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Integrated PV-TEG Cooling System and Support

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ABSTRACT: *Being continuously exposed to solar radiation, photovoltaic cells usually overheat, resulting in rapid degradation over time. For the same reason, the efficiency of energy production also decreases. To overcome these problems, the proposed integrated TEG cooling system removes heat from the cells during periods of strong solar radiation. In contrast to existing products that use the Seebeck or Peltier effect, within the patented system, the given Seebeck effect occurs internally at the same heat sink that acts as a support for the cells and only a small part of the removed heat is used to create the required temperature difference. The invention concerns a drastic simplification of solar cell cooling and thermoelectric conversion technology. This also allows for cascading economic advantages in terms of overall system costs. A preliminary numerical analysis was carried out to analyse the characteristics of the prototype.*

KEYWORDS – *integration; seebeck ; PV cooling; light weight ; energy efficiency.*

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I. INTRODUCTION

In recent years, solar panel cooling techniques have been extensively studied (Ysilyurt,[1]). Some of them disperse the heat removed from the cells into the environment, others transfer it into a heat transfer fluid which makes it available for various uses. The latter systems as described by (Vorobiev[2]) integrate photovoltaics with thermal conversion in a solar panel which is called a hybrid. As a result, the conversion efficiency is greatly increased as the thermal energy is added to the electrical energy obtained from the solar source. However, in a number of practical applications, the thermal energy from the solar cells is not directly exploitable and it is more convenient to disperse it into the environment, electricity being the only energy required. In such cases, the conversion efficiency could be increased by exploiting thermoelectric effects. In particular, several systems have been investigated that exploit Peltier or Seebeck effects. Peltier systems use part of the converted electrical energy to bring the heat removed from the cells to a higher temperature, thus improving thermal convection in the ambient air and keeping the cells at a lower temperature. Systems using the Seebeck effect recover some of the heat removed from the cells and convert it directly into electrical energy. As there are no moving mechanical parts in these TE devices, they are quiet and compact. Chein [3] focused on applications of the thermoelectric cooler (TEG) in electronic cooling. The temperature of the cold side (Tc) and the temperature difference between the cold and hot sides of the TEG (ΔT=Th-Tc, Th= temperature of the hot side of the TEG) were used as parameters. The results indicated that the cooling capacity could be increased by increasing Tc and decreasing ΔT. However, the performance of the TEG was limited by the values of Tc and the thermal resistance of the heat sink on the hot side of the TEG. In photovoltaic panels cooled by systems exploiting the Seebeck effect (as described by Teffah [4] and Shittu [5]), the thermoelectric generator (TEG) is usually placed between the cells and a finned heat sink (Fig.1). In this way, all removed heat passes through the TEG, causing a temperature drop between the cells and the heat sink. Therefore, the lower the temperature drop, the better the efficiency of the photovoltaic cell, but conversely, the lower the efficiency of the TEG. Enescu's article [6] provides a review of recent literature regarding the integration of these devices into PV generators to form PV-TEG hybrid systems. It is concluded that the integration of the TEG device with the PV cells can have two positive consequences: improving the power capacity of the PV modules and increasing the electrical efficiency of the PV system. The technical efficiency of the hybrid PV-TEG solution exists when the power and energy produced by the system with TEG is higher than the power and energy produced by the corresponding solution without TEG. The latest research on heat sink-cooled PV-TE systems has confirmed an increase in electrical efficiency compared to the same area, but low

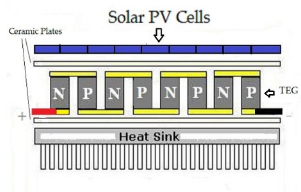


Figure 1. TEG state of the art

thermal efficiency and high installation and operating costs. In this paper we propose an innovative patented cooling system, which forces only part of the heat removed from the cells to pass through the TEG. It also creates the Seebeck effect inside the heat sink.

II. THE PROTOTYPE

The core of the proposed TEG/heat sink module (Fig.2) consists of p e n thermoelectric legs joined together by means of pressure joints, in order to construct thermocouples that are more compact and easier to build and assemble. The apparatus comprises a support for the heat exchanger (to cool the photovoltaic panel) and a fully integrated thermoelectric generator. In addition, the integrated TEG cooling system acts as a support for the solar panel and can be adapted to different requirements thanks to its modularity. Compared to previous PV cooling systems and power generation equipments, the innovative prototype (Fig.2) is smaller in size, more compact and easier to install. It also enables higher PV conversion efficiency and lower overall costs than similar systems.The invention addresses the technical problems of commercially available systems through the integrated combined production of photovoltaics and thermoelectricity by achieving greater compactness and robustness than existing solutions. The prototype presents a clear independence between the efficiency of the heat sink and the efficiency of thermoelectric generation. The final effective integration results from the fact that the Seebeck effect occurs within the heat exchanger itself, which acts as a support and cooling element for the photovoltaic cells.

In addition to this, the proposed solution allows the use of a slot system for fixing the electrical contacts, which reduces the number of screws and the space required for the system.

Direct and indirect applications arising from the present invention relate to the creation of integrated thermoelectric cooling systems that optimise power density (where space is limited) for use as brand new systems or as retrofit solutions for existing photovoltaic systems.

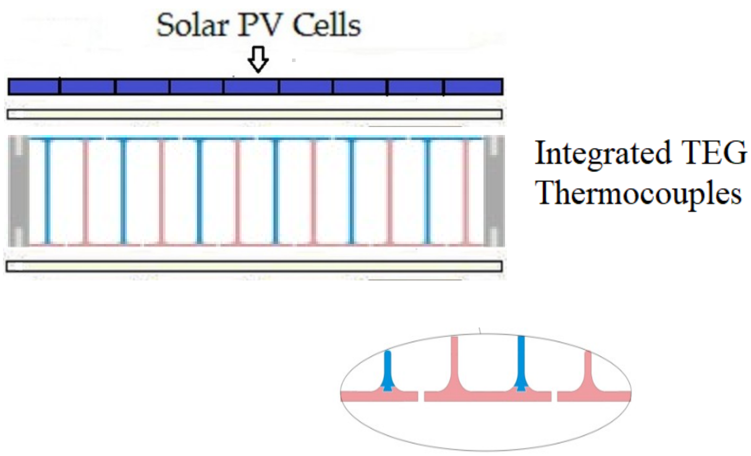


Figure 2. Integrated prototype section

III. NUMERICAL ANALYSIS

The integrated module (Fig.3) consists of a sandwich between two aluminium sheets of thickness d_a and a TEG core. The foil on the PV side is coated on the lower aluminium surface with a layer of elastic electrically insulating material with high thermal conductivity. The foil on the opposite side is coated on the upper surface with the same thermally conductive and electrically insulating elastic material. The external module dimensions are L_t x W_t x H_t. The n and p leg network dimensions are L_n x W_n with the pitch P defined as the space between p and n legs surfaces. A series of M rows of couple of legs in length and N columns of couple of legs in width makes up the TEG module core composed of M x N thermocouples, being each couple of legs of two different conductive or semiconductive materials. The thermoelectric materials are joined together by means of pressure joints. For this preliminary analysis we consider commercial inorganic thermoelectric materials of p and n types such as Bi^2Te^3 (Bismuth Telluride) and PbTe (Lead Telluride).

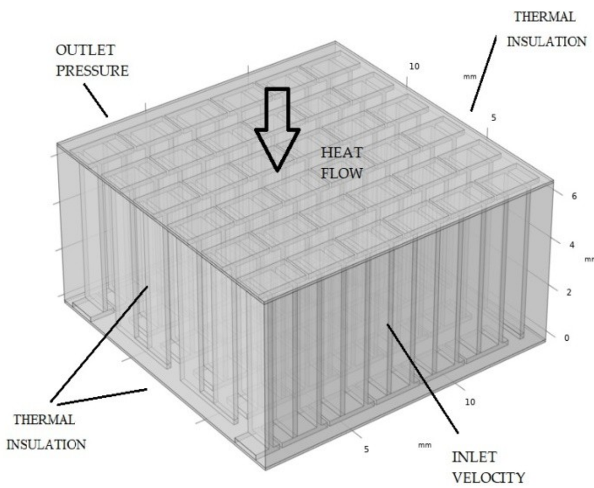


Figure 3. Numerical module

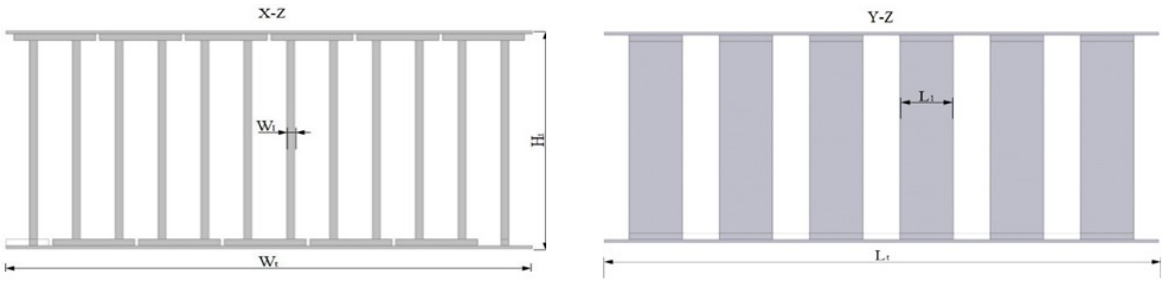


Figure 4 a-b. Integrated module section views (X-Z, Y-Z)

A finite steady-state model was developed to numerically simulate the performance of the integrated PVTE module, bounded by the input and output faces and the thermally insulated ones (Fig. 3). Let L_t be the distance between the input and output planes in the y-direction, W_t the distance between the side planes in the x-direction and H_t the height of the simulated module. The section of the studied domain in the planes normal to the x and y axes is shown in Figure 4 a-b. The numerical boundaries adopted are the inlet and outlet pressure velocities, the insulation on the side walls and the bottom surface, the heat flux equal to 800 W on the front surface modeling absorbed thermal radiation.

Tab.1. Module parameters

Parameters	**Value**	**Unit**
L_t	14.1	mm
W_t	14.1	mm
H_t	7	mm
d_a	0.3	mm
H_l	6.2	mm
n_l	6	-
n_W	12	-
L_n	12.5	mm
W_n	12.8	mm
Q	800	W/m^2
L_l	0.75	mm
W_l	0.15	mm
P	0.8	mm

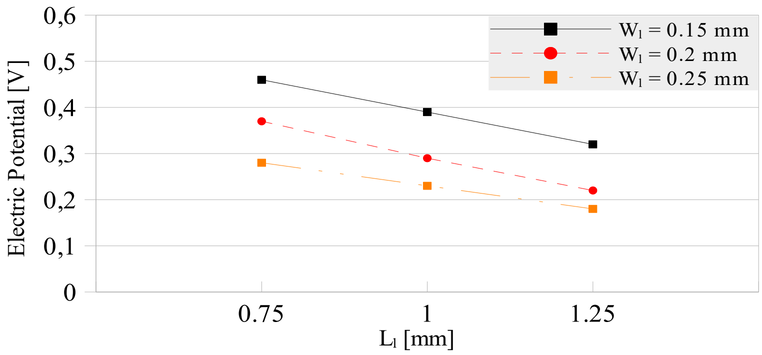
N omenclature	**Description**
L_t	Total length
W_t	Total width
H_t	Total height
d_a	Aluminum sheet thickness
L_l	Leg cross section in length

H_l	Leg height
P	Pitch
n_l	Number of legs in length
n_w	Number of legs in width
L_n	Length of legs network
W_n	Width of legs network
N	Number of thermocouples
T_{ref}	Hot side cell temperature
S_r	Sensitivity ratio
u	Inlet velocity
q	Heat flux
P_v	Ventilation power
P_e	Thermoelectric power

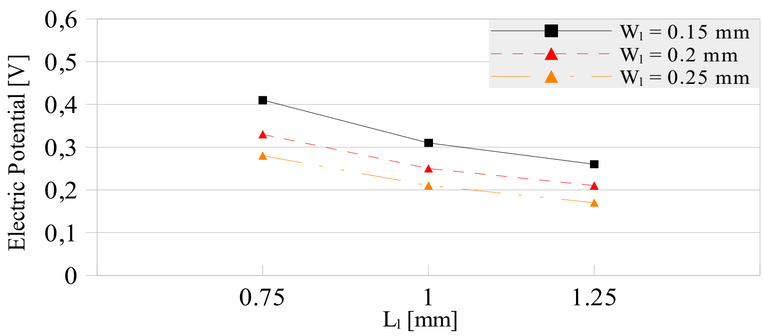
IV. RESULTS

A wide set of geometrical parameters (L_l, W_l and P) at the defined analysis intervals was numerically investigated for the proposed device. Due to technical and operative limits, the final choice should be made on higher leg width and leg length values. The parameters tested for a chosen reference geometry are shown in Table 1. For the geometry considered, the difference between the cooled surface temperature and the incoming air is 50.45 °C (u = 1 m/s) and 48.7 °C (u = 3 m/s), while the electrical potential difference obtained is respectively 0.46 V (u = 1 m/s) and 0.52 V (u = 3 m/s). The pumping power P_v required to move the air is 0.001092 W (u = 1 m/s) and 0.0105 W (u = 3 m/s). It has been calculated as P_v = dP-u-A, where dP is the pressure drop on the module, u the velocity and A the area of the section. The electrical output power of the module P_e is 0.012 W (u = 1 m/s) and 0.014 W (u = 3 m/s). It has been calculated as P_e = V-I, V being the module electric potential and I = J-A the current for a single TEG element with respect to the two semiconductors, J being the current density and A the cross-sectional area. In order to evaluate the influence of the geometrical parameters on the device performance, some geometry variations with respect to the reference case have been considered (Fig.5-6).

a) **P = 0.8 mm**



b) **P = 0.9 mm**



c) P = 1 mm

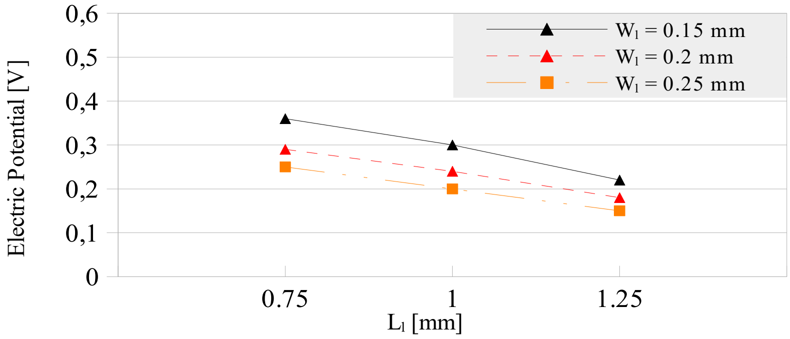
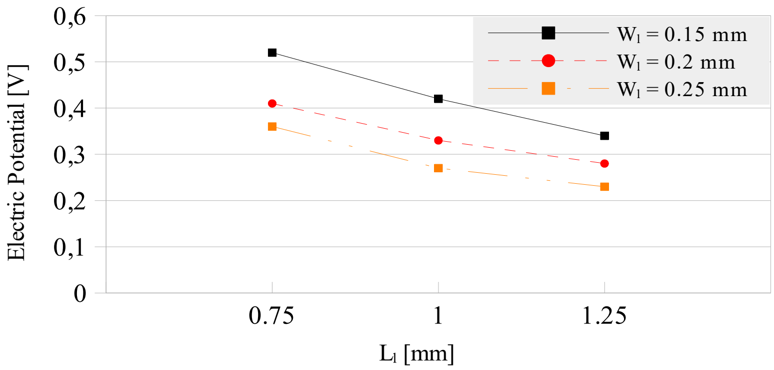
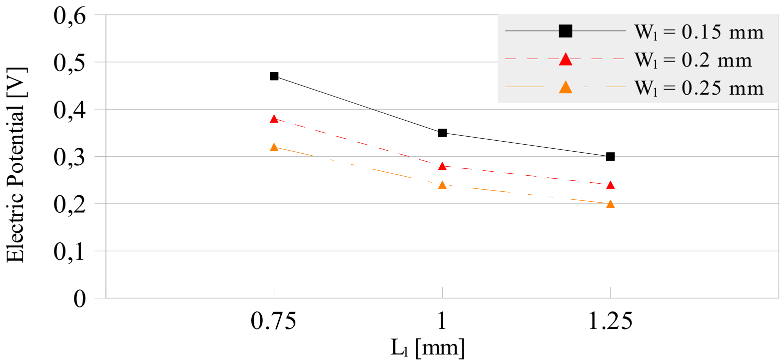


Fig.5 a-b-c Electric potential distribution (u = 1 m/s)

a) **P = 0.8 mm**



b) **P = 0.9 mm**



c) **P = 1 mm**

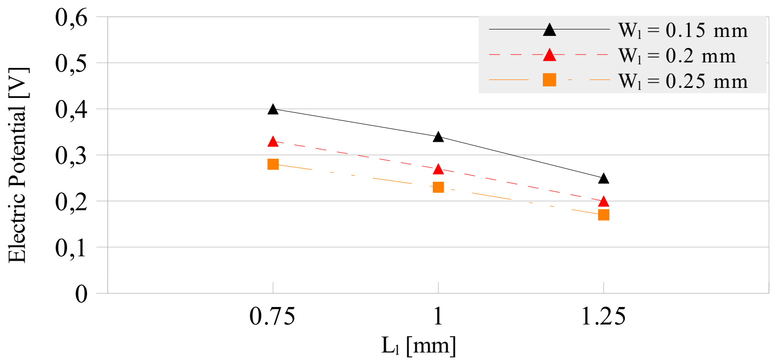


Fig.6 a-b-c Electric potential distribution (u = 3 m/s)

V. CONCLUSION

The following work presents a new integrated thermoelectric cooling and support system that greatly simplifies the overall structure, with the additional aim of maximising energy power density and substantially reducing the final system costs. In order to assess the electrical efficiency of this prototype, a preliminary numerical analysis was carried out . At present, the characteristics of the invention are therefore determined by theoretical analyses carried out on numerical models while waiting for experimental validation through tests on the prototype to be produced soon. The research and development phases are already oriented towards the analysis of new organic materials and low environmental impact solutions capable of making our integrated apparatus even more efficient from an energy and functional point of view.

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