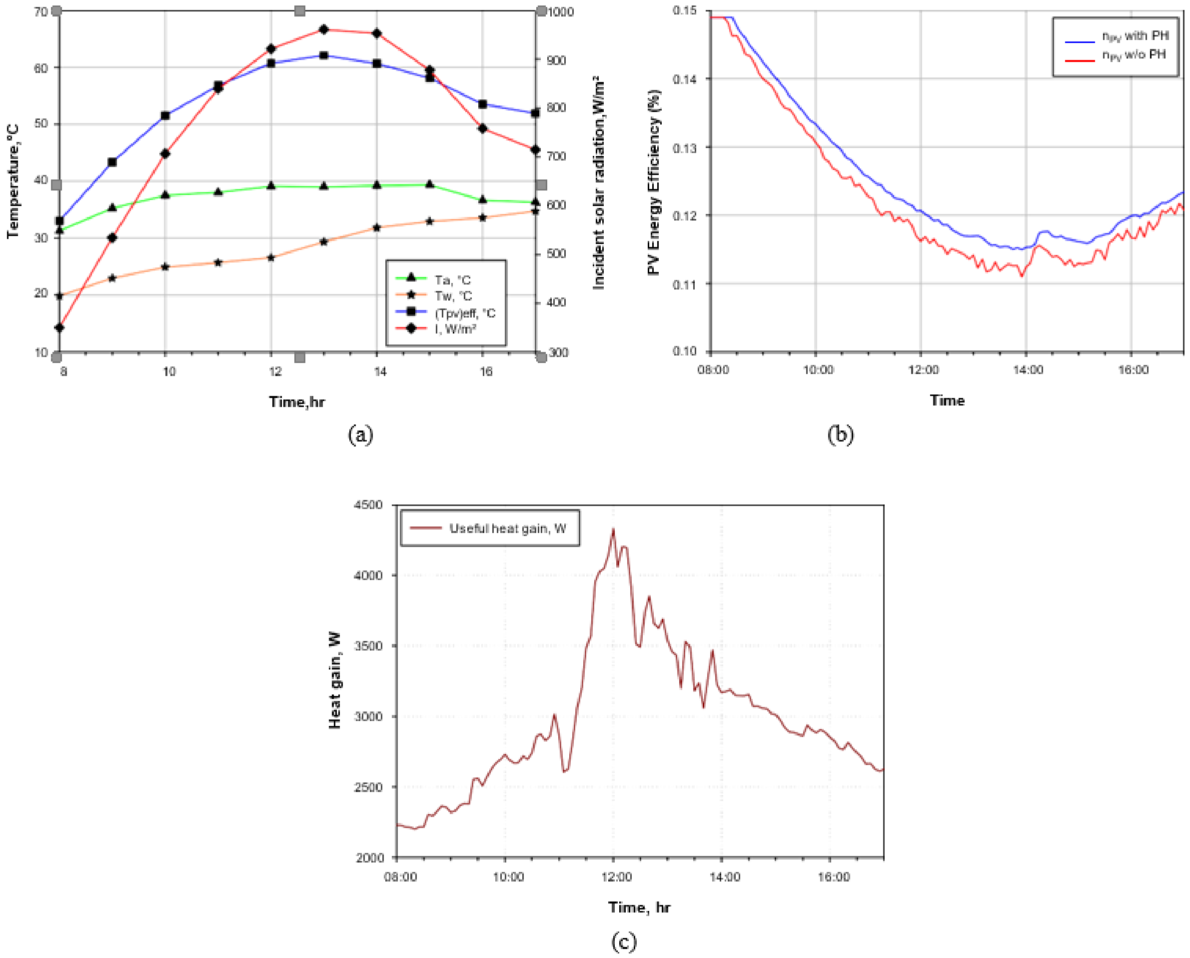


Figure 3 a) Hourly variation of PV, ambient, water temperatures and incident solar radiation b) effect of poly HE on power conversion efficiency c) Useful heat gain

# 4 Product

All photovoltaic elements are available under standard test conditions with a radiation output of 1000 W/m2 and a temperature of 24 °C. PV power and temperature are inextricably linked. For every 1 K temperature increase, the electrical power decreases by 0.5%. At direct sunlight can reach the temperature of a standard PV module at 110 °C, resulting in a 43% reduction in efficiency caused by heat alone. Finally, the annual yield and thus also valuable energy decreases. The active cooling shifts the real temperature closer to the one measured in the laboratory. Values. As a result, the annual performance of the module also increases. An Excell Hybrid PVT Panel, stabilized at an average of 45°C, yields about 20% more yield over a 12-month period than a comparable PV module with equal power.

The collector case is produced from aluminium by Solimpeks solar energy systems. The aluminium used as raw material is 6603-60 (AlMgSi05) (AA-USA). The collector case is produced with a frame which is a user friendly both in terms of mounting and dismounting the system of Volther Hybrid Collectors. Wall thicknesses both for the case and frame are all according to DIN EN 12975 -1 and 2. Collector case is made of aluminium which is electrostatic painted with Ral 9005 matt black powder paint and then oven baked. The use of this technique ensures the system is highly protected against all natural conditions. Also taken into consideration is the possible thermal expansions that could occur on the glass, hence the glass is set up with an optional space during casing and the collectors are produced to be able to work properly in all regions of the world.

TECHNICAL FEATURES

Specific Gravity: 2,70 gr/cm$^3$

Gravitation Endurance: 15,5 (at24C$^0$ )

Flow endurance: 12 (Kg/mm$^2$ )

Hardness: 60-65 Brinell (HB) Kg/mm$^2$ )

Expansion Coefficient: 23*10(200-100C0 )/C$^0$

Hybrid collectors are produced in two different styles. These are in the form of a system that is used directly with Pv glass and which is produced with extra protection afterwards. Glasses used as extra protection are produced in 4 mm thickness and within ± 0.2 mm tolerance range. The glass has a density of 2.5 gr / cm2. While the direct permeability rate of normal iron oxide glass is 82.5%, the permeability rate of low iron oxide glass is 91%. Iron oxide ratio was kept low in order to increase the solar permeability of the glass. Prismatic patterned glass is the glass pattern that breaks the inclined rays of the sun in the morning and evening and drops it perpendicularly to the absorber surface, thus increasing the efficiency. Another feature desired from glass is high strength. Tempering is carried out on glasses in order to provide strength in order not to break glass during shipment or assembly and outside conditions. Tempered glass (low iron) has started to be used in many collectors because of its mechanical strength, safety and higher collector efficiency. It has higher solar permeability than normal glass, rarely breaks and when broken, it is broken into very small, harmless pieces, such as automobile windows.

In this SureFit project, an Excell hybrid PV/T is designed and developed as shown in Figure 4, with technical specification shown in Table 1.

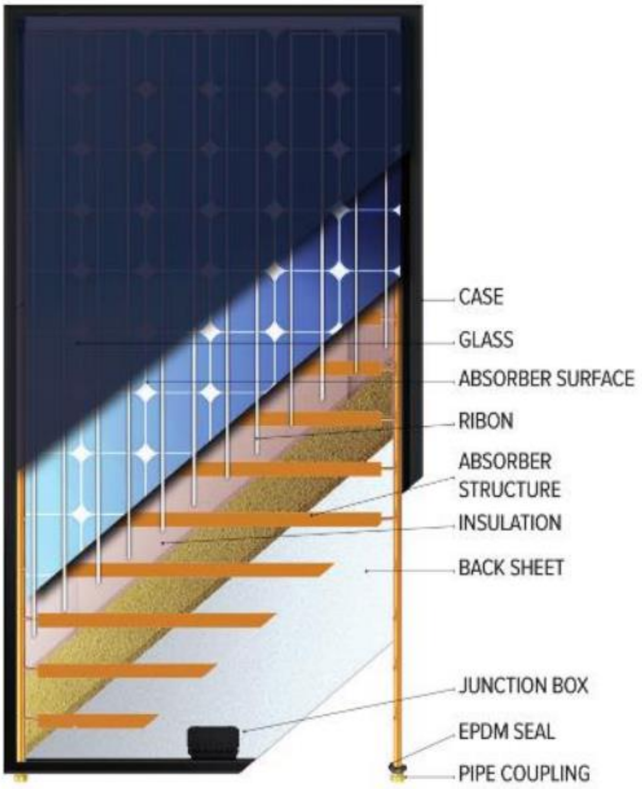


Figure 4 HYBRID COLLECTOR MODEL CROSS-SECTION

Table 1 Technical data

| | |
|---|---|
| **Dimension** | **1670 x 995 x 60** |
| **Area** | **1,66 m²** |
| **Number of cells** | **60** |
| **Dimensions of the cells** | **156 x 156** |
| **Nominal performance** | **315W** |
| **Tolerance** | **Positive tolerance 0 to +5Wp** |
| **Kurzschlussstrom (Isc)** | **9,94 A** |
| **Open clamping voltage (Voc)** | **39.25 V** |
| **Maximum rated voltage (Vpm)** | **32.18 V** |
| **Maximum system voltage** | **UL:600V /IEC : 1000V** |
| **Absorb** | **Copper & Monocrystalline Cells** |
| **Welding method (thermal absorber)** | **Laser** |
| **Number of risers** | **7** |
| **Dimension of the paths and collection lines** | **8 / 18** |
| **Heat exchanger** | **Copper** |
| **Absorbermaterial** | **Copper** |
| **Flüssigkeitsinhalt** | **0.85 l** |
| **Testdruck** | **15 bar** |
| **Maximum operating pressure** | **8,6 bar** |
| **Seal** | **EPDM & Silikon** |
| **Rückwandabdeckung** | **Structured aluminium sheet** |
| **Insulation** | **Mineral wool** |
| **Housing** | **Powder-coated aluminium** |
| **Produktgarantie** | **10 years** |
| **Leistungsgarantie** | **90% < 10 years , 80% 20 years** |

Further suggestions for installation

• Solar modules are certified for operating at voltages up to 1000Vdc. This maximum voltage should not be exceeded in designing a PV system or array configuration. Under normal operating conditions, a solar photovoltaic module is likely to produce more current and /or voltage than the reported values in the datasheet under standard test conditions. In the event of connections are not securely made with gap between the contacts there is a likely chance electrical arcing that can cause a fire hazard and/or an electric shock. So, it is recommended to always use a suitably rated isolator (DC switch) to interrupt the current flow before disconnecting the connectors.

• When fuses are fitted, they should be rated for the maximum DC voltage and connected in each, non-grounded pole of the array (i.e. if the system is not grounded then fuses should be connected in both the positive and negative poles). The maximum rating of a fuse connected in series with an array string is 15A.

• This fuse rating value also corresponds to the maximum reverse current that a module can withstand (when one string is shaded then the other parallel strings of modules will be loaded by the shaded string and current will flow) and therefore impacts the number of strings in parallel.

• The clamps should not loom into the cell area of the module.

• If different metals are used with the mounting system, pay attention to possible contact corrosion due to different fastening material.

• During operation of the plant it could be that the given technical values of voltage and current are in real higher than calculated before under STC. In order to prevent a possible disproportion between theoret ic al and real values it is recommended to add a security margin of 1,25 on all technical values including cable cross sect i on, invert er power, etc.

• It has to be taken into consideration that the load of the plant into the grid is balanced on all three phases of the public power grid. All technical standards for grid- feeding inverters have to be respected. In every case during development the technical data-sheet of the inverter has to be taken into account.

• All inverters have to respect the national and local grid-feeding standards including EMC regulations.

• Depending on the local wind and snow loads, additional module clamps may be required. (All panels are designed for 1600 Pa load. Test load is 2400 Pa, safety factor 1.5)

• PV module connect in parallel should have similar voltage. As reference the maximum number of modules in parallel can be easily calculated by dividing the maximum rated current ( indicated in the electrical specification below) by Isc value of the module, and then plus 1. Please always take into consideration the variation of the current under different temperatures, the Isc of the modules will be rise when the temperature goes up

## 5 Assembly steps PV + part TH

This section describes the assembly steps for PV/T system, as shown in Figure 5, including:

Step 1: Double sides tap application on PV back surface.

Step 2: Applying grease to the PV back surface

Step 3: Placing the thermal part on the greased surface

Step 4: Silicon application to frame channels

Step 5: Long side of frame insertion

Step 6: Short side of frame insertion

| Step 1 | Step 2 |
|---|---|
| Double sided tape application on PV back surface<br> | Applying grease to the PV back surface<br> |
| Step 3 | Step 4 |
| Placing the th part on the greased surface<br> | Silicon application to frame channels<br> |
| Step 5 | Step 6 |
| Long side of frame insertion<br> | Short side of frame insertion<br> |

Figure 5 Assembly steps of PV/T system

## Conclusions

In this work package, the development and construction of a hybrid PV/T system has been completed. Its accuracy has been validated. Optimisation and functional tests with materials are necessary as part of work package 4 previously to the demo site works phase. In this deliverable, the design of PV/T system have been detailed. The different components of the PV/T system have been explained. In addition, the way of installing the equipment, recommendations and solutions to potential problems have been explained. Finally, the construction of the prototype for the SUREFIT Project has been documented. It is important to note that although these developments are considered of great interest in different types of environment, the normative regarding these kind of systems is not ready yet, so it is not clear whether it will finally be possible their installation in any of the demo sites planned in the project. Anyway, this technology will be validated at laboratory scale and the possibility of use in a demo site is being studied.

# References

[1] Zhang Xingxing, et al. Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. Renew Sustain Energy Rev 2012;16:599–617.
[2] Anderson Timothy N, et al. Performance of a building integrated photovoltaic/thermal (BIPVT) solar collector. Sol Energy 2009;83:445–55.