Study on Optimal Solar Thermal Technology Used for DHW Preparation Based on TRNSYS Simulation

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***Abstract*— The aim of the paper is to present the evaluation of two systems which include different types of solar collectors. The performances of the two solar energy technologies were assessed based on a dynamic numerical simulation developed using TRNSYS 18 software. It was considered of main importance the thermal energy produced by the two solar energy technologies given an imposed daily domestic hot water consumption.**

***Index Terms*— domestic hot water, solar energy, solar thermal collectors, TRNSYS, PVT panels**

I. Introduction

One of the most popular system based on renewable energy used for domestic hot water production is the solar heating system. The solar thermal technology converts radiation into heat, transferring it to a medium such as water, antifreeze-water solution or air. A solar water heater comprises three main components: a solar panel, a storage tank and a heat transfer fluid. There is a large variety of solar collectors on the market. The solar thermal collectors (S.Th.C.) are divided into two main categories: concentrating and non-concentrating collectors. One of the most widely used solar device for domestic hot water (DHW) production is the flat plate collector [1]. A photovoltaic (PV) collector is also considered a solar device, but it is used to convert solar radiation into electricity. The temperature of the cells is the main parameter of the PV panels, with a high influence on their performance. An important part of the solar radiation is converted into heat, causing in this way a reduction of their efficiency. According to the experimental studies, a temperature rise with 1ºC reduces the efficiency with 0.5% [2]. Hybrid photovoltaic-thermal (PV/T) technologies used for electricity generation became in the last years an interesting solution for domestic hot water production. Another known solution for DHW production is the technology of hybrid PV/Ts, which are a combination between a S.Th.C. and PV cells, thus generating electricity and thermal energy at the same time.

The solar radiation used to heat up the PV cells is transferred to a fluid and converted in this way into a usable form of energy. Water is the most common fluid used to cool the panels. Glycol or a phase change material can be also a working fluid [3].

A wide number of studies regarding the solar water heaters is reported in the literature. Simulations and experimental studies to evaluate the performance, optimize the design and operating parameters were carried out over the years [4], [5], [6]. The performance of these collectors is significantly influenced by temperature, radiation, wind speed and flow rate [7]. A hybrid PV/T collector may reach an efficiency (thermal and electrical) up to 70% or even higher [8], [9].

In this paper, a comparison between PV/T and S.Th.C. panels for domestic hot water applications along with the results of a technic-economic analysis is presented.

II. System Design

A. PV/T panel

A liquid based flat collector with glazing is studied within this paper. This panel works by circulating behind the PV cells a cooling fluid through a heat exchanger, being heated up by the thermal energy of the cell. The hot fluid then circulates to a heat exchanger into the DHW storage tank and returns to the PV/T inlet with a lower temperature. The thermal absorber is made of copper, with a liquid volume of 1.2 l. On the electrical side, there is a 260 Wp cell array, with an electrical efficiency of 15.95 % tested at S.T.C. (AM 1.5, solar radiation 1000 W/m^2 and 25 ºC ambient temperature). The temperature coefficient (which represents by how much the electrical efficiency drops with every degree above the S.T.C. temperature) is 0.47 %.

B. S.Th.C.

The solar collector used in this study is of flat plate type, made from a copper tube system fixed on a backplate cover with a high absorbing paint in order to help capture as much solar radiation as possible. The pipe-absorber system is confined in an insulated box covered at the top side by a glass sheet.

The hydraulic circuit of the collector uses glycol as the heat transfer fluid.

Each type of collector considered in this study is included in a solar system, used to produce domestic hot water. Both systems also contain a circulation pump and a domestic hot water tank.

Technical characteristics of the two panels are presented in Table I.

TABLE I. PV/T AND S.TH.C. SYSTEM SPECIFICATIONS

Components of the PV/T and S.Th.C. systems	**Specifications**
Collector area [m^2]	3.1
Specific heat of the working fluid [kJ/kg.K]	3.82
Circulation pump power [W]	17
Flow rate of the working fluid [kg/h]	800
Water tank volume [m^3]	0.75
Water tank height [m]	1.9

III. SIMULATION MODEL OF THE PV/T AND S.TH.C. SYSTEMS

In this study, TRNSYS 18 was used to perform the simulations of the two solar technologies, applied for a laboratory building. TRNSYS is a flexible graphically based software environment, very useful in modelling and simulating the behavior of transient systems. This software can simulate almost all types of renewable energy generation, except nuclear, tidal and hydro power. A high number of TRNSYS projects can be found in the field of solar energy applications (thermal and photovoltaics) [6], [10], [11].

In the case of this project, a single deck file containing both hybrid photovoltaic collector and the solar collector was built.

Fig. 1 shows the TRNSYS model of the two solar systems. The first step of the project consists in choosing the components of the model from a standard library. Each component of the system is represented by a "type". The components are connected similarly to how they would be connected in the real project.

The model comprises the following main types:

- *Type 50d* used to model a flat plate collector which incorporates a PV module.
- *Type 73* models the thermal performance of a flat plate collector.
- *Type 3b* represents the circulation pump.
- *Type 534* represents a cylindrical storage tank with an immersed heat exchanger.
- *Type 14b* used to create a hot water load profile.

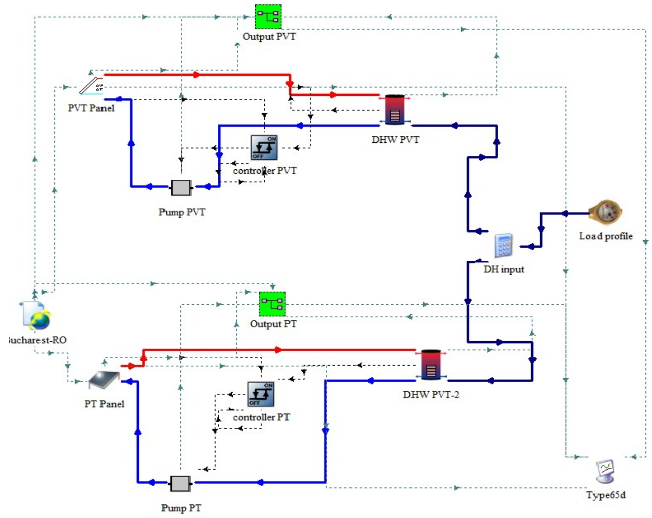

Figure 1. TRNSYS model

The two systems also include a differential controller and a unit used to create equations. The controller generates a control signal with value 0 or 1, depending on the difference between the temperatures at the inlet and at the outlet of the collector.

The daily load profile (Fig.2) was created considering the hot water consumption in the laboratory building

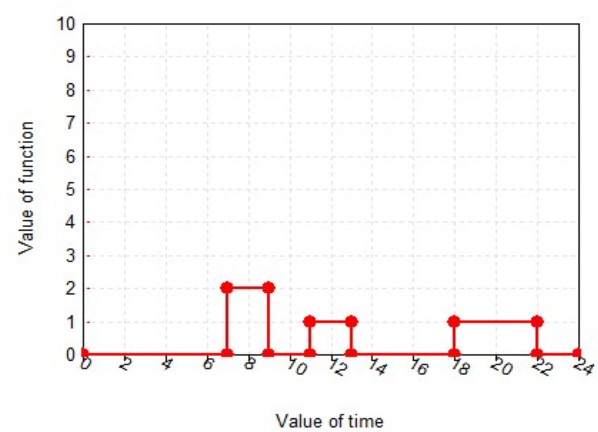

Figure 2. Load profile

The model contains two independent domestic hot water circuits, one for each solar system considered, while the main parameters were determined based on literature research.

The following parameters were used for both solar technologies:

- climatic area.
- area and slope of the collector.
- water tank characteristics.
- working fluid properties.
- mass flow rates.

IV. RESULTS OF THE SIMULATION

A. Weather data

Weather data is also necessary in order to carry out the simulations. The weather data is generated by Meteonorm software. The two solar systems are located in the area of Bucharest city. The ambient temperature, wind velocity and radiation are among the weather parameters with a high influence on the operation of solar collectors.

In Fig. 3 and 4, the variation of outdoor temperature and solar radiation for a typical summer day/month in Bucharest are presented.

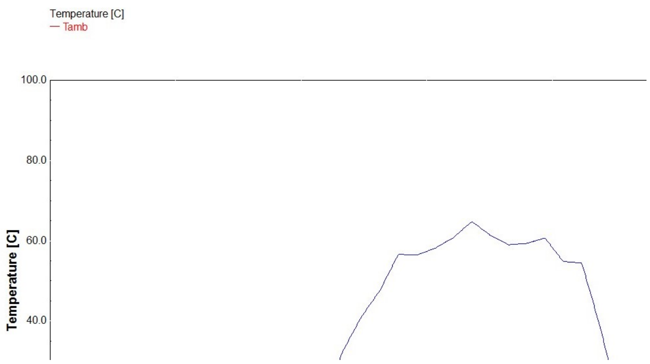

Figure 3. Daily weather data profile

August is the month of the year with the highest values of the outdoor temperature and radiation.

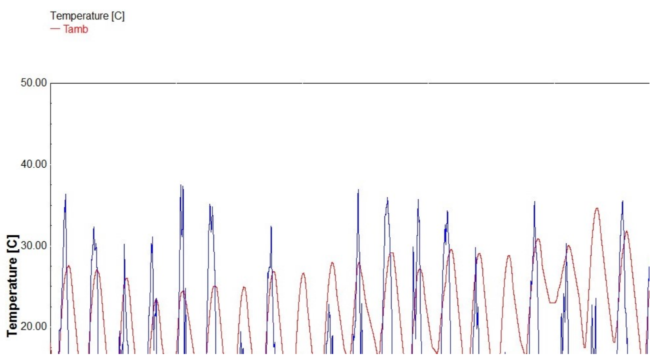

Figure 4. Monthly weather data profile

B. Thermal and electrical results

Fig. 5 emphasizes a comparison between the temperatures reached by the two types of collectors.

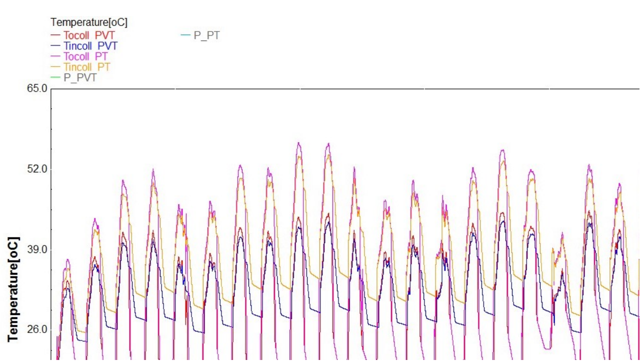

Figure 5. Temperatures at the inlet/outlet of the S.Th.C. and PV/T collectors

As it can be seen, the working fluid has a higher temperature in the case of the S.Th.C. This is due to the fact that in the case of this type of collector, the solar radiation that reaches its surface is converted only into thermal energy. For PV/T panel, only a fraction of the incident solar radiation is transformed into heat, while the main part is being converted into electricity.

The water from the storage tank used as domestic hot water reaches about 52 ºC in case of a S.Th.C. system and about 43 ºC in case of the PV/T system (Fig. 6).

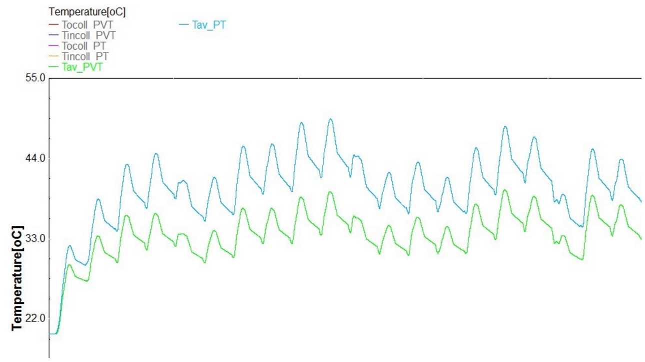

Figure 6. Average water tank temperatures

Another comparison between the two types of collectors is made from the energy gain point of view (Fig. 7). The thermal energy provided by the S.Th.C. is up to 30% higher than the thermal energy gained by the PVT collector.

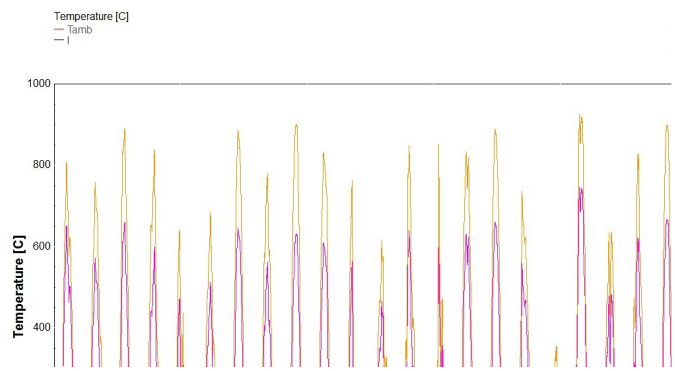

Figure 7. Useful energy gain [kJ/h]

In order to obtain the energy production/consumption of the two systems, the simulations were performed for an entire year.

The total energy production (thermal and electrical) is obtained after integrating the useful energy gain (Table II).

TABLE II. PV/T AND S.TH.C. PERFORMANCE

Calculated parameter	S.Th.C.	PVT collector
Efficiency [%]	0.54	0.37 (thermal)
		0.50 (global)
Energy gain [kJ/h]	307	213.3 (thermal gain)
		70.2 (electricity)

The thermal efficiency of the solar collectors (Table II) was calculated as:

$$\eta_{th} = \frac{E_{th}}{A \cdot I} \quad (1)$$

The global efficiency of PVT collector was given as:

$$\eta_{th} = \frac{E_{th} + E_{el}}{A \cdot I} \quad (2)$$

where:

- E_{th}, E_{el} represent the thermal/electrical energy provided by the collector
- A is the collector surface
- I is total irradiation on the collector surface

C. Technical-economic analysis

The technical-economic analysis' focus was to compare the performances of the two solar technologies in monetary values. Therefore, the following hypothesis were assumed:

- Study duration equal to the expected lifespan of 20 years
- The value of the discount rate of 6 %
- The investment considers only the solar system, without the DHW tank and it is performed for 1 year
- Maintenance and operating costs, electrical energy price and thermal energy price are considered constant over the study period.

In Table III the input data used in the analysis of both solar systems are presented.

TABLE III. INPUT DATA FOR STUDY

Input data	Value
Investment [EUR]	1500
Discount rate [%]	6
Study duration [years]	20
Maintenance cost [EUR/year]	50
Electrical energy prices (without VAT) [EUR/kWh]	0.2126
Thermal energy price (without VAT) [EUR/kWh]	0.118

Using the results of the numerical model, the annual production of useful types of energies was determined for both solar technologies, and the electrical consumption of the pumps are summarized in Table IV.

TABLE IV. YEARLY ENERGY PRODUCTION

Calculated parameter	S.Th.C.	PV/T collector
Thermal energy production [kWh/year]	2290	1503
Electrical energy production [kWh/year]	-	572.9
Electrical energy consumption [kWh/year]	20.9	20.9

In the case of the S.Th.C., the savings in terms of thermal energy that is not bought from the district heating operator at the assumed price were considered as revenue. The operating cost of the system is composed of the electrical energy consumption of the pump.

The PV/T technology has 2 streams of revenues, considered in the analysis:

- Savings in terms of thermal energy (same as in the S.Th.C. case).
- Savings in terms of the electrical energy that is not bought from the local power grid.

For both solar technologies the net present value, internal rate of return and the payback period were determined. The results are presented in Table V.

TABLE V. RESULTS OF ECONOMICAL ANALYSIS

Calculated parameter	S.Th.C.	PV/T collector
Net present value [EUR]	1284	1351
Internal rate of return [%]	5	6
Payback period [years]	7	5.9

CONCLUSIONS

The paper presents the results of a comparative study of two solar energy-based systems. Their auxiliary components and the DHW load imposed are the same for both systems. The only difference between the systems is given by the two types of solar collectors: hybrid photovoltaic thermal solar collector (PVT) and solar thermal collector (S.Th.C.). According to the results of the study, the S.Th.C. system achieves better results: higher thermal energy provided to the storage water tank, higher temperature in the tank and higher thermal efficiency. Even if its performance parameters are lower, the PVT system represents an alternative to classic solar system, its main advantage consisting in the additional production of electrical energy. According to the results of the simulation carried out for August, which is the month of the year with the best weather parameters for solar energy-based systems, the average water temperature in the tank varies between 24 ºC and 43 ºC in the case of the PV/T, respectively 26 ºC and 52 ºC in the case of the S.Th.C. If the user needs a higher water temperature, an auxiliary electrical resistance heater might be added to both solar systems. The PV/T panel is able to provide electrical energy in order to cover the circulation pump consumption, while also ensuring a part of this auxiliary electrical device consumption. The technical-economic analysis shows economic feasibility for both types of solar technologies, while the highest values of the indicators were determined in the case of the PVT panels. Due to the production of electrical energy, the PVT panels offer a payback period that is 16% smaller, with a higher net present value and internal rate of return.

ACKNOWLEDGMENT

This work has received funding from the European Union's Horizon 2020 research and innovation program, under grant agreement No 857801 - "Smart and local

ReneWable Energy DISTRICT heating and cooling solutions for sustainable living" - WEDISTRICT. This text reflects only the author's views, and the Commission is not liable for any use that may be made of the information contained therein.

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