



## POSSIBILITIES OF IMPROVING PV/T SYSTEM EFFICIENCY

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### Abstract

Photovoltaic/thermal hybrid collectors (PV/T) simultaneously are able to produce electrical energy and thermal energy as such unit combines a photovoltaic module with a thermal solar collector. In this paper, we are focusing on the liquid cooled PV/T systems. The paper overviews the energetics models of the PV/T collectors. Furthermore, it is planned to examine the possibilities for development of the photovoltaic thermal resistance network models for different PV/T collector arrangements.

### Keywords

hybrid collector, efficiency, heat flow network, solar energy, influencing factors

### 1. Introduction

At present our world has to face energy problems. Environment is burdened by pollutants emitted by burning traditional energy carriers. In our world heat energy is obtained mostly by burning fossil energy sources (gas, oil, coal) [1]. The so called greenhouse effect is related to the excessive carbon-dioxide emission. Earth average temperature is increasing as the Earth's long-wave length radiation decreases significantly because of the formed polluter envelope [2]. Because of the increasing amount of gases causing greenhouse effect and because of other environment pollution, it is more and more necessary to use renewable energy sources (solar energy, wind energy, geothermal energy, biomass, sea and river energy) [3]. Concerning the use of solar energy, our country's climatic conditions are favourable. In case of architectural constructions, passive solar energy is utilized. In case of utilization of active solar energy, electrical and heat energy are obtained. The former is obtained by photovoltaic systems, the latter is obtained by solar collectors. Heat transfer at high temperature is realized with concentrator collectors.

Photovoltaic-thermal collectors (PV/T) are systems that generate electric energy and heat energy simultaneously, as photovoltaic modules are combined with traditional solar collectors (Figure 1).

A PV/T system consists of a PV module, with a heat exchanger behind it. In order to cool the PV module and extract the useful heat, a cooler fluid (water or air) is circulated in the heat exchanger.

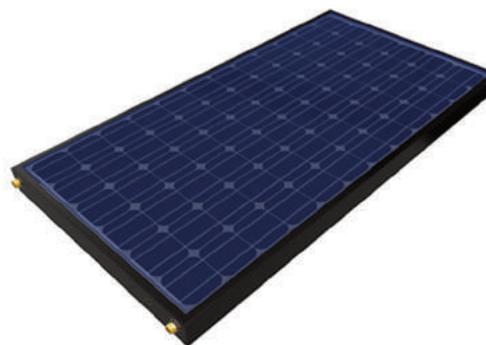


Figure 1. Layout of a PV/T collector

Photovoltaic PV systems absorb solar radiation and convert it into electricity. This is especially advantageous where electrical network is not available. Solar-thermal collectors absorb the solar radiation, and in order to produce heat energy, they convert it into heat with the heat converter fluid (water or air).

Solar radiation conversion efficiency of commercial PV modules is about 5-20%. It means that 80% of the incident solar radiation in the PV module is converted into heat. The generated waste heat is partially lost in the atmosphere, contributing to global warming, and the remaining heat increases the temperature of the PV cells. Cooling is proposed because of the increasing temperature of the cells. This is especially important in case of crystalline silicon cells as at high temperature the electrical conversion efficiency of the cells decreases below the nominal value.

PV/T systems are innovative solutions for increasing solar energy conversion efficiency. The circulating cold fluid maintains the temperatures of the cells as it extracts heat from the module, so it maintains the PV efficiency at an appropriate level. The heat extracted by the fluid is lead through pipes to low temperature applications, such as to industrial or agricultural sectors for drying, apartment heating, domestic water heating [4].

PV/T collectors generate more energy on unit surface than the adjacent solar collectors and PV modules. According to the collecting refrigerant, there are two types of PV/T collectors: water-cooling collectors (Figure 2) and air-cooling collectors [5]. Besides these, concentrating PV/T collectors (CPV/T) are also developed, which use lens or mirrors, and circulating liquid, in order to avoid the high operation temperature of the PV [6].

Water PV/T systems are used for heating buildings, for producing domestic hot water, where the need for running water is high. PV/T systems are more and more frequently combined

with heat pumps. It seems to be a useful application to preheat the flowed air in PV/T and BIPV/T (Building Integrated PV/T) systems, especially during the heating season, but also during the summer season [7].

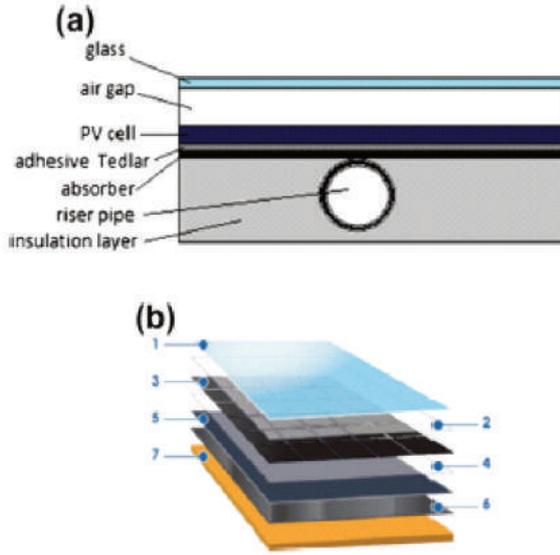


Figure 2. PV/T water systems [6]

To test the operation of the PV/T system, to determine its parameters, to compare measured and simulated results, we need to set up a suitable energy model for the given purpose, the most important ones being discussed below.

## 2. Energetic models used for PV/T collectors

In this paper we present the most often used energetic models in the investigation of photovoltaic (PV) modules, solar collectors and PV/T collectors. In order to present properly the models it is necessary to define the parameters which influence the efficiency of the PV/T collectors.

PV/T collectors are designed according to two basic aspects: the thermal efficiency or the photovoltaic efficiency is considered to be more important.

Thermal efficiency of PV/T collectors:

$$\eta_t = \frac{Q_h}{A_K \cdot I} \quad (1)$$

Thermal performance of PV/T flat-plate collectors:

$$Q_h = \dot{m}c_p(T_{out} - T_{in}) \quad (2)$$

The determination of the heat abstraction factor (FR) is:

$$F_R = \frac{Q_h}{A_K \cdot [I \cdot \tau \cdot \alpha - U_L \cdot (T_{in} - T_w)]} \quad (3)$$

F' factor varies with the material, for water in our study:

$$F' = \frac{1}{U_L} \frac{1}{W \left[ \frac{1}{U_L(D_o + (W - D_o)F)} + \frac{1}{C_b} + \frac{1}{\pi D_i h_{wm}} \right]} \quad (4)$$

Thermal efficiency:

$$\eta_t = \frac{F_R \cdot A_K \cdot [I \cdot \tau \cdot \alpha - U_L \cdot (T_{in} - T_w)]}{A_K \cdot I} \quad (5)$$

Photovoltaic efficiency:

$$\eta_v = \eta_{ref} \cdot [1 - \beta_{pv} \cdot (t_{pv} - t_{ref})] \quad (6)$$

where:  $\eta_{ref}$  is the efficiency measured in Standard Test Conditions (STC),  $\beta_{pv}$  is the temperature coefficient of the module,  $t_{pv}$  is the cell temperature,  $t_{ref}$  is the reference temperature, which is defined during the measurement of the temperature coefficient, which is 25 °C in case of STC.

Total efficiency of PV/T systems:

$$\eta_0 = \eta_t + \eta_v \quad (7)$$

The modelling system should be applied to the local conditions, that is, environmental characteristics have to be input as mathematical functions. For the investigation of the efficiency of the PV/T module and for the calculation of energy generation, we have to develop a proper mathematical model. With this model we can realize the effect of the environmental characteristics on the investigated parameters [8].

Our aim is to develop a model, based on Physics, which presents the operation of the system, taking into consideration the mass flow, the inlet liquid temperature, the ambient temperature, the solar radiation and other parameters. Physical models of the processes can be shown with partial differential equations or equation systems. In this way we can present the dynamic properties of solar energy systems.

Experiments and measurements have to be performed to determine the parameters and physical constants of the models. This is a difficult and long task in case of complex systems, and there are only approaching methods for equation solutions.

The physically based models relates to determine the heat and mass transfer in the system (e.g. solar collector) with several approaches and neglections.

Depending on the mass flow and temperature of the inlet working fluid, the ambient temperature and solar radiation, the Hottel-Whillier model gives the temperature distribution of the flowing working fluid along the collector.

UL is the linear function of TC – TW variable. This model is called a quadratic efficient model. The useful amount of heat per unit of time generated by the collector, divided by the amount of heat per unit of time of the incident solar radiation on the surface of the collector is called the efficiency of the collector.

Where  $T_c$  [°C] is the outlet temperature of the liquid,  $T_w$  [°C] is the ambient temperature of the collector.

Flat-plate collectors are approached by the Hottel-Whillier or quadratic model. The operation of solar systems are modeled by softwares (e.g. TRNSYS, TRANSOLAR). Beside a direct numeric method it is possible to solve the obtained equation system by using indirect methods as well [8].

Buzás et al. [9] developed a model to describe the behavior in time of the flat-plate collectors. On the base of the energy balance of the solar collector.

The heat transfer process in the collector can be described with the following energy balance equation:

$$\frac{[\text{accumulated energy}]}{\text{time}} = \frac{[\text{incoming energy}]}{\text{time}} + \frac{[\text{exhaust energy}]}{\text{time}} \quad (8)$$

Total energy:

$$E = U^* + K + P \quad (9)$$

where  $dK/dt = 0$  and  $dP/dt = 0$ , as the collector does not move,  $dE/dt = dU^*/dt$ .

With the enthalpy change of the system, the internal change of energy can be considered the same in case of change of solid and liquid systems ( $dU^*/dt \sim d\text{Enthalpy}/dt$ ) [9].

The operation of artificial neural networks (NN) is based on biologic neural networks. Neuron is the operational and structural unit of the nervous system, a cell that can adopt, process and transmit information to glands, muscles, nerve cells with biochemical reactions.

The artificial neural network is the network of neurons. In case of practical problems, neural networks are able to help only in solving part tasks, they cannot be applied by themselves. Hybrid systems are used more and more often in case of complex tasks, during which NN is combined with other artificial intelligence methods (e.g. combination of NN and genetic algorithm), so several part tasks are solved with the most appropriate method [10].

Heat flow network modelling is based on that in a properly small part of material conductivity properties are considered constant. Dividing the model that describes the whole system into parts, we can construct the continuum as the interconnection of concentrated units of conductive resistances [11].

We can determine the average temperature of layers (nodes) if we group the whole structure according to its materials and layers. In the model we connect the nodes with heat transfer resistances and we assign the heat capacity to the nodes of the network [8].

### 3. Optimize the efficiency of PV/T collector using a heat-flow model

In a hybrid solar/solar collector, the electric efficiency can be increased by cooling the collector surface while gaining heat from the system. Therefore, the possibilities for optimizing the efficiency of a liquid cooled PV/T collector are discussed below for a heat-flow model. The aim to be achieved is to study a PV/T hybrid system that increases the efficiency of the system by reducing the temperature of the cell by increasing the electrical power and reducing the thermal radiation losses.

The cooling of the panels can be solved by means of cold water circulation or using a heat sink that is either pre-installed in the PV/T module or can be retrofitted to the rear of the module.

The temperature of the photovoltaic panel (PV) depends dynamically on the changes in the incident sunlight. Under realistic operating conditions, the PV panel temperature is subject to wind direction and wind speed fluctuation as well as randomly changing ambient temperature. In indoor experiments, we cannot properly implement these parameters, so we will set up a heat-flow model that includes the effects of the module's structure, its components and atmospheric conditions.

The thermal model to be set up has the following parts: it consists of an RC circuit to model the panel's thermal response. Secondly, it will be necessary to analyse radiation heat losses and to assess the convective heat transfer losses. We can consider the electrical equivalence of the thermal mechanisms of the PV panel so that the thermal resistance corresponds to the electrical resistance and the thermal capacity of the electrical capacity. On the PV panel layers, conductive heat transfer can be determined using these parameters [12].

The optical properties of solar cells limit the thermal efficiency of the PV/T collector since the selective heat absorber used for solar collectors does not match the heat absorbing emission of solar cells. Radiation losses can be reduced by using a casing that has a spectrally selective low emission factor in the infrared spectrum.

The balance equation can be solved for each layer of the module using the heat flow model. Numerically we can solve the energy equilibrium equation in the direction of flow of y water and in the x-direction perpendicular to which all layers are not continuously distributed to  $N_x$  and  $N_y$  nodes. We can solve the energy equation for all finite volumes (Figure 3).

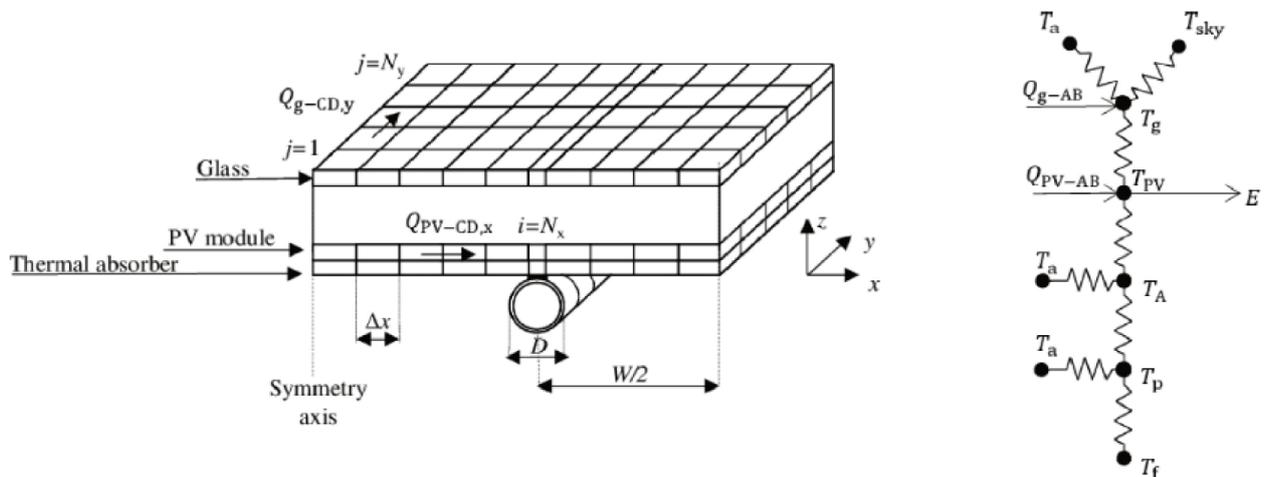


Figure 3. Sketch of the discretization used for the thermal analysis (left) and network of thermal resistances on the x-z plane between the layers of the PVT module (right) [13]

Conversion efficiency, i.e., the efficiency of converting incident sunlight into electricity is reduced by increasing the operating temperature of the cell. The heat absorbing energy balance can be written to any  $i, j$  node, as well as the heat transfer due to heat losses on the rear side of the panel. The convection at the rear of the panel and the thermal conductivity through the insulating layer is taken into account by the heat resistance. From the Energy Balance Equation, we can calculate the energy equilibrium equation for the fluid and the equilibrium equation for the cooling

pipe energy. Then we can calculate the output instantaneous electrical power as well as the thermal and electrical efficiency [13].

### 4. Conclusion

The heat transfer processes in the PV/T collectors to be tested can be written using the heat flow model to determine the thermal or electrical efficiency of the system and the parameters influencing

the efficiency. We can improve efficiency through various procedures, e.g. cold water circulation, reduction of radiation losses, etc. By comparing the simulation results with the results of the measurements, we can draw conclusions about the efficiency of the system, its structural design, its material properties, and further research and development goals which can be the basis for writing articles, conference presentations and development projects.

### Nomenclature

$A_k$	surface of the module	$m^2$
$C_b$	thermal conductivity	$W/mK$
$c_p$	specific heat	$J/kgK$
$D_o$	outer diameters of the pipe	$mm$
$D_i$	inner diameters of the pipe	$mm$
$F$	collector tubing efficiency	-
$F'$	factor varies with the material	-
$F_R$	heat abstraction factor	-
$h_{wm}$	heat transfer coefficient of the liquid	$W/m^2K$
$I$	intensity of the incident radiation	$W$
$\dot{m}$	mass flow	$kg/s$
$K$	kinetic energy	$J$
$P$	potential energy	$J$
$Q_h$	available thermal performance	$W$
$T_C$	outlet temperature of the liquid	$^{\circ}C$
$T_w$	ambient temperature of the solar collector	$^{\circ}C$
$t_{in}$	input temperature	$^{\circ}C$
$t_{pv}$	cell temperature	$^{\circ}C$
$t_{ref}$	reference temperature	$^{\circ}C$
$t_{out}$	output temperature	$^{\circ}C$
$t_w$	ambient temperature	$^{\circ}C$
$U^*$	internal energy	$J$
$U_L$	total heat loss rate	$W/K$
$W$	distance between the rows of the coil of pipes	$m$

### Greek letters

$\alpha$	absorption characteristics of glazing	-
$\beta_{pv}$	temperature coefficient of the module	$\%/^{\circ}C$
$\eta_0$	total efficiency	-
$\eta_v$	photovoltaic efficiency	-
$\eta_t$	thermal efficiency	-
$\tau$	transmittance characteristics of glazing	-

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