Study about the integration of active solar systems in Architecture and wind action upon these systems

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Thesis to obtain the Master of Science Degree in

ARCHITECTURE

EXTENDED ABSTRACT

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April 2015

Abstract

Renewable energy, on a global scale, has been the subject of study in the last decade, and Portugal stands out as one of the European countries with the best weather conditions for the implementation of solar systems.

Therefore, this article focuses on the importance of understanding how these systems interact and how they are integrated in buildings. On the other hand, for its implementation it's necessary to note the factors that may compromise or even hinder it in certain places, like the wind itself, on which a study is made of the pressures acting on these systems using a model introduced in a wind tunnel. At the same time, using the software *Soltherm*, an energy, economic and environmental simulation has been made about various forms of integration of these devices also tested in the wind tunnel.

From the study, it became apparent that in situations with undue architectural integration (when the panels are most distant from the roof) but with the best solar orientation have greater risk that the solar panels get damaged in adverse weather conditions and the better integration case studies with not optimal solar orientation, in large part of the comparisons, have significant energy losses (reaching a maximum of 21%).

KEYWORDS: Renewable Energy, Photovoltaic Panels, Solar Collectors, Integration, Wind Action

1. Introduction

Solar panels placed on roofs or façades has been used in recent years and some lacks of knowledge on the subject means that many designers are making inappropriate choices for the integration of these systems in buildings. These devices are sensitive to wind action and design standards and codes of practice are not very helpful on provisions that designers should choose for these devices. Basically, the evaluation of the loads caused by wind applied in photovoltaic modules and solar collectors plays a crucial role for design purposes (Xypnitou, 2012). For this reason, the effect of a number of factors, such as the exposure in urban or rural environment, the inclination of the panels relative to the gables and the building height should be evaluated using experimental or computational procedures.

The scientific development has therefore provided the creation of solutions economically and energetically viable, however, some safety aspects need to be studied and to make a thorough investigation on this topic, it's important to realize which devices the market offers to the consumers and their characteristics, as described in the literature research following shown.

2. Solar systems in Architecture

In this section it will be explained the various types of solar systems and its interaction with other building elements.

2.1. Characterization of solar systems

2.1.1. Photovoltaic (PV) panels

Photovoltaic modules can have different components, such as: the monocrystalline or polycrystalline silicon and thin films made of amorphous silicon, copper indium diselenide, gallium arsenide, or cadmium telluride (Costa, 2012).

The monocrystalline silicon cells are sold with dimensions up to 15 cm normally in blue or gray colors. They have a very ordered atomic structure and the forms defined for these cells vary between the circular and semi-square (where the corners are cut down). The efficiency of them is around 15% (cells commonly marketed).

Instead, the panels which silicon is in the form of crystals with different dimensions (polycrystalline silicon) have a market share quite acceptable in the order of 30%. The colors that these equipments adopt are similar to those of the monocrystalline silicon panels but the efficiency is lower, around 13% for cells commonly marketed.

The panels and thin films made with amorphous silicon have lower efficiency than other technologies because there is no atomic organization of silicon but on the other hand, are less expensive in its manufacturing process. Other compounds such as copper indium diselenide are limited in nature and they are toxic, but its application and study have been developed due to the growth of the percentage of efficiency that is obtained.

2.1.2. Solar collectors

Solar collectors can have a flat plate or vacuum tubes or even compound parabolic concentrators.

The flat plate collectors, whose common area varies between 2 and 2,6 m^2, have a plate absorber that converts the collected energy in heat, and in this type of devices, a phenomenon of greenhouse effect is created when a transparent cover is present whose functionality is to decrease the losses to the outside, reaching temperatures between 50 and 100° C (Probst and Roecker, 2012).

In turn, parabolic collectors and parabolic concentrators are devices created to have a better performance than flat panels by having a catchment area clearly larger than the area of the receiving surface.

The collectors having vacuum tubes can be of two types: direct flow or heat pipes collector, but in general, these panels reach temperatures between 120º and 180º, being therefore superior to those of flat plate collectors. In terms of dimensions, normally, the companies that sell vacuum tube collectors, exhibit panels with maximum dimensions of 2 meters in length or in width.

2.2. Integration of solar systems in buildings

There are some recent innovations in the field of solar energy that deserve attention, such as the solar roof tiles, the placement of new tones and colors in panel surfaces and thin films that enable light permeability due to the application of a laser treatment.

Of all of these products it's important to emphasize the use of photovoltaic solar tiles that beyond ensuring the watertightness of the roof, are made of monocrystalline silicon which gives them a great reliability in the market for solar technologies in general.

Concerning to the configuration adopted, the adaptation of solar systems should take into account the following aspects as the site of integration – Figure 2.1.

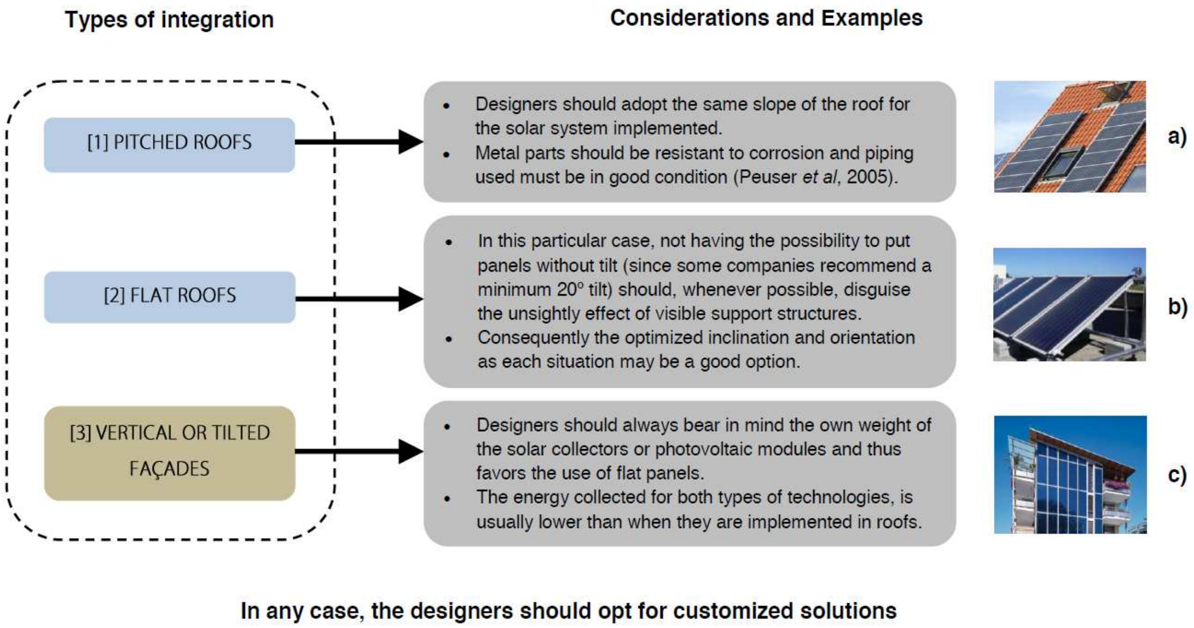

Figure 2.1. – Considerations and good examples of each type of integration of solar systems in Architecture: a) photovoltaic modules placed in a pitched roof (Greenest, 2014); b) solar collectors placed in a flat roof (Engisun, 2014); c) solar collectors disposed in a façade (AllChem, 2013).

When the placement of the solar panels is not the most appropriate in order to obtain the best solar orientation, not respecting the principles presented in Figure 2.1., there are situations that may compromise the security of the structures that support these active solar systems. Figure 2.2 shows several examples of placement of solar panels in which the inclination of the solar panels is higher than the pitched roof itself and, therefore, the aesthetics of the building is impaired.

Figure 2.2. – Photographed cases of undue architectural integration

3. Wind loads on buildings and solar collectors

Generally, buildings are subject to external actions, which highlight the wind loads. The wind is characterized by being an irregular force acting on buildings surfaces.

In order to understand the wind action on solar panels, wind tunnel tests were carried out in a 1:20 scale PVC building model with dimensions of 100 x 50 x 29.5 cm (Figure 3.1.) and a pitched roof (with 30º tilted angle). Two reduced scale models of acrylic solar panels (10 x 5 cm) were placed on the roof of the building model with several common configurations with undue architectural integration, especially when the angle of the solar panel is higher than the pitched roof in which they are placed. Three different azimuth angles were studied (0º, 45º and 90º) for solar panels with an inclination of 35º, as shown in Figures 3.1 and 3.2.

The option of using two solar panels was made in order to study the effect of wind shielding that one panel could be over the other. Each one has a standard area of 2 m^2 (1 x 2 m) in full scale, which usually is sufficient to cover the hot water energy necessities of 5 persons, and both faced South in all situations, as it's the most indicated solar panel orientation in the Northern Hemisphere to maximize the collected solar energy.

Each panel has 9 measurement points on each face, totalizing 18 measurement points per solar panel. In this study, the 18 measuring points of the left solar panel are designated with letter A and with letter B the ones from the right solar panel.

In order to assess the influence of the wind direction on the solar panels, 12 different wind directions were tested as shown in Figure 3.3.

The tests were conducted in an open suction wind tunnel at LNEC (Laboratório Nacional de Engenharia Civil) with a rectangular work section of 3,1 x 2 m of area and 9 m of length. The following equipments (that allow quantitative measurement of pressure coefficients) were used in the simulation: i) two Pitot-Prandlt tubes, one for determining the dynamic pressure of the flow and another that is a reference for the evaluation of pressure coefficients; ii) a micromanometer van Essen, Betz type associated with one of the Pitot-Prandlt tubes for determining the reference dynamic pressure flow; iii) a Scanner - pressure transducer, combined with a data acquisition system DTC Initium.

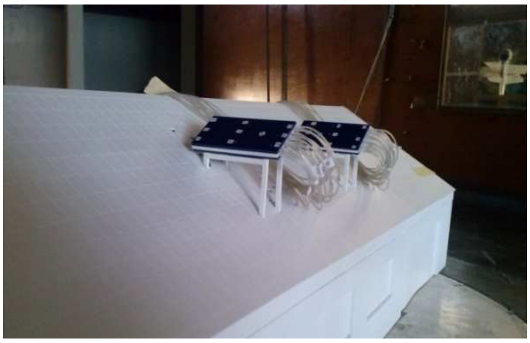

Figure 3.1. - Side view of the PVC model in 1:20 scale with the acrylic solar panels.

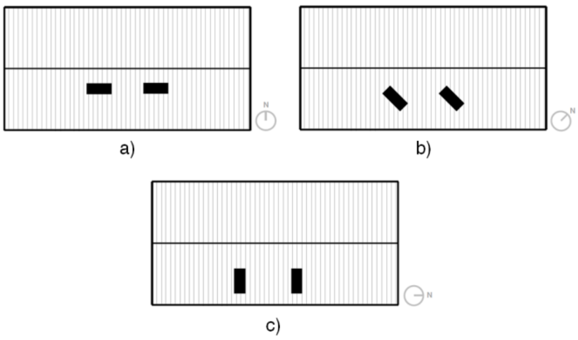

Figure 3.2. – Top view with representation of azimuth angles for each configuration of solar panels: a) azimuthal angle of 0 °; b) azimuthal angle of 45º; c) azimuthal angle of 90º.

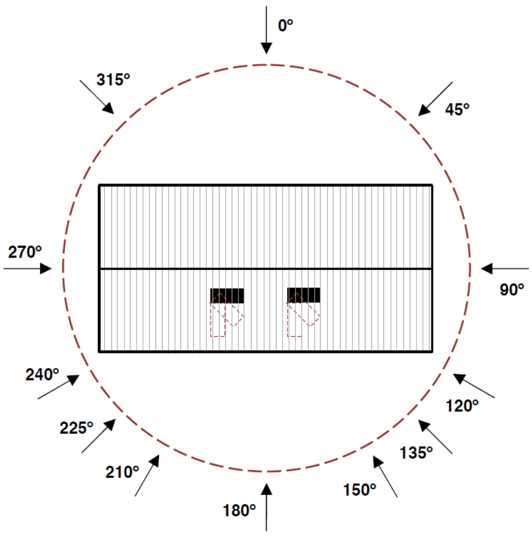

Figure 3.3. - Schematic representation of the wind directions in the experimental campaign

In this investigation, the experimental method proposed by Irwin (Irwin, 1981) was used, in which the average flow velocity profile is described by the following equation, up to a height from the ground which has almost no influence on this profile – equation 3.1.

$$\overline{V}(z) = \overline{V}_{\delta} \times \left(\frac{z}{\delta}\right)^{\alpha} \quad (3.1)$$

From the previous equation: z is a certain height of the atmospheric boundary layer, δ is the maximum height of the boundary layer, $\overline{V}_{\delta}$ is the average speed at maximum height of atmospheric boundary layer, $\overline{V}(z)$ is the average speed for the height z and α is the exponent of the equation for the type of terrain that, in this case, is suburban and acquires a value of 0.23.

The methodology followed is to put at the beginning of the tunnel some passive elements (triangular pinnacles), to originate an effect of turbulence on the whole length of the tunnel and a preferential flow from the top of the wind tunnel. Along the boundary layer, were still arranged some cubic elements transversely and longitudinally along the floor of the tunnel, to create an aerodynamic roughness and, at the same time, to facilitate the collision between the vortices created and simulate a real atmospheric boundary layer (Castanho, 2012).

At the same time, a study using the *Soltherm* software was made for the energy captured yearly by collectors, the economic return and the environmental impacts avoided. Current data on solar panels prices and natural gas (substitute of the solar energy) were used for the city of Lisbon.

4. Results and discussion

4.1. Pressure coefficients and differential pressure coefficients

For this experimental work in wind tunnel two formulas were used: one for determining the pressure coefficients on each measurement point and other for the differential pressure coefficients (between top and bottom faces), described in equations 4.1 and 4.2.

$$c_p = \frac{p - p_0}{\frac{1}{2} \times \rho \times V^2} \quad (4.1)$$

$$dc_p = c_{p,top} - c_{p,bottom} \quad (4.2)$$

In equation 4.1., p is the pressure measured at a given point of a surface and p_0 is the static pressure at reference conditions. The expression $\frac{1}{2} \times \rho \times V^2$ is the dynamic pressure of the wind not affected by the obstacles which depends on its specific mass ρ and velocity V (Lopes, 2008).

In equation 4.2., $c_{p,top}$ corresponds to the top face pressure coefficient and $c_{p,bottom}$ is the bottom face pressure coefficient. As the name itself indicates, dc_p is the difference of pressure coefficients between the indicated faces.

4.1.1. Azimuthal angle of 0º

For the azimuthal angle of 0°, in which the solar panels are closer to the roof, it was perceived that:

- On the top faces are recorded, in general, moderate or near zero suctions, constituting exception the incidences of 120° to 150° where the recorded values reach -0,7≤$c_{p,top}$≤-0.6 and the incidence of 45° in panel A where are registered slightly positive values ($c_{p,top}$ <0.3).
- The bottom faces, although there are mainly slightly positive values ($c_{p,bottom}$<0.3) also show some variability in panel A with negative values ($c_{p,bottom}$≤-0.6) for the 315° incidence, and positive values ($c_{p,bottom}$ ≤ 0.5) in the incidence of 240°.
- Finally, the differential coefficients between the two faces, that means the effective load applied by the wind on the panels, in the incidences of Southest quadrants (120° to 240°) have the most grievous values dc_p ≤-0,7. Figure 4.1. shows the differential pressure coefficients for the incidence of 135º.

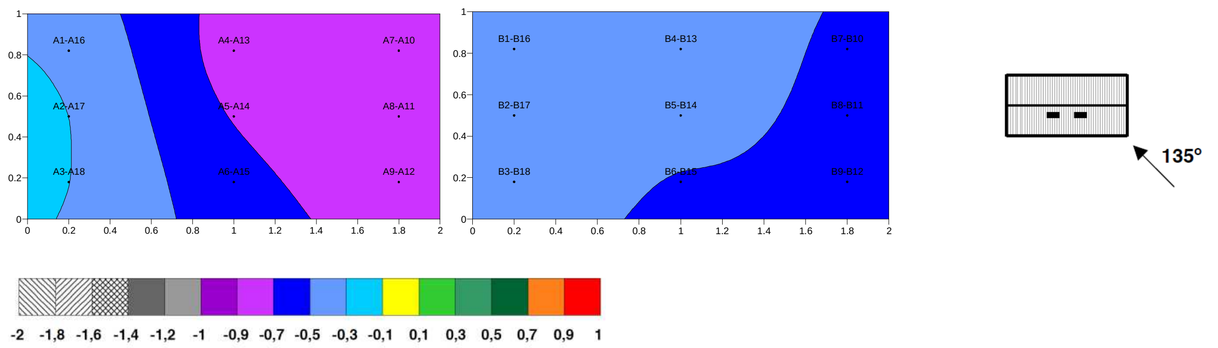

Figure 4.1 - Differential pressure coefficients for the incidence of 135º and azimuth of 0º.

4.1.2. Azimuthal angle of 45º

In the azimuthal angle of 45º, it was verified that:

- On the top faces, the values reported were more negative than in the azimuth of 0°. In the direction of 135° some of the pressure taps recorded the highest negative values ($c_{p,top}$ <-1.2).
- The bottom faces exhibited positive values near the roof ($c_{p,bottom}$>0.3) and negative in the furthest zone ($c_{p,bottom}$<-0.5). Most positive values were registered in the directions of 0º to 90º and the most negative values in wind directions of 225º and 240º.
- The differential coefficients between the two faces, in turn, show that the directions of 135º and 150º are those which have the worst results. For 135º, one differential coefficient recorded is under -1.8 - Figure 4.2.

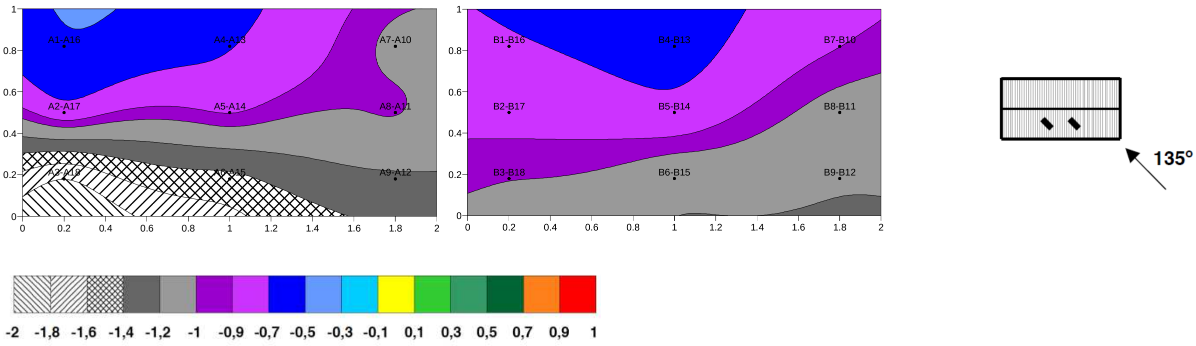

Figure 4.2 - Differential pressure coefficients for the incidence of 135º and azimuth of 45º.

4.1.3. Azimuthal angle of 90º

For the azimuth in which the panels are further away from the roof (90º), the analysis performed concludes that:

- On the top faces, as in 45º azimuth angle, suctions are present. In the directions of 135º and 150º pressure taps reported several very negative values ($c_{p,top}$<-1).
- On the bottom faces there are positive and negative values. There was some $c_{p,bottom}$> 0.3 in the directions of 120º to 150º and $c_{p,bottom}$<-0.3 in the directions of 210º, 240º and 315º.
- Finally, the differential pressure coefficients between faces shows that the directions of 135º - Figure 4.3. - and 150º have the worst results presented as the differential pressure coefficients between faces in the azimuth of 45º. In both directions there are dc_p <-1.4.

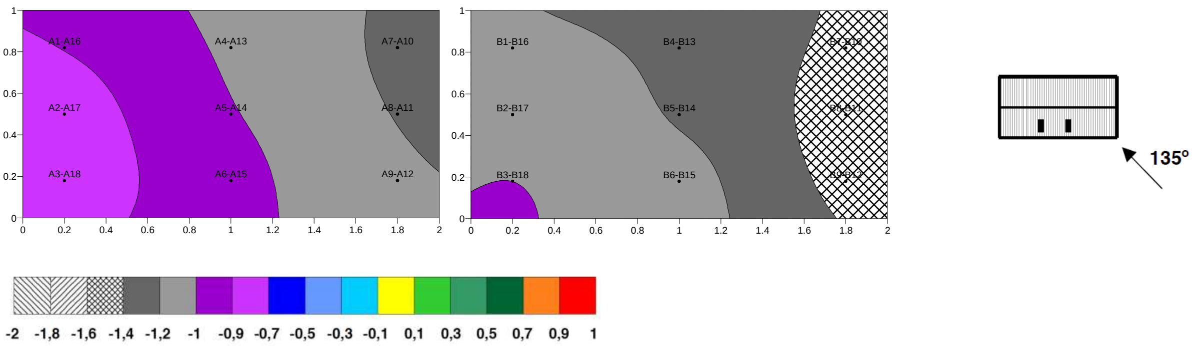

Figure 4.3 - Differential pressure coefficients for the incidence of 135º and azimuth of 90º.

4.2. *Soltherm* energy, economic and environmental simulations

This study considered the three situations analyzed in the wind tunnel (solar panels with an inclination of 35º in a 30º roof and oriented to South) as well as three other situations of better integration in Architecture, with solar panels placed on the 30º roof inclination and oriented to South, Southeast and East.

As expected, the energy simulation study has proved that the South orientation (with the inclinations of the panels of 30º and 35º) is always the most favorable in terms of solar energy captured by the collectors, because Lisbon is in the Northern Hemisphere and, therefore, the South orientation has the greatest daily sun exposure. Despite the inclination of 35º is the most favorable in terms of energy delivered by the collectors by being more closer to the latitude of Lisbon, it should be noted that the situations in which collectors have an inclination of 35º in a 30º roof (South facing) include the case with worst architectural integration (azimuthal angle of 90º tested in wind tunnel). Therefore, if it's desired to adopt the same angle of the roof in solar systems, it's necessary to note the decrease of energy collected (in the analyzed cases reached a maximum of 507 kWh – decrease of 21% - between the situation with worst architectural integration and the case of solar panels placed on a 30º pitched roof and oriented to East).

It can be concluded that in these cases analyzed, is easier and more profitable, as in the case of panels already oriented to the South, changing the inclination to get this equal to the roof than performing a rotation to them in order to be best installed but oriented along another cardinal point.

Concerning the economic analysis, for a greater amount of energy supplied yearly, the avoided primary energy consumption - what may be viewed as an environmental analysis - is also significant but for East and Southeast orientations payback is delayed, making a lower net present value (NPV), as estimated by *Soltherm*.

Table 4.1. summarizes the values obtained through *Soltherm* simulations.

Table 4.1 – Synthesis of energy, economic and environmental aspects analyzed in *Soltherm*

	35º - South	**30º - South**	**30º - Southeast**	**30º - East**
Energy supplied yearly [KWh]	2427	2413	2261	1920
Net present value [€]	1347	1303	843	-191
Avoided energy costs [€]	8196	8148	7635	6484
Consumption of primary energy avoided [MWh/year]	3,24 (307 m^3 of Natural gas / year)	3,22 (306 m^3 of Natural gas / year)	3,01 (286 m^3 of Natural gas / year)	2,56 (243 m^3 of Natural gas / year)

5. Conclusions

In all this research, it became apparent that the various types of solar systems have evolved and designers have given utmost importance to reflect their positioning in new constructions. Each device has its physical characteristics and energy specifications that are best suited to certain parts of a building. In other words, architects need to understand that there are universal principles of integration that must be respected to avoid problems in the later use.

In the experimental activity in wind tunnel, it was perceived that the solution in which the solar panels are near to the roof (azimuthal angle of 0°), is among the three examined, the one that fewer problems causes. The pressure coefficients are positive and negative but closer to 0, causing smaller differences in pressure coefficients obtained between faces. In general, the most significant differential pressure coefficients in azimuths of 45° and 90° were observed for the 135° directions up to a negative value (-1.8).

For the results observed in the Soltherm energy, economic and environmental simulations, it's concluded that the optimum orientation for the collectors in the Northern Hemisphere is the South and leads to better results in terms of energy. Effectively, the placement of collectors in other direction than the South, leads to energy losses in East orientation of 21% but it's important to take into account the data on the tests in the wind tunnel that indicate positions near to roof as more desirable.

Consequently, as each case, is necessary to consider if the decrease of collected energy and energy avoided costs may or not may be compensated with the increase of structural safety.

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