EFFECT OF VENTILATION IN A PHOTOVOLTAIC ROOF

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Abstract: This report analyzes the convenience of installing PV panels on roofs leaving some space between the roof and the panel. The report also compares the differences between cold and warm conditions, showing the importance of leaving some ventilation space to get better efficiency on the panel.

Keywords: Photovoltaic, ventilation gap, roof installation.

Introduction

Solar energy has become a real alternative to replace some fossil fuel consumption. One important application of solar energy is the integration of PV panels on buildings. Today there are many options to integrate PV panels in buildings new buildings, on the façade, roof, windows, as shadow elements... But in old buildings the most used option is the integration on the roof.

Temperature is an important factor to consider when a PV system is designed. We could make the mistake of thinking that the higher temperature we have the better efficiency we'll get. The real effect of temperature is just the opposite. The conductivity of a semiconductor increases when the temperature is higher, therefore it is easier for electrons to holes elsewhere in the material to fill, being the electrical balance in the cell increases, the electric field falls away to the boundary, so the load can no longer remain well separated. The result is a decreasing tension between the two layers. This effect is illustrated in the figure below:

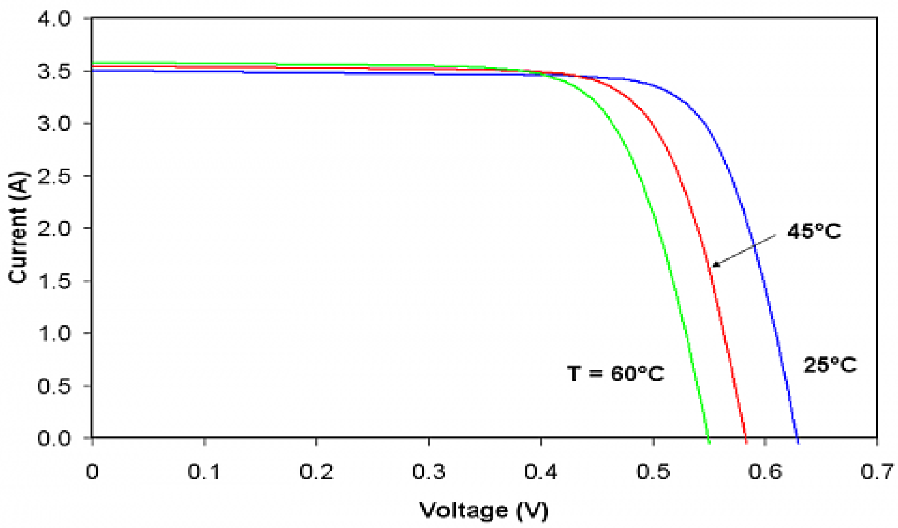

Figure 1: Effect of temperature on voltage

On a polycrystalline panel, the effect of temperature on efficiency can be around 0,45%/ºC, while in a monocrystalline panel the effect is a bit lower. In terms of watts, in a polycrystalline panel of 135 Watts, with an efficiency of 14% at 25ºC, we could lose around 12 Watts per panel at 45ºC and 24 Watts per panel at 65ºC.

We should try to keep the panel as cool as possible by applying passive measures such as a natural ventilation system. In the following parts of this report we'll analyze the real effect of having ventilation between the panel and the roof for different climate conditions.

Methodology

The problem to analyse consists of three different situations one without ventilation one with a gap of 10cm between the panel and the roof and another case with 50cm between the roof and the solar panel, these three situations are shown in figure 2 and figure 3.

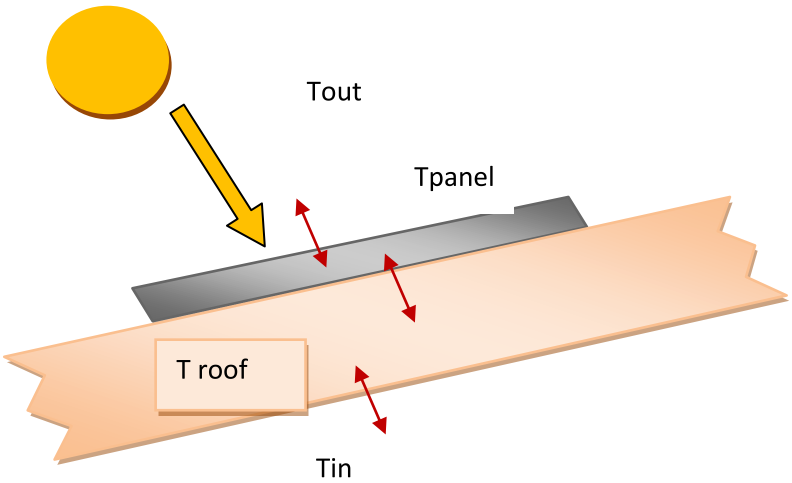

Figure2: PV installation without ventillation

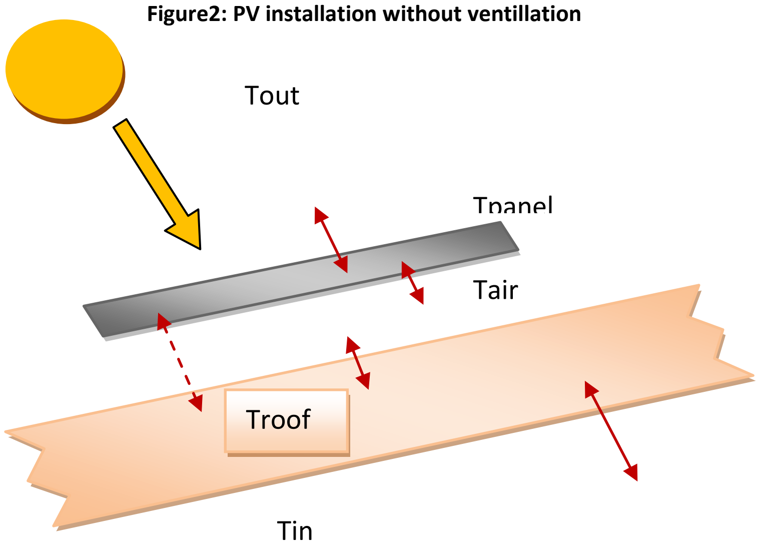

Figure 3: PV installation with ventillation

For this problem we will assume that the outside temperature is constant in each case and can't be affected by the temperature of the PV panel. We will also consider the indoor temperature constant for all cases and equal to 21ºC. According to these assumptions we will have to analyze the temperature changes in the PV panel and roof for the first case, and the temperature changes in the PV panel, roof for the second case. And for the third case we will neglect the effect of the roof temperature since the distance between the roof and the solar panel is big enough to do it. The roof is completely covered by the PV installation so there is no sun heating the roof.

To solve the problem we propose the following thermal models,

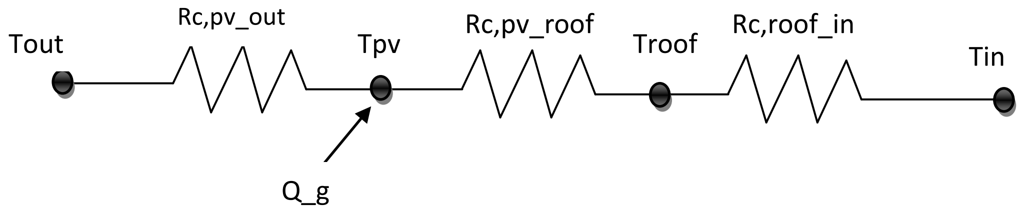

Figure 4: Thermal model for a PV installation without ventilation

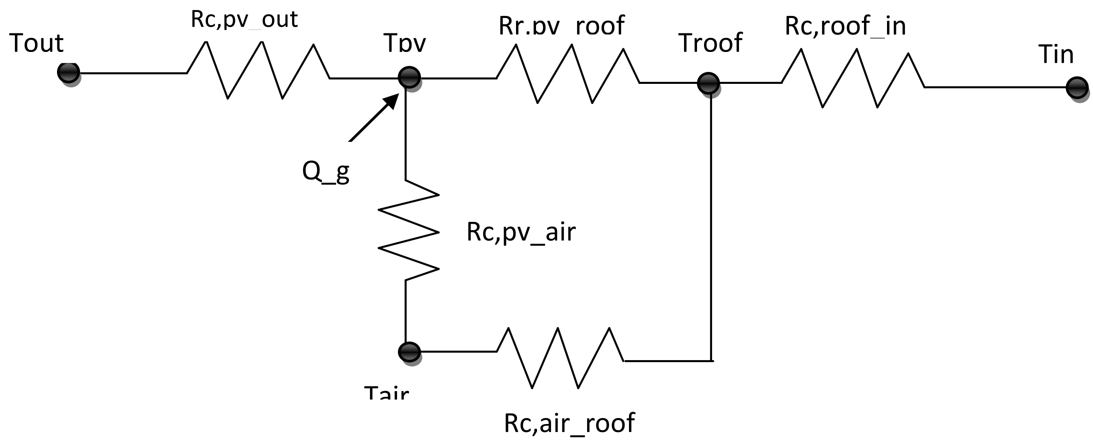

Figure 5: Thermal model for a PV installation with 10 cm ventilation

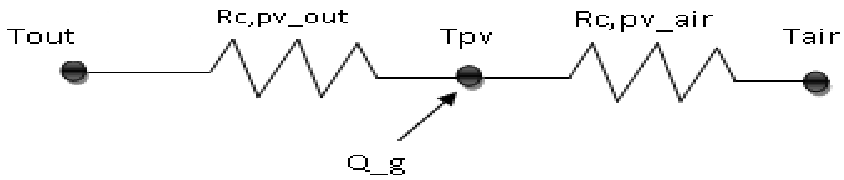

Figure 6 : Thermal model for a PV installation with 50 cm ventillation

For the first case the physical model is represented by the following system of equations:

$$\frac{dT_{pv}}{dt}\rho_{pv}Cp_{pv}d_{pv} = R_{c,pv-out}\left(T_{out} - T_{pv}\right) + R_{c,pv-roof}\left(T_{roof} - T_{pv}\right) + Q_g$$

$$\frac{dT_{roof}}{dt}\rho_{roof}Cp_{roof}d_{roof} = R_{c,pv-roof}\left(T_{pv} - T_{roof}\right) + R_{c,roof-in}\left(T_{in} - T_{roof}\right)$$

The physical model for the second case is represented by the following system of equations:

$$\frac{dT_{pv}}{dt}\rho_{pv}Cp_{pv}d_{pv} = R_{c,pv-out}(T_{out} - T_{pv}) + R_{r,pv-roof}(T_{roof} - T_{pv}) + R_{c,pv-air}(T_{air} - T_{pv}) + Q_g$$

$$\frac{dT_{roof}}{dt}\rho_{roof}Cp_{roof}d_{roof} = R_{r,pv-roof}(T_{pv} - T_{roof}) + R_{c,roof-in}(T_{in} - T_{roof}) + R_{c,roof-air}(T_{air} - T_{roof})$$

$$\frac{dT_{air}}{dt}\rho_{air}Cp_{air}d_{air} = R_{c,pv-air}(T_{pv} - T_{air}) + R_{c,roof-air}(T_{roof} - T_{air})$$

Finally the physical model for the third case corresponds to the following equations:

$$\frac{dT_{pv}}{dt}\rho_{pv}Cp_{pv}d_{pv} = R_{c,pv-out}(T_{out} - T_{pv}) + R_{c,pv-air}(T_{air} - T_{pv}) + Q_g$$

$$\frac{dT_{air}}{dt}\rho_{air}Cp_{air}d_{air} = R_{c,pv-air}(T_{pv} - T_{air})$$

To simplify the model we will consider that the wind blows strong enough to renew the air in the gap, so the temperature of the air will be constant and equal to the outdoor temperature. In that case the last equations of the second and the third model won't be useful since $\frac{dT_{air}}{dt} \approx 0$.

In the equations above Tout represent the outside temperature, we will consider three cases, one in a cold day, $T_{out} = 0°C$, another for a temperate day $T_{out} = 20°C$ and the last one for a warm day $T_{out} = 40°C$. Tin represents the temperature inside the building, we will consider this temperature constant for each case and equal to 21ºC. Tpv,roof,air represents the temperature of the PV cells, the roof and the air respectively in [ºC]. $\rho_{pv,roof,air}$ represents the density of each layer in [Kg/m3]. $Cp_{pv,roof,air}$ represents the heat capacity of each layer in [J/kg·K]. $d_{pv,roof,air}$ is the thickness of each layer in [m]. Qg is the solar radiation falling on the surface of the PV panel in [W/m2]. $R_{r,pv-roof}$ is the radiation heat transfer coefficient between the roof and the PV panel when there is ventilation in [W/m2·K]. $R_{c,i-j}$ are the convection/conduction heat transfer coefficients between different elements.

Calculations

The first things to consider is the convection, conduction and radiation heat transfer coefficients. In order to calculate this we should establish the properties of the materials used in the system. We'll consider the solar panel as three layers, the top one made of glass, the middle one made of Silicon and the bottom one made of Aluminium. We got this data from different database available on the Internet (see references).

The different parameters to consider are shown in the following table:

Material	Conductivity coefficient [W/m2·K]	Convective coefficient [W/m2·K]	Emissivity	Absorptivity	Density [Kg/m3]	Heat capacity [J/kg·K]	Thickness [m]
Air	0,02	30	0.67(sky)		1,23(Normal conditions)	1012	0.1-0.5
Glass	0.81		0.9	0.13	2500	890	0.003
Silicon	148		0.87	0.08	2300	753	0.005
Aluminium	236		0.07	0.15	2700	897	0.005
Reinforced concrete	1.63		0.88	0.6	2400	880	0.5

Tabla 1: Parameters for each material

We'll neglect the conductivity coefficient between air and the PV panel since the conductivity coefficient is pretty small. For the convective coefficient we have chosen an average value, it would be interesting to study the variation in the air convective coefficient with the air velocity. Many models have been proposed to calculate this coefficient such as the model proposed by Seokyoun Kang et al. 2008. It would take a whole project to determine this value so we have decided to take an average of 30 W/m2K for an air with a slow motion.

For the radiation heat transfer coefficient we'll use the following equation

$$R_{r,layer1-layer2} = \frac{\sigma \cdot (T_{layer1} + 273.15 + T_{layer2} + 273.15) \cdot \left(\left(T_{layer1} + 273.15\right)^2 + \left(T_{layer2} + 273.15\right)^2 \right)}{\dfrac{1-\varepsilon_{layer1}}{\varepsilon_{layer1} \cdot A_{layer1}} + \dfrac{1-\varepsilon_{layer2}}{\varepsilon_{layer2} \cdot A_{layer2}} + \dfrac{1}{A_{layer1} \cdot F_{layer1-layer2}}}$$

To simplify the calculations we'll consider the view factor between aluminium and concrete equal to one. The area is 1 m2 and σ is the Stefan-Boltzmann constant [5.669·10-08 W/m2·K4].

We used Matlab to perform all the calculations. The solar irradiation considered was 750 Wh/m2. The results obtained are shown in the following tables

Conditions	T cells [ºC]	T roof[ºC]
Cold day	34.9	21,65
Temperate day	51.03	34.54
Warm day	60.52	35.2

Table 2: Results without ventilation

Conditions	T cells	T roof
Cold day	8,3	20,9
Temperate day	24,7	21
Warm	43,5	21,1

Table 3: Results with 10 cm ventilation

Conditions	T cells[ºC]
Cold day	5.325
Temperate day	25.325
Warm day	45.325

Table 4: Results with 50 cm ventilation

With this results we can analyze how would they affect to the efficiency of a panel. We will consider the panel A-135 of ATERSA, a common panel in the market. This is a polycrystalline panel with a peak power of 135 Wpk an efficiency at 25ºC of 13,88% and a temperature coefficient of $\pm 0{,}43\%℃$.

The effect over the efficiency and the power for each case are shown in table 5

Case	Climate	Efficiency	Power [W]	Power variation [W]	Power variation [%]
Without ventilation	Cold	13,29	129,25	-5,75	-4,26%
	Temperate	12,33	119,89	-15,11	-11,19%
	Warm	11,76	114,38	-20,62	-15,27%
With 10cm ventilation	Cold	14,88	144,69	+9,69	+7,18%
	Temperate	13,90	135,17	+0,17	+0,13%
	Warm	12,78	124,26	-10,74	-7,96%
With 50 cm ventilation	Cold	15,05	146,42	+11,42	+8,46%
	Temperate	13,86	134,81	-0,19	-0,14%
	Warm	12,67	123,20	-11,80	-8,74%

Table 5: Effect of temperature over efficiency and power

DISCUSSION

The model proposed has many limitations. The first one is to assume that the air temperature in the gap for the second case it will remain constant, it's obvious that in a small gap of 10 cm the air temperature will be affected by the temperature of the roof and the solar panel, that is why in the second case we should get higher temperatures for the PV cells.

We should also have considered the wind speed, but that would have complicated the model. That would be an interesting study for a master thesis.

Apart from the limitations of the model, we can get interesting conclusions. The variation between having and not having a ventilation gap can be of 15 W per panel for a cold climate, surprisingly this difference is lower in warm climates. That can be explained as a consequence of the effect of the roof temperature. In a warm climate if we keep the indoor temperature of the building at 21ºC it will act as a cooling system for the PV panel. Of course in that case the energy demand of the building will increase considerably. We'll try to avoid this situation not only because we get better efficiency in the panel but also because we will reduce the energy demand of the building. In cold climates we could improve the isolation of the building by installing the solar panels without ventilation gap, as we have seen that will reduce the efficiency of the panel but it may be interesting for the building heating.

In any case we will have to study each building separately, but in general terms the ventilation gap between the building and the panels will improve both the efficiency of the panel and the energy demand of the building.

Considering that this model has the limitations we mention before, we can see that is not really worth it to have a bigger gap, the effect of heat transfer by radiation between the roof and the panel can be neglected and the only problem we can have is a circulation problem in the gap if it's not well designed. The fact of leaving a bigger gap will increase considerably the cost of the installation because the mechanic load on the building will be much higher and construction material will have to be more rigid.

According to this argumentation the best solution will be to leave a small gap between the roof and the PV installation. We will avoid overheating problems getting more energy and making the installation more profitable even if we will slightly increase the investment cost.

References

- Candanedo, Luis et al.: Numerical modelling of heat transfer in photovoltaic-thermal air based systems

- Dehra, Himanshu. 2008: A two dimensional thermal network model for a photovoltaic solar wall

- Del Pilar Villena, Ana & Quispe Maldonado, Paúl Alejandro 2006: Diseño y construcción de un sistema de extracción de energía térmica para el enfriamiento de un panel fotovoltaico de 43 w y análisis del mejoramiento de la eficiencia de conversión fotoeléctrica

- Dominguez, Anthony. 2010: Modeling of roof heat transfer under solar photovoltaic panels

- Infield D.G. et al. 2003: Thermal aspects of building integrated pv systems

- Kang, Seokyoun. 2008: Theoretical analysis of photovoltaic module integrated blinds

- Knaupp, Werner 1996: Operation behaviour of roof installed photovoltaic modules

- Rahman Elbakheit, Abdel. 2008: Effect of duct width in ducted photovoltaic facades

- Sharaf, A.M. et al. 2000: Building-integrated solar photovoltaic systems on a hybrid solar cooled ventilation technique for hot climate applications.

- Zhu, Zuojin et al. 2004: Investigation of conjugate heat transfer in a photovoltaic wall

- www.pveducation.org

- www.atersa.com

- http://www.arquimaster.com.ar/articulos/articulo410.htm

- http://editorial.cda.ulpgc.es/ftp/icaro/anexos/2-%20calor/4-construccion/c.6.4%20conductividad%20t%e9rmica%20y%20densidad.pdf

- http://www.fisicanet.com.ar/fisica/termodinamica/tb03_conductividad.php

- http://webserver.dmt.upm.es/~isidoro/bk3/c12/conveccion%20termica%20y%20masica.pdf

- http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php