Solar hybrid collectors analysis - Experimental and numerical study

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Abstract. The resource economy is currently a global priority and the preservation of the planet and its resources are becoming the main international objectives. In this regard, EU states must establish clear lines and long-term strategies. Also, the goal of developed countries must involve reducing emissions by 80-95% by 2050. The global economic context leads to an intense concern in the field of unconventional sources, with solar energy occupying an important place. Solar energy can be collected and transformed either into electricity using photovoltaic or thermal technologies, through the use of different types of solar thermal panels or through the use of hybrid panels (PV/T Hybrid solar photovoltaic - thermal collectors, often known as PV/T are systems that simultaneously convert solar radiation into electricity and heat - operating in cogeneration. The paper includes experimental measurements and numerical analysis of a hybrid solar panel. A decrease in the surface of the panel was observed, thus an increase in electricity production by up to 6%. The original part is the experimental protocol used and the comparison of two solutions of energy production under the same conditions. The numerical campaign accompanies the experimental study and provide interesting data.

Keywords. Solar hybrid panels, experimental measurements, numerical simulations.
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1. Introduction

The global economic context leads to an intense concern in the field of unconventional sources, solar energy occupying an important place. Renewable energy sources can be a form of energy production with a minimal impact on the environment and a low cost of implementation/operation. Of these, solar-powered systems are easy to implement and can become accessible in areas with solar potential, with a relatively short payback period. Solar energy can be captured and transformed either into electricity using photovoltaic technologies, or into thermal energy by different types of solar thermal panels.

According to Wu J. et al. [1] PV/T collectors could become a potential solution, as the simultaneous production of electricity and heat leads to a higher overall conversion of solar energy (94%) than independent collectors.

Based on the findings from the literature review, four general types [2] of PV/T installations can be identified: PV/T collectors with air, PV/T collectors with liquid - small scale, PV/T with liquid on a large scale where heat pumps and the latest category of PV/T concentrators mounted on the roof of industrial buildings and on non-residential buildings are also included.

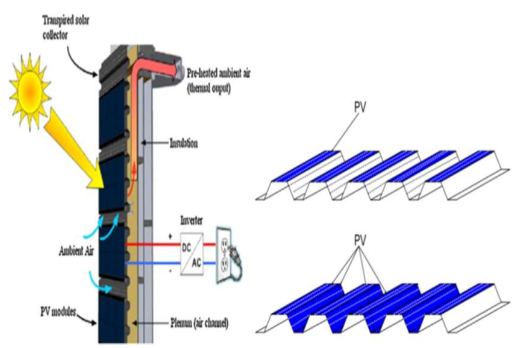


Fig. 1 – Conceptual scheme of hybrid PV / T collectors for facades and roofs [3,4]

The thermal efficiency of PV/T collectors can be improved by adding a layer of glass, while in PV collectors the efficiency decreases in this case. A compromise on photovoltaic and thermal efficiency must be considered in order to achieve the best performance for PV/T collectors in practice. [5].

Other major benefits of PV/T (according to Al-Waelia Ali HA, Sopiana K, Kazemb Hussein A, Chaichan Miqdam T.) [6]:

- more efficient use of the entire solar spectrum with photovoltaic and thermal components in a single unit;
- reduction of installation and space costs;
- decreasing the thermal load of the entire

building;
- a better architectural aesthetic integration compared to two individual collectors (one photovoltaic and one thermal).

China is by far the largest solar thermal market in the world, with 86% of the market and 64% of total installed capacity [7,8]. PV/T systems are not at the heart of research and development in China, but there is a growing interest in PV/T systems for water heating and direct connection to heat pumps. PV/T hot water systems are expected to become one of the main solar systems in buildings in China. [9]. Over the last 26 years, energy consumption in Sweden has been stable in the range of 46 to 53 Mtons (equivalent to millions of tons of petrol) compared to global energy consumption. [10] This is mainly due to the decrease in the use of fossil fuels but also a slight increase in the use of renewable energy sources, an increase from 38% to 64% in the period 1990-2016, but also in the future it is estimated that Renewable energy sources (solar and wind power) will have a continuous average increase of 2.8% per year between 2015 and 2040. [11] In Sweden a target has been set, in 2040, electricity will be 100% of renewable sources, solar energy will contribute 5-10% to electricity generation, compared to 2017 when the contribution was 0.1%. [12]. In Sweden PV/T collectors (used for electricity but especially for hot water) can be integrated into constructions in several variants (installation on the floor, on the roof, walls, balcony but even integration in windows in new buildings but also in old buildings) [13,14,15], PV/T collectors are able to connect with complex heating systems such as: district heating systems [16], desalination [17], industrial processing [18], waste heat recovery [19], electricity generation [20,21].

Grammer Solar & Bau in Germany currently have a commercially available PV/T product, the PV / T panel is air-conditioned and preheats the ventilation air. The product is available in 4 different module sizes ranging from 50 kWp to 250 kWp per module. [22.23,32]

In 1993, the Japanese government invested more than 1,200 million yen to test photovoltaic panels. One area of interest has been the development of PV / T collectors for buildings in Japan. A prototype for residential buildings was developed, which was tested on a house in Japan. PV / T collectors consist of photovoltaic cells supported by a thermal absorber, the collectors produce daily about 3.2 kWp of electricity and 25 kW of thermal energy for domestic water [24]. In Japan, Sekisui Chemical Co., Ltd installs the PV/T collector that converts about 10% of solar energy into electricity and 30% for average hot water annually.

At the Mataro Spain Library, PV/T collectors are mounted on the façade and on the skylights on the roof. The PV / T collectors used are those with air, the air is used to preheat the water in the conventional heating system. [25]

Yellow House in Aalborg, Denmark has 5 different groups of PV / T installations on the facade. [26-30]

Millennium Electric's Multi Solar System with a daily power of 2 to 4 kWh of electricity and 6,000 kcal of hot water has been installed in residential homes in Klil, a small mountain community in northern Galilee, Israel. . The systems have been in operation and have been monitored since 1991 [31,32].

The Canadian company Conserval Engineering has developed a PV / T air collector (SolarWall PV / T). The PV / T concept was developed at Concordia University, Montreal, and the demonstration system was installed at the university in 2007 [33].

In the UK, the number of PV / T installations has grown rapidly over the last decade. Newform Energia claims to have hundreds of installations across the country, from small systems to multiple complex sources of energy installations [34].

One example of a warmer climate is the Cogenra installation on a building at the University of Arizona Tech Park, which supplies the building with 191 kW of heat and 36 kW of electricity [35]. The project was partially funded by a local incentive program.

Solar energy is a significant source of renewable energy for buildings that have the same type of construction. The efficiency of electricity generation of photovoltaic systems is affected by the temperature of the photovoltaic panel. As the temperature of the panel increases, the efficiency of electricity production decreases due to the increase in resistance. To overcome this drawback, photovoltaic (PV / T) systems were introduced in the 1970 [36,37].

The purpose of this paper is to analyze by means of experimental measurements and later on using numerical simulations the performance of a hybrid solar panel compared to a classic photovoltaic one.

2. Experimental set-up

The experimental set-up was placed in the courtyard of the Faculty of Building Services Bucharest.

The activity within this stage are preparation of the experimental protocol (see Figure 2 and 3) , the installation of sensors (temperature, pyranometer, energy meters) and the effective measures with the related analysis. The equipment's are:

- 2 solar panels (one hybrid PV/T and one photovoltaic)

- 2 microinverters
- 2 storage tanks
- 2 flow meter
- 2 circulation pumps
- 1 acquisition station
- ALMEMO temperatures
- 1 thermal imaging camera
- 1 power acquisition station
- electrical panel

Fig. 2 – Experimental campaign – during October 2021

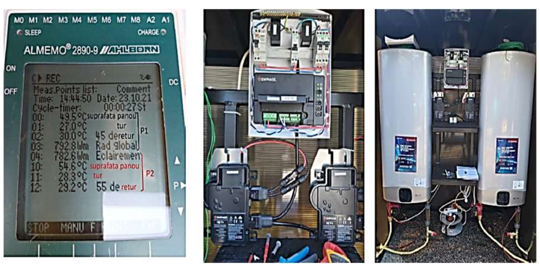


Fig. 3 – Photos with the Almemo temperature acquisition system, electrical connections, and water storage tanks

Using the infrared thermal camera multiple images were taken and it can be seen that the hybrid solar panel are colder by up to 10ºC due to the water circulation inside it.

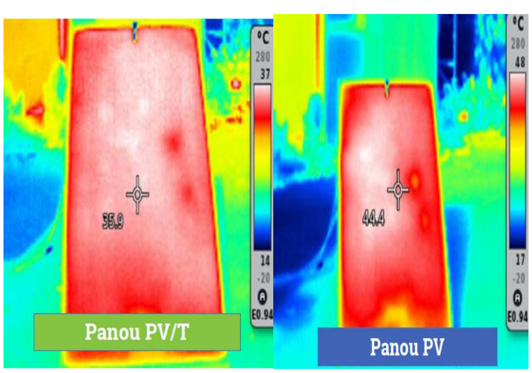
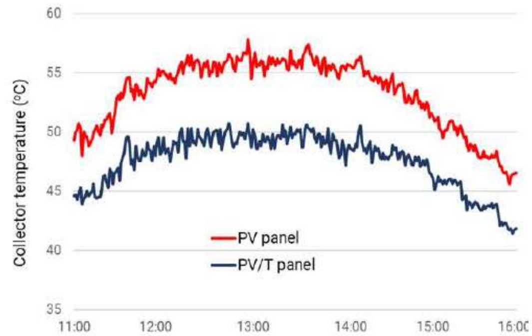


Fig. 4 – Thermal camera images for the two analyzed panels



3. Numerical simulations

The built numerical model will allow the investigation of the operation of the PV / T hybrid solar panel and in other working conditions.

It is mentioned that the Ansys R15.0 software (Academic) was used to develop the CFD numerical model. The construction of the model took into account the real geometry resulting from the experimental stand (Fig. 1). The geometry of the computing domain thus includes the following elements: the panel itself, the thermal insulation layer and the copper coil.

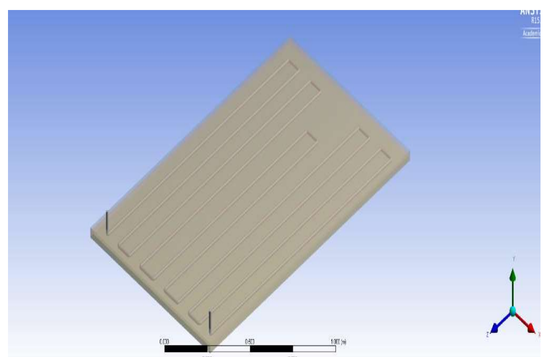
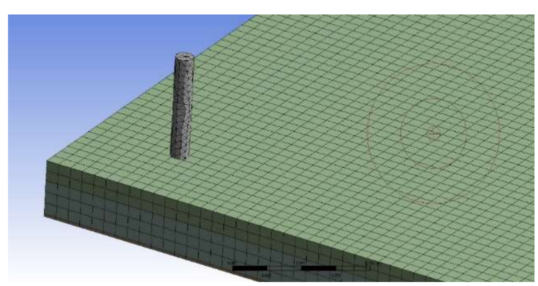


Fig. 1 – 3D geometry of the hybrid panel

The total number of finite volumes resulting from the discretization operation of the computational domain is 281,376 (Fig. 2 a). It is also shown in Fig. 2 b a detail with the discretization network made. It is specified that for the serpentine a finer discretization was made in order to be able to correctly capture its geometric shape, as well as the physical phenomena involved at its level (Fig. 4).



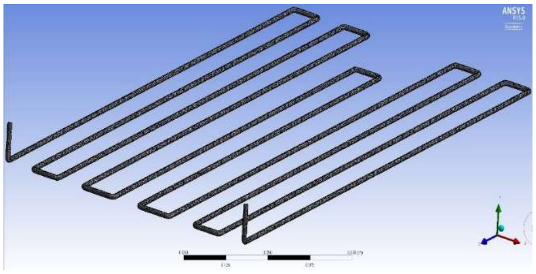


Fig. 2 – Discretisation detail (a) and serpentine (b)

The main hypotheses, physical models and numerical methods used are summarized in Table 1.

Tab. 1 - The main components of the numerical model

Element	Description
Flow	3D, turbulent, non-isothermal, permanent mode
Turbulence model	k-epsilon standard
Flowing near solid borders	Wall functions
Numerical solution	Default solver “segregated”; diffusive terms: schemes centered by ordinal 2; convective terms: ordinal up-wind scheme 2; SIMPLE algorithm (pressure-speed coupling)

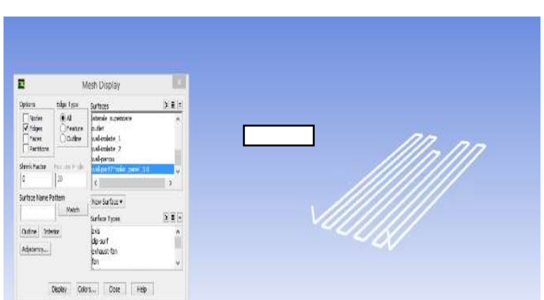
The boundary conditions imposed in the numerical model were as follows:

• upper panel face: temperature imposed on the surface, constant value 50°C (according to experimental data)

• lower face of the panel (thermal insulation): temperature imposed on the surface, constant value, 25 ° C (according to experimental data),

• serpentine inlet: «velocity inlet», imposed speed - value that would allow obtaining the water flow from the experimental study, respectively 2.5 l/min; imposed temperature: 10°C

• coil outlet: «outflow»



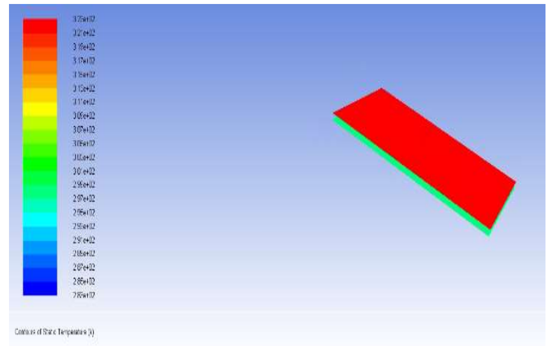


Fig. 3 – Boundary conditions inlet/outlet serpentine (a) and solar panel surfaces (b)

The main result of the numerical simulations consists in the water temperature at the exit of the coil with which the PV/T hybrid solar panel was provided. The temperature obtained was 13.78°C - practically a difference of 3.78 °C from the inlet. The experimental data showed an outlet-in-water temperature difference between 5°C and 6°C. Future calibrations and simulations will seek to improve the numerical prediction of water heat transfer within the analyzed PV/T hybrid solar panel. On the other hand, it is mentioned that the simulation results showed a more than acceptable balance (lower than the value of 10-6) in terms of the water inlet flow /water outlet flow ratio. This first numerical study highlighted the ability of the developed CFD model to accurately represent the heat transfer and fluid flow phenomena within the analyzed PV/T hybrid solar panel. The numerical model can also be used for other working conditions to extrapolate the results. Also, based on the developed CFD model, research will continue for the integration of aspects related to the insertion of phase change materials in the PV / T hybrid solar panel.

4. Conclusions

Using an experimental set-up several parameters were measured for two types of solar panels: one hybrid PV/T and another one PV. It can be concluded that the PV/T surface temperature was on average by 10oC colder than the PV solar panel which is translated in better performance in terms of energy production. From the energy data from both panels we have calculated that the electric energy production for a PV/T panel is higher by 5-6% than a classical PV panel. The second part of the paper was dedicated to the numerical modelling of the hybrid solar panel. Using the input data from the experimental measurements (water flow, temperatures) we were able to simulate the heat flow. The numerical study represents the first step in optimizing further the solar panel by introducing phase change materials for example. A decrease in the surface of the panel was observed, thus an increase in electricity production by up to 6%.

5. Acknowledgement

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