Ranking Configurations of Shading Devices by Its Thermal and Luminous Performance

KAMILA MENDONÇA DE LIMA[1], LEONARDO SALAZAR BITTENCOURT[2], ROSANA MARIA CARAM[3]

[1,3]Instituto de Arquitetura e Urbanismo, Universidade de São Paulo, São Carlos, Brasil
[2]Faculdade de Arquitetura e Urbanismo, Universidade Federal de Alagoas, Maceió, Brasil

ABSTRACT: This paper evaluates the thermal and luminous performance of different louver configurations on an office room model located in Maceió-AL (Brazil), ranking the alternatives in a way that leads to choices for alternatives with potential balanced performance. Parametric analyses were done, based on computer simulations on software Troplux 5 and DesignBuilder 2. The variables examined were number of slats, slat slope and slat reflectance, considering the window facing North, South, East and West and a fixed shading mask for each orientation. Results refer to internal average illuminance and solar heat gains through windows. It was observed that configurations of shading devices with the same shading mask may have different luminous and thermal performance. The alternatives were ranked, so the information here produced has the potential to support decisions on designing shading devices in practice.
Keywords: Shading devices; Solar control; Daylighting; Computer simulation; Early design

INTRODUCTION

Shading is a key bioclimatic strategy on hot and humid climates. In these regions, shading devices design must achieve a balance between daylighting and thermal requirements. Some authors have shown that a proper selection of properties and geometry of the shading device can lead to a balanced performance, by combining experimental studies and computer simulations [1] or addressing coefficients for thermal and luminous performance by dynamic simulations [2].

In this process, defining the shading mask for different solar orientations is an important step, which is followed by the choice of the shading device geometry, among many configurations able to produce the determined shading period (see Fig. 1) [3].

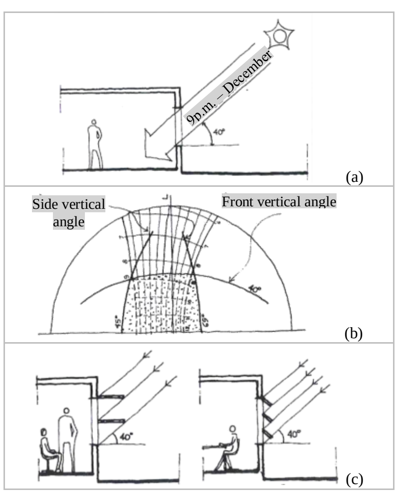

Figure 1: Definition of shading period (a), shading mask (b) and possible louver geometry sections (c). Adapted from [4].

Different louver geometry and properties can present different impact on indoor thermal and luminous performance and, consequently, on building energy consumption associated to environmental comfort. Rating and ranking alternatives of building components by its performance is an interesting way to support building designers during decision-making process [4, 5]. Therefore, estimating thermal and luminous performance of the shading components can address a more conscious decision on window issues.

This paper aims to evaluate the thermal and luminous performance of different louver configurations on an office room model located in the city of Maceió-AL (Brazil), ranking them in a way that allows to adequate choices regarding alternatives with balanced performance.

METHODOLOGY

The work consists of a comparative analysis based on computer simulations from *TropLux 5* [6] and *DesignBuilder 2* softwares [7]. External horizontal louvers in offices on the geographic context of the city of Maceió-AL were modelled. Variables analysed were: number of slats, slat slope and slat reflectance, considering a given shading mask, defined for each of the four main orientations (N, S, E and W).

Data

Maceió is located on the Northeastern region of Brazil, with latitude of 9.66° South and longitude 35.73° West [8]. The climate is hot and humid, with intense solar irradiation and small daily and seasonal variations on air temperatures (Fig. 2).

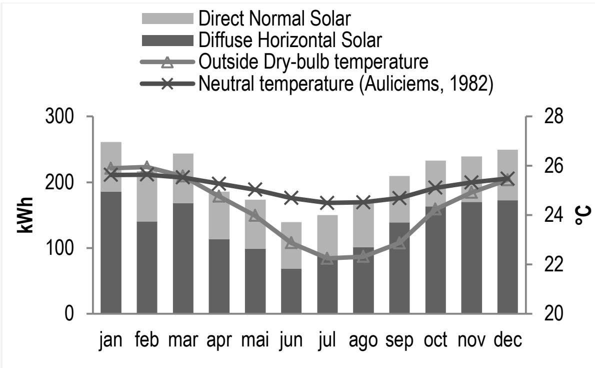

Figure 2: Insolation and air temperature data for Maceió-AL. Source: Test Reference Year weather data file (Available in [9]) on DesignBuilder 2.

Based on the solar chart for this location, the shading devices were dimensioned following a fixed shading mask for each orientation. Figure 3 and Table 1 register the cut-off angle determined according to a methodology [10] where the shading period is defined considering acceptable limits regarding thermal comfort, expressed on data plotted over the solar chart. For the studied cases, this limit refers to when mensal mean air temperature is at least 2°C above the neutral temperature (a concept described by Auliciems [11]), and global solar irradiation incident on the facade is above 600W/m^2.

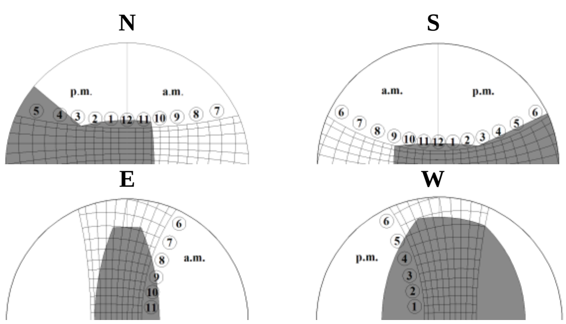

Figure 3: Shading mask (transparent grey colored cover) for the four examined orientations. Source: Adapted from [12].

Table 1 – Cut-off angles correspondent to the shading masks.

Orientation	**Vertical**	**Horiz. Right**	**Horiz. Left**	**Side Right**	**Side Left**
N	50°	-	50°	65°	-
S	70°	65°	-	-	50°
E	15°	-	-	60°	60°
W	10°	-	-	20°	40°

The dimensions of the studied room are 5m x 6m x 3m, with a window of 5m x 1m (dimensions that are coherent with existing office buildings in Maceió-AL). The scenarios simulated on both software correspond to the parameters presented on Table 2. In order to achieve the shading masks where it would be needed vertical shading or lateral extension, an auxiliary single slat was modelled, with fixed properties (Fig. 4). The thicknesses of the slats were ignored.

The code for naming the louver configurations is formed by the first letter of the name of each parameter (Number of louvers, Slope, Reflectance), followed by the numeral correspondent to the value on the used metrics (dimensionless for the number of louvers and reflectance and degrees for slope). On East and West orientations, some cases were not simulated for thermal performance (N2S0R0,8, N2S0R0,8, on both orientations; N4S0R0,8 and N4S0R0,8, on East), since the used software only accepts slat up to 1.0m. For visualization of possible tendencies, these situations were maintained on luminous analysis. On final ranking, all case scenarios with horizontal slats for East and West orientations were not considered due to the fact that they would correspond to unpractical dimensions in reality.

Table 2: Combination of parameters examined

Orientation of window	**No shading**	***Shading by louvers***		
North, South, East e West	Reference room	Number of slats	Slat slope[1] (°)	Slat reflectance
		2; 4; 8	0; 30; 45; 60	0.5; 0,8

1- Angle between the slat plan and the normal to façade.

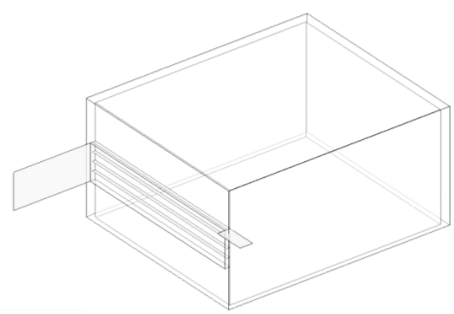

Figure 4: Room with louvers (Case scenario N4S0R0,8)

Input data are described on tables 3 and 4. The software *TropLux* uses Monte Carlo approach, ray tracing and daylight coefficients [13]. The software DesignBuilder has an interface for the EnergyPlus simulation engine [14], which simulates energy flows on buildings.

Table 3: Model input on TropLux.

Location	Maceió-AL (available on the software)
Workplane	0,75m from floor
Points	Orthogonal grid of 30 points
Error	5%
Period	8a.m. to 6p.m., all year
Sky conditions	CIE sky types 1,10 and 14 [15]
External horizontal illuminance	Data from *Illuminating Engineering Society of North America* – IES (available on the software)
Glazing	Clear 3mm (available on the software)
Refletances	floor=0.4, ceiling=0.7, walls=0.6

Table 4: Model input on DesignBuilder.

Location	
Weather data file (.epw)	Maceió-AL. Available: [9]
Construction	
Walls	Ceramic block with six holes of square section + white mortar (wall with window) - U=2,53W/m^{2}K; Adiabatic (other walls).
Glazing	Single Clear 3mm - U = 5,89W/m^{2}K
Louvers	*Aluzinc* (material composed by aluminium (55%), zinc (43,4%) and silicon (1,6%))
Occupancy and internal gains	
Period	8a.m. to 6p.m., from Monday to Friday; 8h às 12h, on Saturdays, all year
Occupancy and clothing	4 occupants; 0,8clo on winter and 0,5clo on summer
Activity	Light office work - 120W/person
Equipment	4 computers with printers – 22W/m^2
Lighting	Fluorescent (Surface mount) - 11W/ m^2
Split (Air conditioning)	Coefficient of Performance = 3,54; Cooling setpoint temperature (operative) = 24,5°C

Criteria and metrics for performance analysis

For luminous performance analysis, it was considered the obtained useful daylight illuminances - UDI [16]. The percentage of hours when average illuminances on workplane were between 100 e 2000lx was the target range. Three CIE sky types [15] were simulated: clear, partially cloudy and cloudy. These represent the annual variations of sky conditions for Maceió-AL [13], with probability of occurrence corresponding to 12,4%, 61,8% and 25,8% (p. 3-10), respectively. The results were weighted according to these probabilities of occurrence, setting a dynamic sky condition that resulted in a single UDI value for each configuration.

For thermal performance analysis, it was identified the annual sum of solar gains through windows, in kWh, directly from the software. In order to have a dimensionless value, it was determined the solar transmitted to solar incident ratio (called T on this paper) for the different models.

Ranking

The final rate for each one of the configurations considers the average of the two previously attributed rates: the value for UDI and the value for solar gains. This last one was subtracted from 100, so higher final rates corresponds to higher number of hours of useful illuminances and lower total of solar gains through windows, desirable conditions on warm climates. The alternatives were ordered from those with higher ratings for those with minimal and the resulting framework was briefly discussed.

RESULTS

The next subsections show the results and discussion on this study.

Luminous and thermal performance

Figure 5 shows the useful daylight illuminance obtained for each one of the situations analysed.

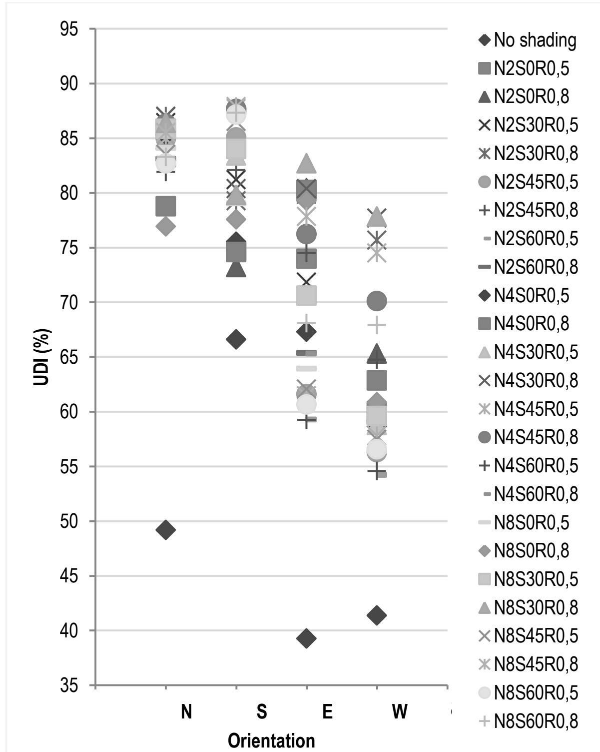

Figure 5: Percentage of annual hours when average illuminance on workplane is between 100 and 2000lx.

It was observed that in all louver scenarios, illuminances were between 100 and 2000lx during more than 50% of the time. In windows facing North and South this value was always above 70%. These conditions, however, were not achieved in cases with no shading (see detailed limits on Table 5).

Table 5: Useful daylight illuminances (100 to 2000lx)

	No shading	With shading	Increment
North	49%	77 to 87%	+57 to +78%
South	67%	73 to 88%	+9 to +31%
East	39%	59 to 83%	+51 to +113%
West	41%	54 to 78%	+32 to +90%

It was shown that window shading, though reducing the availability of daylight, can increase useful daylighting, by reducing the excessive illuminance (above 2000lx) (Fig. 6). Considering minimal illuminances needed for office visual tasks (500, 750 or 1000lx according to the Brazilian standards [17]), it can be pointed out a range between 500 and 2000lx, condition in which artificial lighting could be completely switched off.

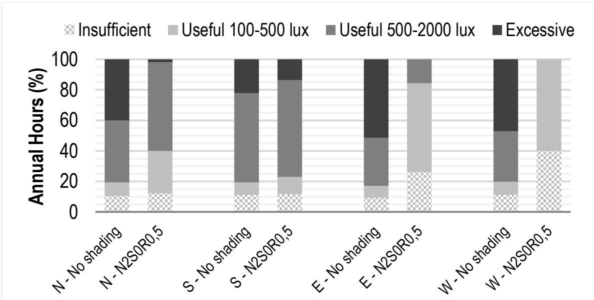

Figure 6: Useful daylight illuminances (All ranges)

According to the results, this condition is possible with the window facing North or South, on until 66% of annual occupied hours (Table 6). On East and West, although the addition of louvers can result in a poor luminous performance, it is also possible to increase the useful daylight in comparison to the case without shading. The best scenarios will be shown on the ranking topic.

Table 6: Modified useful daylight illuminance (500 to 2000lx)

	No shading	**With shading**	Increase
North	40%	40 to 59%	0 to +48%
South	58%	53 to 66%	-9 to +14%
East	31%	0 to 47%	-100 to +52%
West	33%	0 to 35%	-100 to +6%

Concerning thermal performance, Figure 7 shows the results obtained for the analyzed louver configurations.

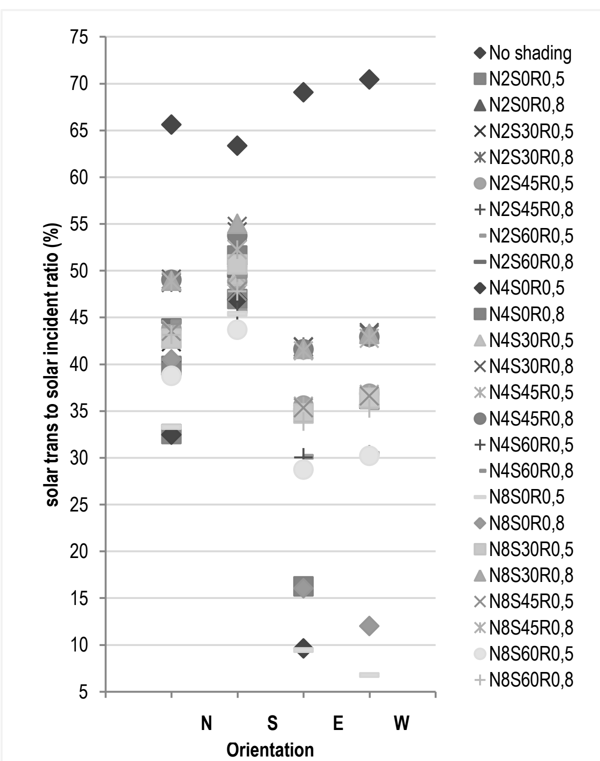

Figure 7: Annual solar gains through windows

It was observed that the choice on the number of slats presents very little influence on the solar gains (as already discussed in [18]). The increase in slats slope, reduces these gains. Comparing the cases with and without shading, naturally the shaded scenarios decrease the solar gains. This reduction was more significant on West orientation (90%) and less significant on South orientation (13%), as seen in Table 7. The consequent reduction on cooling energy consumption can be seen in Table 8.

Table 7: Solar trans to incident solar ratio

	No shading	**With shading**	Increase
North	66%	32 to 49%	-52 to -26%
South	63%	44 to 55%	-30 to -13%
East	69%	9 to 42%	-87 to -39%
West	70%	7 to 43%	-90 to -39%

Comparing the results for the different orientations, it was observed that when the window with louvers is facing North or South the values for daylight availability and solar gains are greater than those on orientations East and West. As the shading mask for the analyzed location was defined taking into consideration thermal criteria, obstruction on windows facing these last two orientations were very restrictive. Without shading they would present higher values.

Table 8 shows the cooling and lighting annual energy consumption of the simulated room. For the purpose of comparison, both systems were assumed as being switched on all the time (i.e. without considering the participation of daylight or natural ventilation). In this way, it was possible to estimate the participation of thermal and lighting loads on total energy consumption. It was observed that the air conditioning energy consumption is greater than lighting consumption, in a proportion of 60/40.

Table 8: Room annual energy consumption (kWh)

End use	Orientation	**No shading**	**With shading**
Cooling	North	1626,8	1330,0 to 1464,2
	South	1494,7	1348,4 to 1409,1
	East	1706,6	1221,6 to 1477,0
	West	2192,4	1328,1 to 1791,7
Lighting	All	926,64	
Sum	North	2553,4	2256,6 to 2390,8
	South	2421,3	2275,0 to 2335,7
	East	2633,2	2148,2 to 2403,6
	West	3119,0	2254,7 to 2718,3

Thus, the final rates for each configuration analyzed were attributed considering a weighting of indexes (Eq. 1), as an attempt to reflect the approximate verified proportion.

FINAL RATE= [UDI+1.5*(100-T)]/2.5 (Eq.1)

Where:

UDI = percentage of hours when average illuminance on workplane is between 100 e 2000lx
T = solar transmitted to solar incident ratio

Ranking

The ranking of louver alternatives studied is shown in figures 8,9, 10 and 11.

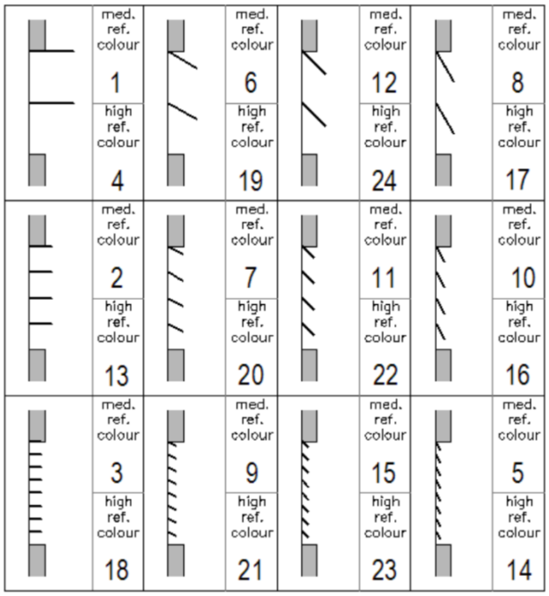

Figure 8 – Ranking louvers with window facing North

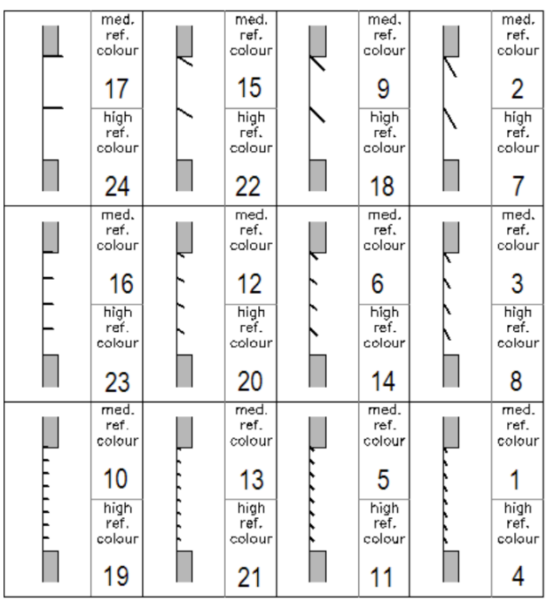

Figure 9: Ranking louvers with window facing South

With the window facing North, the best case scenarios were those with medium reflectance (0,5). This is the orientation with more insolation time on the analyzed city (as seen on solar chart from Figure 3), it being possible to reach the target illuminance range even with the presence of louvers. The medium reflective slats, as potentially enables enough daylight availability with less solar gains than those alternatives with high reflectance, presented more favorable balanced results for this orientation. The best scenarios with window facing South were those with slat slope equals to 60° and medium reflectance, followed by those cases with slat slope equals to 45° and medium reflectance.

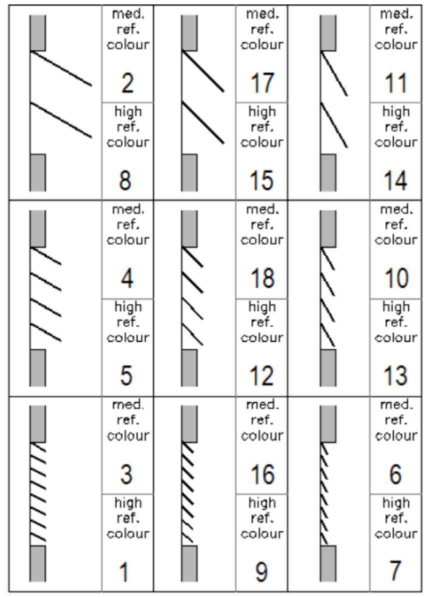

Figure 10: Ranking louvers with window facing East

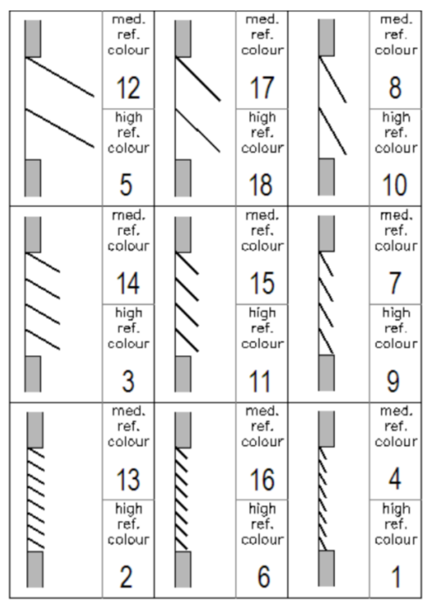

Figure 11: Ranking louvers with window facing West

On orientations East (Fig. 10) and West (Fig.11), the cases where the slats are sloped 45° presented the worst performances. This intermediate status do not prioritizes neither higher illuminances (such as the cases with lower slat slopes that allows more daylight into the room) nor the solar gains protection (such as the cases with higher slopes). The best rates were obtained by the configurations with slats sloped 30° in the East oriented facade and sloped 30° or 60° in the West one, depending on the color (reflectance) considered. If is intended to design horizontal louvers for more than one orientation, maintaining an uniform geometry, louvers with eight medium reflective slats and sloped 60° can be used, as they presented good rates for all orientations. It can also be noted that configurations with the best thermal performance tended to be those with the best balanced performance, as a consequence of the weight attributed to this aspect. It was observed a good trade-off between thermal and lighting requirements, on North and South orientations. In East and West oriented facades, a balance is harder to achieve considering the louver solutions analyzed (not movable). As mentioned earlier, their sun exposure condition in the studied location demands restrictive shading masks.

This work, by comparing shading devices configurations, is a contribution to the decision-making processes on architectural design aiming to achieve environmental comfort and low energy consumption. It is worth remembering that in addition to observing tendencies, it is important to consider the specificities of each design context.

CONCLUSION

The conclusions of this work are summarized below:

(a) Louvers with the same shading mask may present different thermal and luminous performances.

(b) It is possible to achieve useful illuminances (between 100 and 2000lx) in the studied office room with any of the louver configurations analyzed, at least in 50% of the annual occupied hours. By reducing excessive illuminances, all shaded scenarios presented better performance than the unshaded condition.

(c) It is possible to reduce the amount of solar irradiation transmitted through the window by 13% to 90% in comparison to the unshaded condition.

(d) The best ranked louver alternatives include: with window facing North, all those with medium reflectance; with window facing South, those with slats sloped 60°; on East and West, those with lower slope.

(e) Among the case scenarios analyzed, the louver configurations that presented a good final performance in all orientations were those with medium reflectance and slat slope equals to 60°.

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