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Numerical study of air cooling photovoltaic panels using heat sinks*

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Abstract. *In this paper is presented a numerical study for the air cooling of the photovoltaic panels integrated in buildings. The studied cases assume the integration of photovoltaic panel on a double skin façade. Numerical simulations were achieved in ANSYS-Fluent software, for 3D model, in forced convection and turbulent flow. The improvement of the air cooling is studied for different inlet velocities and also in case of using a heat sink with ribs. The investigation is focused on the influence of different heights of the ribs on the heat transfer between photovoltaic panel and circulating air. The results are aimed on the conversion efficiency of the photovoltaic cells that is dependent on the average temperature of it.*

Key words: photovoltaic panel, passive cooling, numerical modeling, heat sink, ventilated façade

1. Introduction

A photovoltaic (PV) panel is composed from several photovoltaic cells that are designed to convert solar radiation into electric energy. The performance of photovoltaic panels is quantified as conversion efficiency, or how much solar radiation [W/m^2] is transformed into electric power [W/m^2] in certain conditions. Currently, this efficiency has maximum values between 14% and 17% for mono-crystalline silicon solar cell. The other 80% of solar radiation is transformed almost completely into heat.

The absorption of photons in far layers of p-n junction, that causes the recombination of free electrons, also generates extra heat inside the cells. Another heat source for photovoltaic cell is represented by the absorption of photons at lower energetic levels, without releasing electrons. The heat generated by Joule effect is also influencing the temperature of the PV panel.

In literature there are many studies talking about the dependence between the conversion efficiency and the temperature of photovoltaic cell [9]. The conclusion is that the efficiency is decreasing when the temperature of PV cell is rising, and the variation of maximum power production with temperature is considered almost linear.

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In fig. 1 it can be remarked that the I_{sc} (short-circuit current) value is rising once the temperature of the cell is greater but the V_{oc} (open circuit voltage) value is dropping abruptly, and in consequence the P_{max} (maximum power) is dropping too. The reduction of efficiency can be considered as approximately 0.3%…0.5% for each degree of temperature rise over 25 °C.

In this regard, the best conversion efficiency would be realized into the space, where the average temperature is near 0 K.

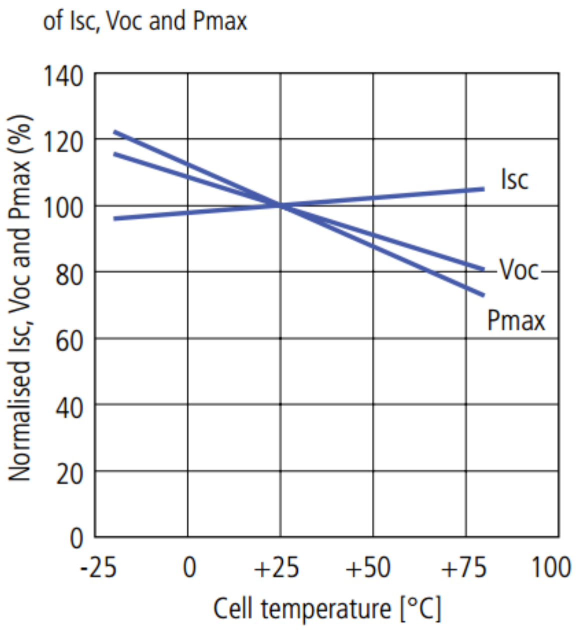


Fig. 1. The influence of temperature over conversion efficiency [1]

Skoplaki E. et al. [2] present different methods and relations for calculating the dependence between conversion efficiency and temperature of PV cells.

Because the power of a PV cell is dependent on temperature changes and solar irradiation level, in literature [10], are defined the standard parameters that are generating the Watt-peak (Wp). Therefore, the electrical power produced by a photovoltaic panel, measured in Wp, is defined for an average temperature of the cell of 25 °C, wind speed of 1 m/s and intensity of solar radiation of 1000 W/m^2.

In literature are presented many solutions for cooling the photovoltaic panels, by using the air, water or phase changing materials.

Cuce et al. [3] studied a method for improving the temperature of photovoltaic panels by using the air as a passive cooling. In that study the efficiency of PV panels is considered in three ways: energetic efficiency, efficiency of the conversion power and exergetic efficiency.

Another important study of the air cooling of photovoltaic panels was realized by Tonui et al. [4]. The cooling is obtained by realizing a ventilated channel of 10 cm width behind the photovoltaic panel. That study presents the PV/T technology that represents an optimized way of using photovoltaic panels with an additional role of producing thermal energy. This aspect is very important because are produced two of the most used types of energy and the proper functioning of each one brings benefits to the other. It must be mentioned that in case of using PV/T systems the priority is represented by electrical energy production.

2. Case description

In this paper is studied the air cooling solution for PV panels by adding a ventilated channel behind them, that represents an interesting solution in case of integration of photovoltaic panels into buildings. For the buildings equipped with double skin façade, the PV panels can be inserted as exterior glazing and the channel of the façade can be used for air cooling. The ventilation of the channel can be realized naturally, determined by the thermal circulation or pressure differences, or mechanically for achieving velocities over 0.5 m/s.

The usual photovoltaic panels have some different layers depending on the technology of conception and producer. An example of structure for PV panels is presented and studied by Armstrong el al. in [5]. Thus, the main layers are: exterior glass, ARC (anti reflexive coating), PV cells, EVA (ethylene-vinyl acetate), metal rear contact and tedlar (realized from PVF). The thermo-physical properties of these layers are presented in table 1 [5].

Table 1

Thermo-physical properties of the PV panel layers

Layer	Thickness (m)	Thermal conductivity (W/mK)	Density (kg/m^3)	Specific heat Capacity (J/kgC)
1. Glass	0.003	1.8	3000	500
2. ARC	100×10^{-9}	32	2400	691
3. PV Cells	225×10^{-6}	148	2330	677
4. EVA	500×10^{-6}	0.35	960	2090
5. Rear contact	10×10^{-6}	237	2700	900
6. Tedlar	0.0001	0.2	1200	1250

In this paper, the photovoltaic panel is considered as a single layer with thermal characteristics of the PV cells. For realizing a better heat transfer from the photovoltaic cell, a heat sink with ribs is connected behind it. The heat sink must be realized from metals with high conductivity like copper.

3. Numerical Modeling

For this study, a small scale photovoltaic panel of 500mm x 500mm was considered. Since the temperature of photovoltaic cell is decisive regarding conversion efficiency, we considered the solution of air cooling the cells by using a heat sink connected to the PV panel. The heat sink is designed like a ribbed wall (fig. 2.), using ANSYS-Design Modeler, with the following dimensional characteristics:

- h – rib height (1...5 cm);
- s –step between ribs (5 cm);
- L, H – length and width of heat sink (L = H = 500 mm);
- g – thickness of heat sink base (2 mm);
- g_n – thickness of ribs (2 mm);
- l_n – length of ribs (480 mm);

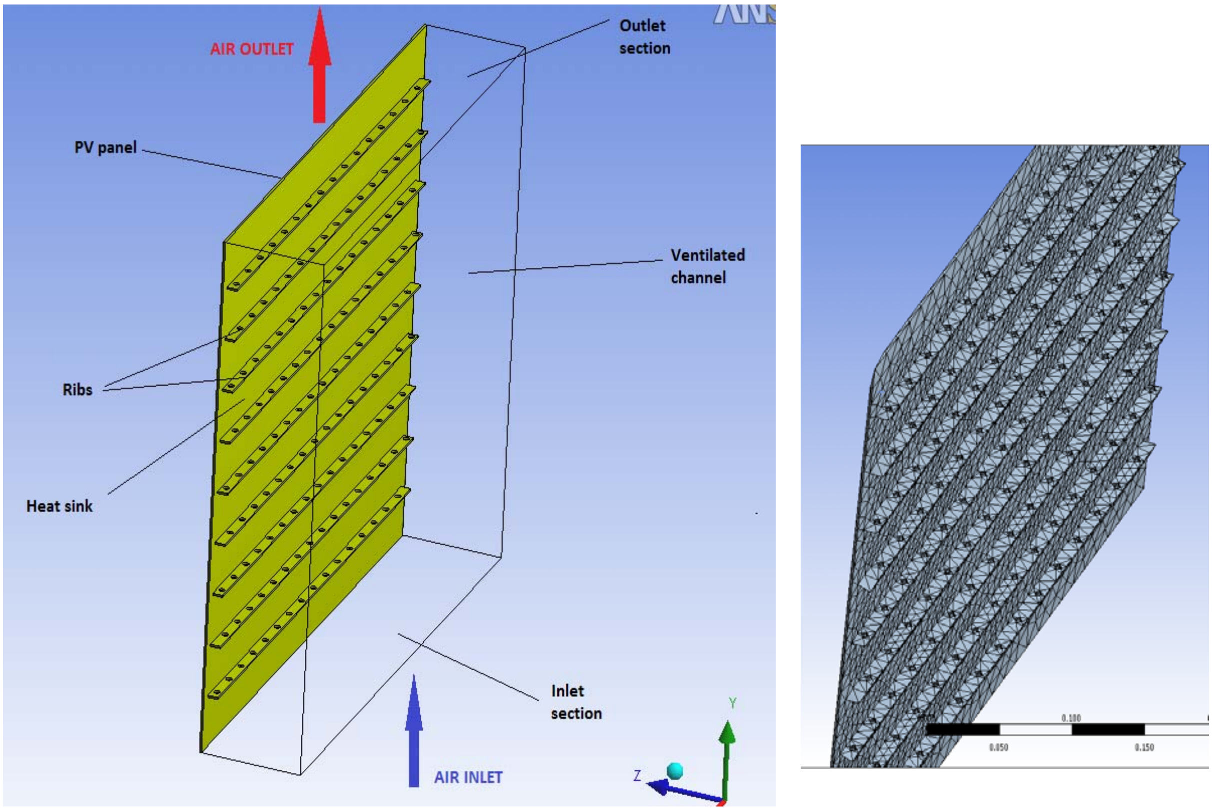


Fig. 2. Geometry and mesh of the model

The mesh – fig. 2 was realized with different refinement for the heat sink and ventilation channel. Hence, the minimum size of the finite element is about 2 mm for the heat sink and ribs and about 8 mm for the air channel. This fact was necessary taking into account the time needed for simulations. The mesh was created using ANSYS-Meshing and resulted a number of 194921 tetrahedral cells and 382888 interior faces.

The double skin facade system is created behind this ensemble and consists of a ventilated channel of 10 cm width. In this way, the heat sink is placed inside the channel and can be cooled using the ventilation system of the double skin facade.

The ribs of the heat sink have circular holes of 3 mm radius, placed at 30 mm distance one to another in order to improve the air circulation near the heat sink and extract more heat from the PV panel.

The different cases studied in this paper were realized by modifying the height of ribs from 1 cm to 5 cm with the step of 1 cm. Once the height is growing another row of holes is added on the rib.

The numerical simulation was realized using ANSYS-Fluent software. It was determined the average temperatures of photovoltaic panel in steady regime for the five configurations of heat sink for inlet velocities of 0.5 m/s, 1 m/s, 1.5 m/s and exterior temperature of 35 °C. In this study the variation of the height is considered in terms of h/s ratio. The sunlight conditions were considered for a summer day, without clouds, near Iasi and for a vertical position of photovoltaic panel. Hence, the maximum solar radiation for these conditions is about 500 W/m^2.

The flow regime considered is the turbulent one. The model of turbulence used in numerical simulations was k-ε RNG that is the most realistic for air flow inside channels [6].

The turbulence intensity I can be estimated as:

$$I = 0.16 \cdot \mathrm{Re}^{-\frac{1}{8}} \quad [7]$$

The characteristic values used as input for turbulence model was:

I – turbulence intensity of 5.5 %, 5 % and 4.8 % respectively for inlet velocities of 0.5 m/s, 1 m/s and 1.5 m/s;

D_H – hydraulic diameter of 0.166 m;

The results of simulations, for numerical model, are obtained for a solar radiation of 500 W/m^2. To the outer surface of photovoltaic panel, exposed to the sun, was considered a convective heat transfer with the exterior air with following values: $\alpha = 8\ W/m^2K$ and exterior temperature.

The optical parameters of photovoltaic panel, as ensemble, were synthesized in the software model as the coefficient of absorption of solar radiation of $\alpha = 0.7$ [8]. The model used to simulate the solar radiation was the Fluent specific tool Solar Ray Tracing.

To resolve the continuity, the momentum and the energy equations, a computational program named Fluent based on the control volume method have been used with a SIMPLE algorithm. This method uses a relationship between velocity and pressure corrections to enforce mass conservation and to obtain the pressure field. In order to reduce the time necessary for simulations the soft was set for First Order Upwind in equation solver. A fully implicit numerical scheme is employed, in which upwind differences are used for the convective terms and central differences for the diffusion terms. The calculation is an iterative one, the chosen convergence criteria are 10^{-6} for the energy equation and 10^{-3} for the pressure, velocities and continuity equations.

4. Results and discussion

The results are presented as velocities and temperatures spectra and as parametric curves like:

$$t_{medPV} = f\,(h/S;\ v_{in}) \quad [°C]$$

The first step consisted in determining the most favorable velocity regime in order to obtain a good cooling for the photovoltaic panel. Thus, for a constant ratio h/S of 1/5 and inlet temperature of 35 °C we realized a variation of inlet velocity of the air and the results are presented in fig. 3.

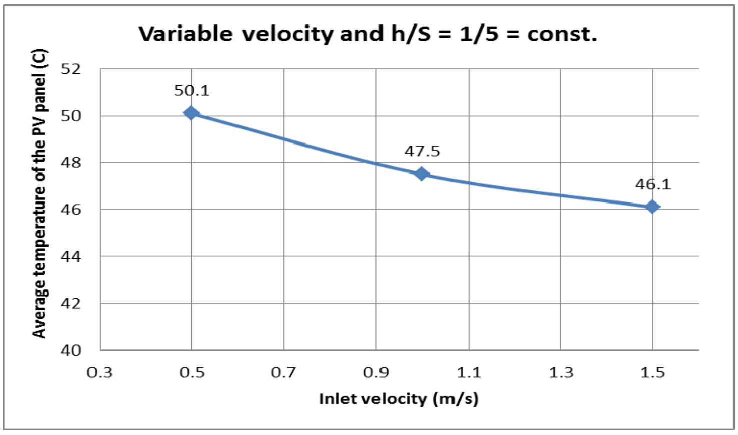


Fig. 3. Variation of PV panel temperature (interior surface) for different inlet velocities

It can be observed – fig. 3, that for this configuration, the lowest temperature of PV panel is achieved for the inlet velocity of 1.5 m/s. This value is used in the following simulations as constant for determining the relation between the average temperature of PV panel and h/s ratio.

By increasing the height of the ribs and maintaining constant the other parameters, the following cases are resulting:

Case 1: h/s = 1/5

Case 2: h/s = 2/5

Case 3: h/s = 3/5

Case 4: h/s = 4/5

Case 5: h/s = 5/5

In fig. 4 are presented the results obtained in all five studied cases, for similar temperature and solar radiation conditions, considering the inlet velocity v = 1.5 m/s, same for all simulations.

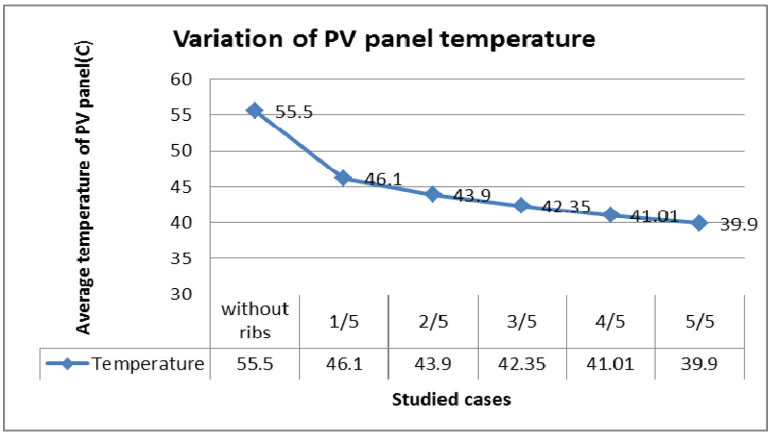
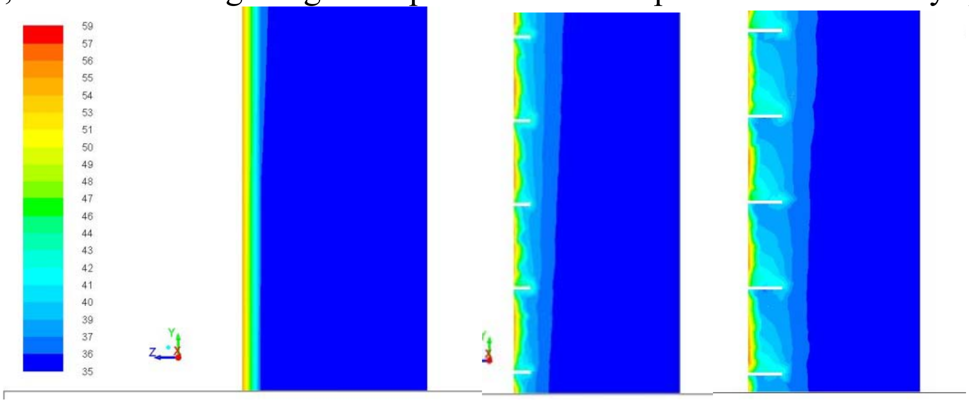


Fig. 4. Average temperature of PV panel for diferent h/S values

It can be observed - fig. 4 that the average temperature of photovoltaic panel has the tendency to decrease once the height of the ribs is growing. For the studied cases, an improvement of PV average temperature can be remarked with a ratio of minimum 1 °C for each centimeter raise of height.

For the base case, without using ribs, the location of the PV panel is similar to other studied cases, but there is no heat sink connected behind it. A reducing of almost 10 °C is recorded when there are used the smallest ribs of 1 cm height comparing to the case without ribs, and 15 °C for the case with 5 cm height – fig. 4.

For a better view over the phenomena inside the channel and near the ribs of the heat sink, in the following images are presented the temperature and velocity spectra.



a) b) c)

Fig. 5. Temperature spectra for cases: a) without ribs; b) h=1 cm; c) h = 2 cm

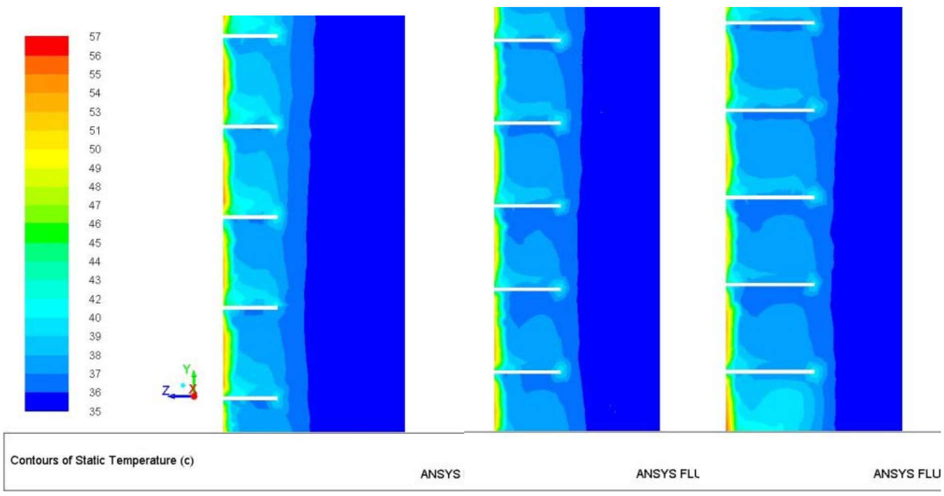


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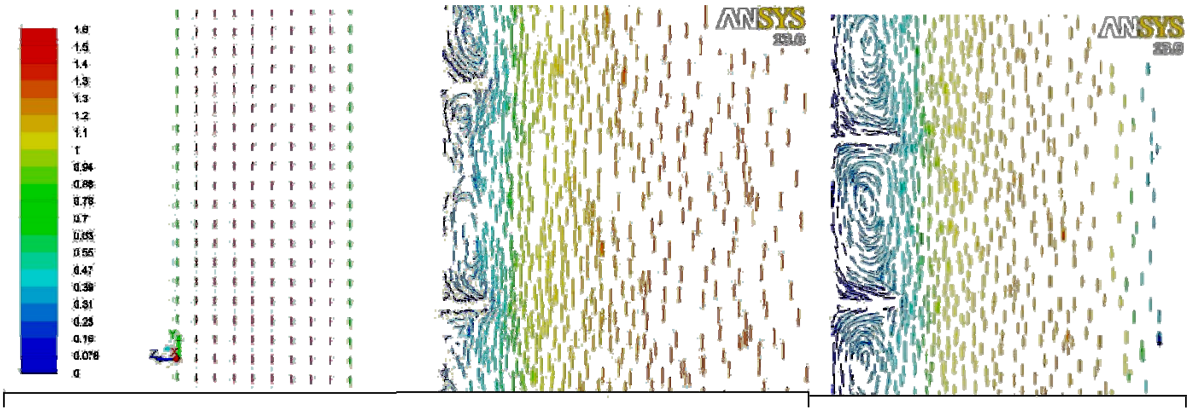
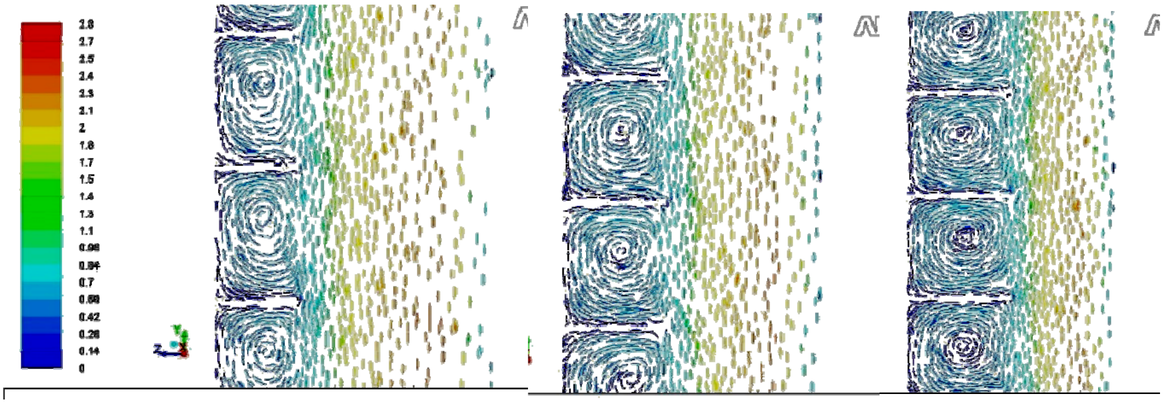
Fig. 6. Temperature spectra for cases: a) h = 3 cm; b) h = 4 cm; c) h = 5 cm



a) b) c)

Fig. 7. Velocity magnitude for cases: a) without ribs; b) h=1 cm; c) h = 2 cm



a) b) c)

Fig. 8. Velocity magnitude for cases: a) h = 3 cm; b) h = 4 cm; c) h = 5 cm

The temperature spectra, fig. 5,6, highlights that the heat transfer from the heat sink to the air inside the channel is becoming more intense once the height of the ribs becomes larger. It can be observed that the warm air near the heat sink is combining better with the colder one that is circulating inside the channel, and so there is obtained a more efficient cooling of the PV panel.

Figures 7,8 confirm the precedent affirmations, the heat transfer being better because of the amplified turbulence phenomena determined by the ribs presence. Also, the recirculation between ribs becomes more important when the ribs are higher and the efficiency of the heat sink is increasing.

According to fig. 1, the efficiency of photovoltaic panel has a strong variation depending on the temperature of PV silicon cell. The performance can be represented by the main parameters of photovoltaic panel like the voltage and intensity of the current produced, globally expressed as maximum produced power. In this way, it can be seen that for a temperature of 55.5 °C, the electrical power produced by solar cell becomes approximately 85 % of the nominal one. These values of power percentage depending on temperatures are presented in table 2.

Table 2

Influence of temperature on the efficiency of PV panels for studied cases

Case	t_p [°C]	*[%] of P_N	η	**P_{elspec} [W/m^2]	S [m^2]	P_{el} [W]	Increase compared to base case [%]
base***	55.5	86	0.1376	68.8	0.25	17.2	-
h/S=1/5	46.1	89	0.1424	71.2	0.25	17.8	3.48
h/S=2/5	43.9	91	0.1456	72.8	0.25	18.2	5.82
h/S=3/5	42.35	92	0.1472	73.6	0.25	18.4	6.98
h/S=4/5	41.01	93	0.1488	74.4	0.25	18.6	8.14
h/S=5/5	39.9	94	0.1504	75.2	0.25	18.8	9.31
Nominal	25	100	0.16	80	0.25	20	16.28

* According to fig. 1
** For solar radiation of 500 W/m^2
*** Case without ribs

Where: t_p – average temperature of PV panel [°C];
P_N – nominal produced power at 25 °C [W];
η – conversion efficiency;
$P_{elespec}$ – specific electric power [W/m^2];
S – Surface of PV panel [m^2];
P_{el} – electrical power produced by the studied PV panel [W];

5. Conclusions

For a nominal conversion efficiency of 16%, in table 2 are also presented the respectively performances for different cases: η. A performance of 16% can be expressed as an electric energy production of 160 W/m^2, in nominal conditions that requires 1000 W/m^2 of solar radiation. In this paper, in the studied models we used the maximum value of solar radiation of 500 W/m^2 as constant and the surface of PV panel of 0.25 m^2. But the maximum power produced by a photovoltaic cell also depends of the value of solar radiation, most often linearly and proportionally. So, the maximum power that can be produced by studied panel in our imposed conditions can reach 80 W/m^2, for a temperature of 25 °C.

It can be concluded that the purpose of decreasing the average temperature of PV panel is very important. Though for the studied case, a small dimension photovoltaic panel of 0.5m x 0.5m, the difference between the cases with no ribs to the cases when the ribs are used is about 0.6 to 1.6 W of electrical power produced, the problem must be traced deeper. In this way, we can focus on the percentage of increase that is from 3.5% to 9.3%. From this point of view, the improvement is more significant in case of using of a large scale building integrated photovoltaic system with installed power of several kWp. In this case every percent of extra power produced is very important, taking into account the investment that is quite expensive.

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