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Optimal Position of Two Fans Cooling a Large PV Panel

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Abstract: To overcome the negative effect of the rise in temperature of photovoltaic (PV) panel on its performance, cooling is used. However, this cooling must be as homogeneous as possible. Indeed, the uniform cooling of a photovoltaic (PV) panel is important to maintain its conversion efficiency at a high level. In this work, a cooling system is proposed using two fans that blow ambient air onto the backside of the PV panel. Several configurations of fans positions (air inlets) and air outlets are studied by simulations in order to optimize the cooling system and to achieve a uniform temperature distribution on the PV panel. On a typical summer day with an optimal air flow rate of 200g/s, the optimized cooling system reduces the temperature of the PV panel by 21.66°C and improves its conversion efficiency by about 8.85%. In the absence or at low wind speeds, these values can reach 35.84°C and 16.5%.

Keywords: Cooling, efficiency, Fan, Homogenization, Temperature field, Photovoltaic panel.

Introduction

Air cooling of solar PV panels has been widely investigated (Shukla et al., 2017; Hasanuzzaman et al., 2016). Most of them were only interested in improving the efficiency of the cooled PV panel without taking into account the homogeneity of the temperature field distribution on the PV panel. Indeed, significant temperature gradients on the PV panel can generate thermal stresses which can contribute to its premature degradation (Røyne, 2005).

Muneeshwaran et al. (2020) proposed to use the air supplied by an air conditioning unit to cool a PV panel. The cold air then circulates through a channel of uniform section. Thus, the maximum temperature gradient reached 7°C. By using a converging cross-section channel, the temperature gradient was reduced to only 2.5°C. This resulted in a 20-25% efficiency improvement. Another cooling system that consists on fans that blow ambient air on the rear face of a PV panel was investigated by Bayrak (2022). He studied the influence of the number of fans that cool a medium-sized (0.665m²) PV panel. He improved the electrical efficiency of the PV panel by only 2.69% by using four fans.

Syafiqah et al. (2017) investigated the cooling of a medium-sized (0.648m²) PV panel using two fans. They improved the electrical efficiency of the PV panel by 3% by lowering the average PV panel temperature from 66.2°C to 53.6°C. However, the temperature distribution was not uniform. It showed a maximum temperature difference between the cold and hot zones of about 14°C. Using a single fan on a small PV panel (0.064 m²), Nebbali et al. (2020) obtained 29% of the efficiency improvement of the cooled PV panel but with a significant heterogeneity of the temperature field. Bevilacqua et al. (2020) confirmed this observation on a large PV panel (1.66m²) cooled by a single fan.

The objective of this work is to investigate the cooling provided by two fans placed at the backside of a standard size (1.28m²) PV panel. Through 3D numerical simulations, the effect of different positions of these fans, associated with two air outlets configurations were studied to determine the optimal configuration. In addition, the thermal and electrical responses of the PV panel during a typical day were also studied.

Problem Position

The device consists of a standard size (158x80.8cm) PV panel that is cooled from its rear face by the ambient air which is blowing by two fans. The optimal case that corresponds to the judicious positions of the two fans and the air outlets (Fig. 1) which allow better ventilation was determined in order to ensure well cooling of the PV panel with homogeneous temperature field. For this purpose, six scenarios were considered (Fig. 1, Table 1).

Simulations were carried out under extreme climatic conditions characterized by a situation of no wind, 1000W/m² of solar radiation and 50°C of air temperature. Thus, the total air flow rate supplied by the two fans was considered equal to 400 g/s. Finally, using the optimal case, we studied the effect of climatic conditions of a typical summer day on the performance of the cooled PV panel.

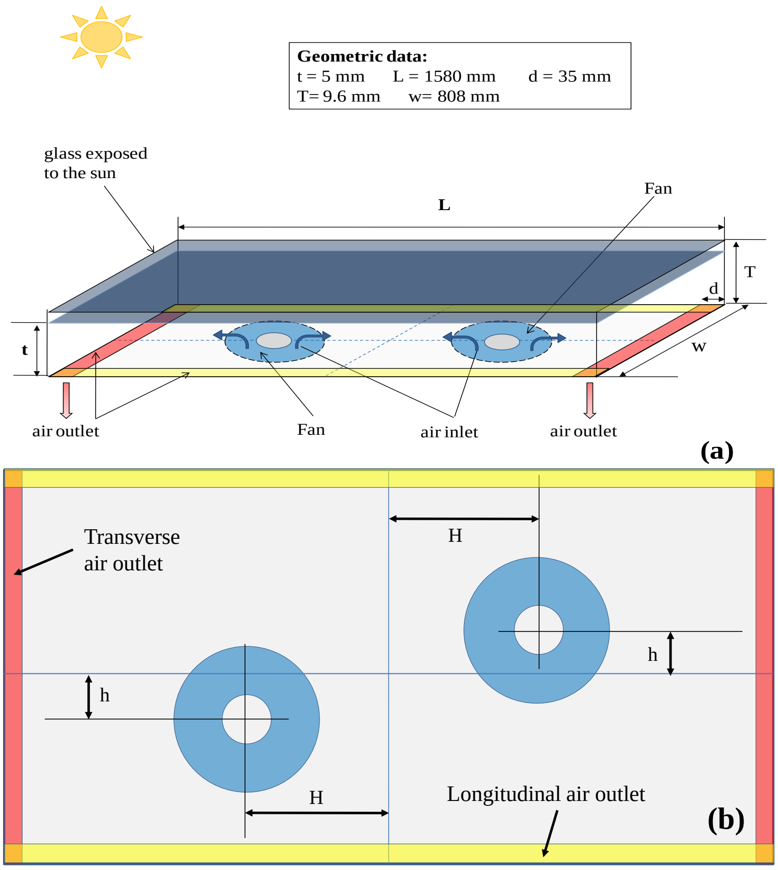

Figure 1. (a) Sketch of the PV panel with the cooling system; (b) Bottom view of the cooled PV panel with different configurations.

Table 1. Positions of the fans and of the air outlets.

	H(cm)	h(cm)	Diameter of two fans (cm)	Air Outlet
Case (a)	39.5	0	30	Transverse air Outlet
Case (b)	39.5	0	30	Longitudinal air outlet
Case (c)	0	20.2	20	Transverse air Outlet
Case (d)	0	20.2	20	Longitudinal air outlet
Case (e)	29.5	10	30	Transverse air outlet
Case (f)	29.5	10	30	Longitudinal air outlet

Calculation Domain, Mesh and Boundary Conditions

The six calculations domains were constructed in 3D. Each of them, included the airflow cavity, the air inlets occurred by fans, air outlets and the different layers that make up the PV panel (Table. 2).

Table 2. Characteristics of the different layers that make up the photovoltaic module(Armstrong and Hurley, 2010).

Layer	Thickness "e" (mm)	λ(W/m/k)	ρ(kg/m^3)	C$_P$(J/kg/°C)
Glass	3.2	1.8	3000	500
Silicon	0.3	148	2330	677
EVA	0.5	0.35	960	2090
Tedlar	0.1	0.2	1200	1250

For good mesh resolution, the bottom plane of the PV panel, where the air inlets and outlets were grafted, was first meshed in 2D. Then, by extrusion, a 3D mesh was generated. For the 5mm high air cavity a 1mm deep mesh was used, while for Tedlar, EVA, Silicone and Glass the depth equal to the thickness of each layer.

The air inlets, which represent the cross-sections of the fans, were equated to the "MASSFLOW-INLET" type condition which allowed define the air mass flow rate as well as the air temperature blowing by the two fans. The air outlet sections were "OUTFLOW" type. This ensured the conservation of flows between the air inlets and outlets. The glass and the silicon media were the seat of heat sources produced by the heat exchanged between the PV panel and its surrounding.

Associate Equations

Heat Equation

The heat equation associated to each solid layer of the PV panel corresponds to the Poisson equation in steady state. It is expressed by the equations (1) and (2), respectively, for the glass (g) and silicon (si):

$$\Delta T + \frac{\alpha_g R_G - \varepsilon\sigma\left(T_g^4 - T_V^4\right)}{e_g \lambda_g} = 0 \tag{1}$$

$$\Delta \mathrm{T} + \frac{\alpha_{\mathrm{si}} \tau_{\mathrm{g}} \mathrm{R}_{\mathrm{G}}}{\mathrm{e}_{\mathrm{si}} \lambda_{\mathrm{si}}} = 0 \tag{2}$$

where "Δ" is the Laplacian operator, T is the temperature, α is the absorption coefficient, ε is the emissivity of the surface of the PV, σ is the Boltzmann constant, eis the thickness and τ_g is the transmissivity of the glass.
T_V is the sky temperature correlated by the following relation (Kaplani and Kaplanis, 2014):

$$\mathrm{T_V} = 0.0552\ \mathrm{T_{air}^{1.5}} \tag{3}$$

Furthermore, the EVA is considered transparent while the silicon is opaque.
In addition, the PV panel is the seat of convective heat exchange between each face and the ambient air. Thus, for a PV panel inclined at θ < 60° with respect to the vertical, the Nusselt number of the front face in natural convection is expressed by (Fujiiand Imura (1972), Kaplani and Kaplanis (2014)):

$$\mathrm{N_{u_n}} = \begin{cases} \mathrm{f}\left\{0.16\left[\mathrm{R_a^{0.33}} - (\mathrm{G_{r_c}P_r})^{0.33}\right]\right\} + 0.56\left(\mathrm{G_{r_c}P_r}\cos\cos(\theta)\right)^{0.25}, & \mathrm{R_a} < 5\,.\,10^8 \\ \mathrm{f}\left\{0.13\left[\mathrm{R_a^{0.33}} - (\mathrm{G_{r_c}P_r})^{0.33}\right]\right\} + 0.56\left(\mathrm{G_{r_c}P_r}\cos\cos(\theta)\right)^{0.25}, & \mathrm{R_a} \geq 5\,.\,10^8 \\ \mathrm{G_{r_c}} = 1.327\,.\,10^{10}\mathrm{e}^{\left(-3.708\left(\frac{\pi}{180}\theta\right)\right)} \\ \mathrm{f} = 0 \text{ si } \mathrm{R_a} < \mathrm{G_{r_c}P_r} \\ \mathrm{f} = 1 \text{ si } \mathrm{R_a} > \mathrm{G_{r_c}P_r} \end{cases} \tag{4}$$

While for the rear side of the uncooled PV panel, the Nusselt number corresponds to (Bergman et al. 2011):

$$N_{u_n} = \begin{cases} 0.68 + \dfrac{0.67\, R_a^{0.25}}{\left(1+\left(\frac{0.492}{P_r}\right)^{\frac{9}{16}}\right)^{\frac{4}{9}}}, & R_a \leq 10^9 \\ \left(0.825 + \dfrac{0.387\, R_a^{\frac{1}{6}}}{\left(1+\left(\frac{0.492}{P_r}\right)^{\frac{9}{19}}\right)^{\frac{8}{27}}}\right)^2, & R_a > 10^9 \end{cases} \tag{5}$$

In other convections situations occurred by the wind, the following relationships are adopted (Armstrong and Hurley (2010); Kaplani and Kaplanis(2014)):

$$h_{conv} = \begin{cases} h_n = \frac{N_{u_n} \lambda_{air}}{L_c}, & \frac{G_r}{R_e^2} > 100 \\ h_f = 2.56\, V + 8.55\,, & \frac{G_r}{R_e^2} < 0.01 \\ h_{mixt} = \sqrt[3]{h_n^3 + h_f^3}, & 0.01 \leq \frac{G_r}{R_e^2} \leq 100 \end{cases} \tag{6}$$

Where Ra is the Rayleigh number which is a function of the Grashof and Prandtl. L_c is the characteristic dimension of the plate expressed as the ratio of the area of the plate to its perimeter. For the cooled PV panel, the heat exchange between the rear face and the ambient air is determined by solving the coupled equations of continuity, momentum and energy. To do this, we used CFD-Fluent code (Fluent Inc., 2001).

Fan Power

Nominal values of the fan are given by the manufacturer, as well as: Power fan (P_{fan}^n=80W), air flowrate (Q^n =980g/s), Diameter (D^n=30.5cm) and rotation speed (N^n=2250rpm). In other operating conditions, the electrical power P_{fan} consumed by the fan of diameter D, that blow an airflow Q at rotation speed of N , can be evaluated by the following expressions (He et al. 2014, Zhang et al. 2022):

$$\frac{Q}{Q^n} = \left(\frac{D}{D^n}\right)^3 \frac{N}{N^n} \tag{7}$$

$$\frac{P_{fan}}{P_{fan}^n} = \left(\frac{D}{D^n}\right)^5 \left(\frac{N}{N^n}\right)^3 \tag{8}$$

PV Panel Efficiency

The electrical efficiency of a PV panel is defined by (Skoplaki and Palyvos, 2009):

$$\eta = \eta_{ref}(1 - \mu(T_{si} - 25)).100 \tag{9}$$

Where η_{ref}=15.74% is the efficiency of the PV panel at standard conditions. μ is the power temperature coefficient equal to 0.37%/°C and T_{si} is the equilibrium temperature of the uncooled PV panel. In the case of the cooled PV panel, which equilibrium temperature is T_{si}^*, the electrical power P_{fan} consumed by the two fans supplied by the PV panel must be taken into account, so the efficiency (η^*) of the cooled PV panel that area is S, becomes:

$$\eta^* = 100\left(\eta_{ref}(1 - \mu(T_{si}^* - 25)) - \frac{P_{fan}}{R_G S}\right) \tag{10}$$

The improvement electrical efficiency of the cooled PV panel compared to the uncooled one is then quantified by:

$$\eta_r = 100.\frac{\eta^* - \eta}{\eta} \tag{11}$$

Results and Discussion

Temperature Field

Optimal Configuration

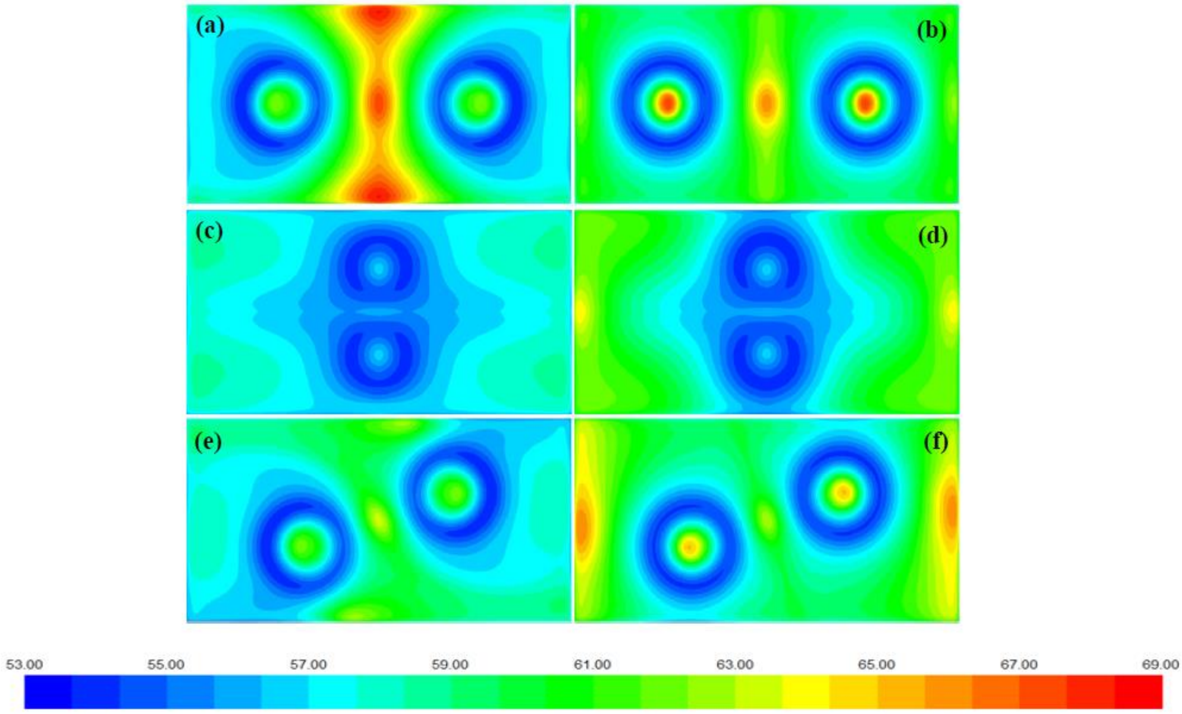

Figure 2. Temperature field (°C) on the cooled PV panel for the six configurations at T_{air} = 50°C, R_G=1000W/m² and Q=400g/s.

Fig. 2 shows the temperature distribution on the cooled PV panel with different fans configurations as shown in Table 1. It appears that the case (c) is the optimum configuration. Indeed, it allows good circulation of air through the cavity and ensures better cooling with lowest average silicon temperature of 56.74°C and well homogeneity of the temperature field (δT_{max}= 4.5°C).

Effect of Real Climatic Conditions

By using the optimal configuration (Case C), we studied the effect of the climatic conditions varying during a typical summer day of 30 July prevailing at Tizi-Ouzou, north of Algeria (36.7N, 4.05E). Thus, The PV panel was oriented facing south and tilted by 32° (Kecili et al., 2022). Moreover, the PV panel was cooled by two fans that blow a total mass flow rates varying from 100 to 250g/s. Using the PVGIS database for the year 2020, we obtained the daily evolution of the global incident solar radiation (R_G), the ambient air temperature (T_{air}) and the wind speed (Fig. 3-a).

The simulations led then to the daily evolution of the PV panel temperature in cooled and uncooled situations (Fig. 3-b).The maximum temperature of the uncooled PV panel reaches 69°C at the culmination time (midday) while the temperature of the cooled PV panel drops significantly.

In addition, Table 3 gives the temperature difference (δT) between the minimum and maximum values reached by the cooled PV panel for each airflow. This allowed to assess the homogeneity of the temperature field on the PV panel. It appears that the increase in the air flow attenuates the heterogeneity of the temperature field. The maximum temperature difference between the hot and cold zones reaches 9.47°C with 100 g/s of airflow to settle at only 5.46°C with 250 g/s. Moreover, the lowering temperature (σT) generated by the cooling of the PV panel rises when the airflow increases. Indeed, σT reaches 17.06°C at 100g/s airflow and 22.34°C at 250g/s.

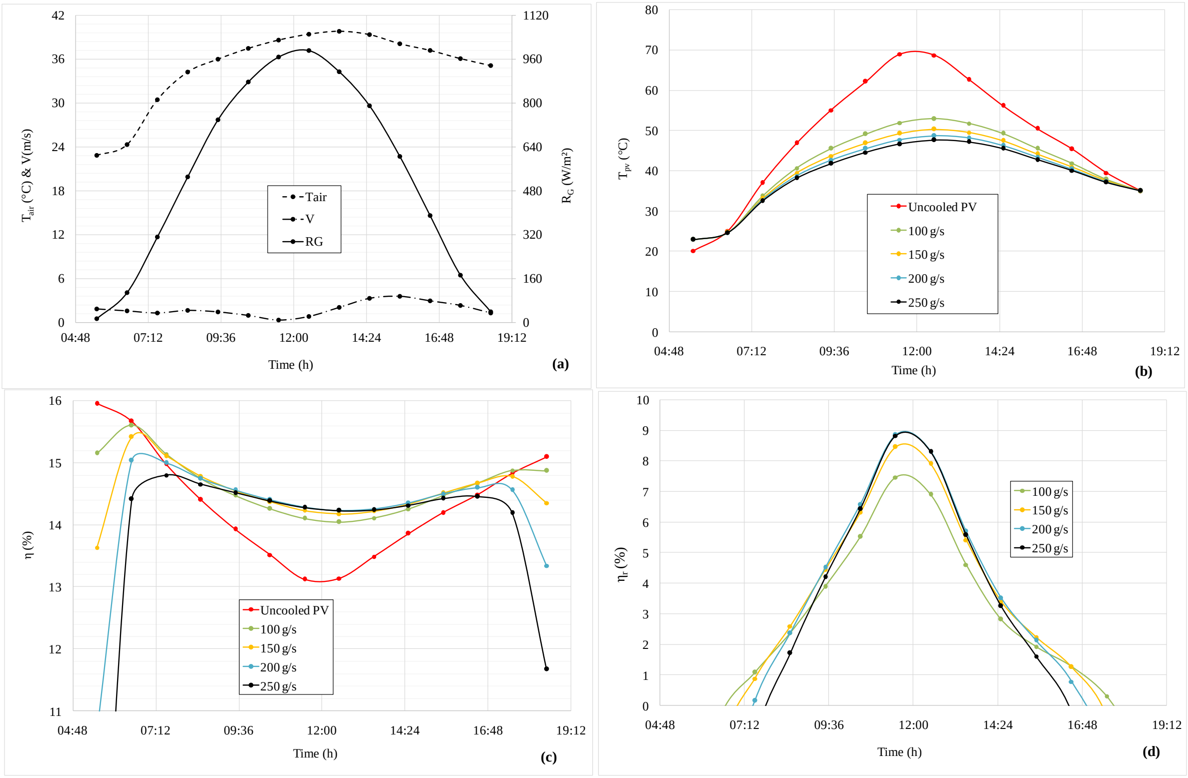

Figure 3. Evolution of: (a) temperature ambient, solar radiation and wind velocity on 30 July, (b) PV panel temperature, (c) PV efficiency and (d) efficiency improvement of the cooled PV with respect of the uncooled one for different airflow rates.

Table 3. Minimum (T_{min}), maximum (T_{max}) and average temperatures of the cooled and uncooled PV panel at midday.

Cooled PV panel					Uncooled PV panel	$\sigma T = T_{PV}^{uncooled} - T_{PV}^{cooled}$
Airflow rate	T_{min}	T_{max}	$\delta T = T_{max} - T_{min}$	T_{PV}^{cooled} (°C)	$T_{PV}^{uncooled}$ (°C)	
100 g/s	45.16	54.63	9.47	51.86	68.92	17.06
150 g/s	44.02	51.57	7.55	49.25		19.67
200 g/s	43.35	49.68	6.33	47.66		21.26
250 g/s	42.92	48.38	5.46	46.58		22.34

Efficiency Improvement

The efficiencies of the PV panel are shown in Fig. 3-c, the effect of cooling is clearly seen during the period between two hours after sunrise and two hours before sunset. Thus, higher is the airflow, better is the efficiency. Outside this period, the efficiency of the cooled PV panel is significantly lower than that of the uncooled one, as the fans consume more energy than the gain generated by the cooled PV panel. The efficiency improvement of the cooled PV panel compared to the uncooled one is given by the figure (3-d). We can observe that the maximum improvement of 8.85% is reached at only 200g/s of airflow.

Conclusion

The homogenization of the temperature field in a PV panel is an important parameter that should not be neglected in a study of a cooling system. For this purpose, numerical simulations were carried out to propose an optimal cooling device that allows homogenize this temperature distribution. Using two axial fans that blow air onto the backside of a large standard commercial PV panel, the effect of their positions and those of the air outlet sections on the cooling provided were studied. First, the simulations were carried out under extreme climatic conditions (No wind situation, R_G=1000W/m² and T_{air}= 50°C). Then, the configuration favoring the consequent cooling of the PV panel with a homogeneous temperature distribution was selected as the optimal configuration. Then, we studied the effect of the climatic conditions varying during a typical summer day of 30 July prevailing at Tizi-Ouzou, north of Algeria (36.7N, 4.05E). It was shown that at noon, from an air flow of 200g/s, the improvement in the efficiency of the cooled PV panel was settled 8.85% while the lowering of temperature was 21.26°C.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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