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Effect of Tests Norms on the Instantaneous Efficiency of a Plate Solar Collector

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Abstract

Recent Algerian data have shown that affording conventional energy to some rural areas is as yet very costly. The objective of this paper is to calculate the instantaneous efficiency of a plate solar collector according to two different norms, (EN 12975-2 and ASHRAE). For this purpose, a closed loop test bench was been made in the unit of applied research on renewable energies of Ghardaia (Algeria) according to the considered norms. This site is characterized by an important clarity factor of 0.75. Experimental tests were conducted in order to calibrate the test bench, time constant and to calculate the instantaneous efficiency of the collector according to the two norms. In this work the curves of the instantaneous efficiency according to the two norms (optical efficiency and global thermal losses) were drawn as well as the daily efficiency of the collector.

Keywords Test bench; Plate Solar Collector; ASHRAE norm; calibration of test bench; time constant; instantaneous efficiency.

1. Introduction

in 1981 G. Beghi [1] highlighted his experience in the field of experimental tests of the flat plate solar collectors followed by D. Proctor [2] in 1984 who contributed to the spread of test methods for plane solar collectors.The study conducted in 2002 by Kratzenberg, [3] dealed with the certification of solar collectors, also Rojas and Klein [4] tested a flat plate with a single glazing as ASHRAE 93-2003 and EN 12975-2.

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Nomenclature

Ac	Collector aperture	m^2
Cp	Specific heat of the heat transfer fluid	kJ/kg K
F	Efficacité de l'ailette	
F'	Collector efficient factor	
F_R	Solar collector heat removal factor	
I_g	Solar irradiance	W/m^2
Qu	Net heat energy absorbed by working fluid,	W
R	Thermal resistance,	W/m^2k
Ta	Ambient temperature	°C
Te, Ts	Collector inlet and outel temperature	°C
Tp, Tv, Tmf	Temperature of the absorber and glass and average fluid temperature	°C
TSV	True solar time	heure
Uc	Solar collector heat loss coefficient	W/m^2 K
V	Wind speed	m/s
h	heat transfer coefficient	W/m2 K
k	Conductivity of absorber tube	W/mK
m	Mass flow rate of heat transfer fluid	kg/s
α_p	Absorptivité de la plaque absorbante	
ε_v ε_p	The emissivity of the selective absorbing and glass coating	
η	Solar collector efficiency	
θ	Angle of incidence	deg
ρ	Ground reflectivity (albedo)	
σ	Stefan–Boltzmann constant	$W./m^2 K^2$
$(\tau_v \alpha_p)_n$	Effective transmittance–absorptance product at normal incidence	
φ	Latitude	deg
β	Tilt angle of the collector	deg

In 2004, Fisher and Steinhargen [5], did their work on a new standard for two different regimes according to EN 12975. In 2008 Boudihardjo and Morison [6] performed a comparative study of performance of a solar plane collector and the other vacuum. In 2010, Zambolin [7] tested two types of solar vacuum and an alternative plane collector for the quasi-static and dynamic regimes according to EN 12975-2. Among the most recent studies in the characterization of solar collectors we can give you the work done in 2011 by Tin.Tai. Chow,[8] on the tests of the sensors under vacuum at two different systems (open and closed). But what about the Maghreb, little work has been made in the field of standardization. These include the 2001 study in Morocco by Ghedira. [9]. On the other hand in Algeria several works were completed on the studying of the thermal performances of the plane solar collectors. Nevertheless, there is few work on the characterization and the effect of the angle of incidence modified on the daily output of the sensor. But the experimental studies remain very limited.

We can quote the work completed in 1986 by Kasbadji and Merzouk, [10] that were related to the theoretical and experimental study of solar collectors in steady state. The aim of the present work was to study of the influence of the angle of incidence on the performances of the plane solar collectors such as the possibility on the choice of the sensors for several solar applications.

2. Presentation of the study region

The test bench is realized in the Unit of Applied Research on Renewable Energies of Ghardaia. This site is located in the Algerian South with latitude of 32.38° and a longitude of 3.81° and an altitude of 450 m.
Ghardaia is a sunny region with an estimated daily mean irradiation of 60006 kWh/m^2 during 3000 hours/year and average clarity factor of 0.75 [11].

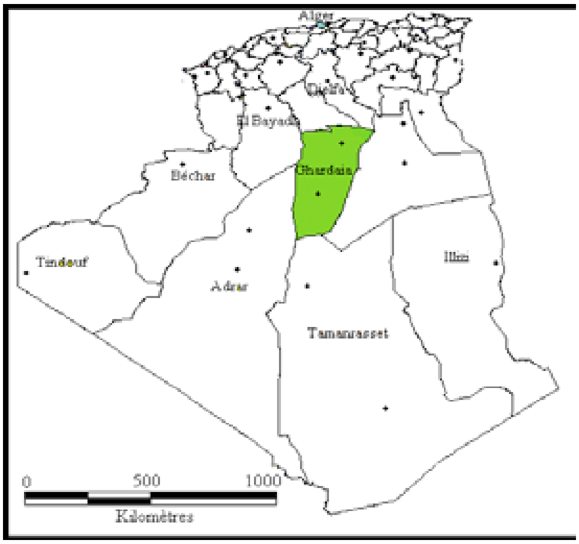

Fig. 1 Position of the study region

3. Mathematical Modelling

3.1 Calculation of collector instantaneous efficiency

The expression of instantaneous efficiency of the collector according to the norm EN 12975-2 is given by Kasbadji, [13]:

$$\eta_i = F' \left[(\tau\alpha)_{eff} - U_c \frac{(T_{mf} - T_a)}{I_g} \right] \tag{1}$$

Where F' is the efficiency factor of the absorbing plate and its value can be calculated as given in Equation (2) :

$$F' = \frac{\frac{1}{U_c}}{\ell \left[\frac{1}{[(\ell - D_e)F + D_e]U_c} \right] + \frac{1}{h_i \pi D_i} + \frac{e_t}{k\pi D_i}} \tag{2}$$

According to the ASHRAE norm, the expression of instantaneous efficiency was given by Kasbadji [13] :

$$\eta_i = F_R\left[(\tau\alpha)_{eff} - U_c\frac{(T_e - T_a)}{I_g}\right] \tag{3}$$

and

$$F_R = \frac{\dot{m}}{Ac\ h_p}\left[1 - \exp\left(\frac{n\ A_c\ h_p}{\dot{m}\ C_f}\right)\right] \tag{4}$$

Where F_R is the conductance factor.

3.2 Modeling of modified incidence angle factor

The theoretical global expression of transmission absorption coefficient is given by Merzouk, [14] :

$$(\tau\alpha)_{eff} = \frac{\alpha_n(\cos(\theta))^{0,25}\left[\frac{1}{2}\left(\frac{\sin^2(\theta+\theta_r) - \sin^2(\theta-\theta_r)}{\sin^2(\theta+\theta_r) + \sin^2(\theta-\theta_r)} + \frac{tg^2(\theta+\theta_r) - tg^2(\theta-\theta_r)}{tg^2(\theta+\theta_r) + tg^2(\theta-\theta_r)}\right)\exp\left(\frac{-Ke}{\cos(\theta_r)}\right)\right]}{1 - \left[1 - \left(\alpha_n(\cos(\theta))^{0,25}\right)\right]\ \rho_d} \tag{5}$$

Where Cos(θ) = sin(δ) sin(Φ) cos(β) -sin(δ) cos(Φ) sin(β) cos(γ+)

and cosδ cosΦ cosβ cosω+cosδ sinΦ sinβ cosγ cosω+cosδ sinβ sinγ sinω

By considering an inclination angle of the collector with the latitude of the site (Φ=32.38°) and the south orientation of the collector (γ = 0), we get:

Cos θ = sin δ sin (32.38- β) + cos δ cos (32.38- β) cos ω

Using Equation (4), we deduce the evolution of each parameter during the test.

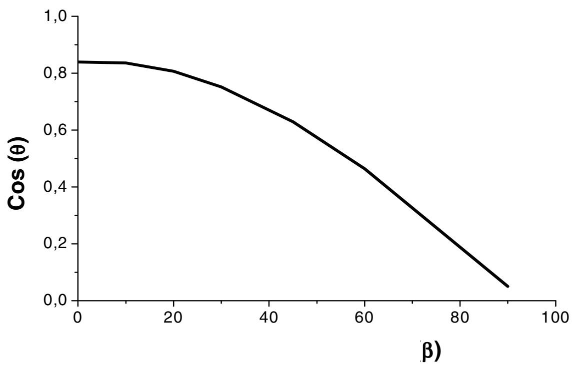

Fig. 2. Evolution of the incidence angle according to tilt angle of the collector

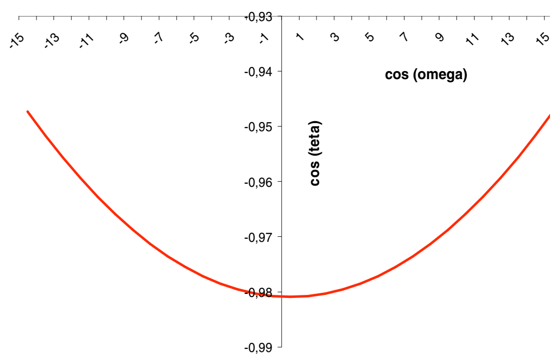

Fig. 3a Evolution of the cos (θ) according to cos (ω)

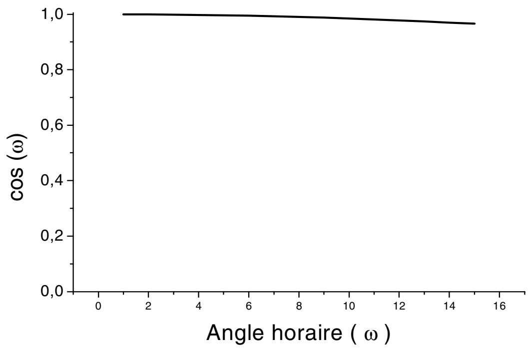

Fig. 3b. Evolution of cos (ω) according to hour angle (ω)

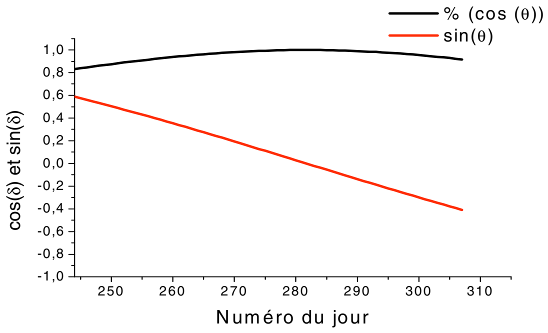

Fig. 4. Evolution of declination according to number of days.

Different variations of parameters influencing on incidence angle are arranged in Table 1. It can be seen that inclination angle β of the collector is the main parameter that is influencing on the incidence angle (θ), on the contrary to the other parameters (δ, ω et Φ) which have a slight influence on incidence angle (θ).

Table 1. Recapitulation of different parameters influence on incidence angle

δ	ω	β	Cos (θ)
-13,8°à 6,6°	0°	32°	-0,08 à +0,08
0°	-15°à15°	32°	– 0,95 à +0,98
c	0°	0°à 90°	0,05 à 0,84

4. Experimental tests

4.1 Presentation of test bench

Realized test bench is a closed loop according to the considered norms. It is mainly composed of three circuits. A primary circuit composed essentially of one glazing solar plate collector as depicted in Fig. 2, where the global surface equals to 2.6 m^2.
A secondary circuit is open and a heat exchanger which is used to connect the two circuits.

4.2 Calibration of test bench

The calibration of the test bench is done by using an insulated galvanized box containing an electrical resistance (1500 W) as presented in the Fig. 6..

The inlet and outlet temperatures are measured for a rate of flow defined by the norm as 0.02 kg/s.m^2. The power of the resistance is expressed by:

$$Pu= \dot{m}\, Cp\ (Ts\text{-}Te.) \tag{5}$$

Fig.5 Representation of solar test collector

Fig. 6 Representation of test bench

The relative error of the power is given by :

$$\varepsilon_r = \frac{P_{uc} - P_{um}}{P_{uc}} = 0.048 \quad (6)$$

So, it can be considered that the realization of test bench is adequate.

4.3 Tests conditions

To consider if a test is acceptable, a series of conditions ensuring permanent regime or quasi permanent regime have to fulfilled. During these tests, fluctuations of variables θ, Ta, Ig, V, m and T(s) are checked out to be in the limit tolerated by norms as shown in Table 2.

Table 2 : Parameters conditions during tests [15].

Parameters	ASHRAE	EN 12975
θ (°)	-30° à +30°	40° à +40°
$(T_s$-$T_e)$ (°C)	------	1.5 à 15
T_a (°C)	30°	5° à 30°
I_g (W/m^2)	> 790W/m^2	> 750W/m^2
m (kg/s.m^2)	0.02 +/- 10%	0.02 +/- 10%
V (m/s)	< 4.5	1.5 à 5.5

Different norms define the variations ranges of theses parameters as indicated in Table 3.

Table 3 : Condition defining permanent regime and quasi permanent regime [16].

Grandeur	ASHRAE	EN 12975-2
ΔTe	+/- 0.1 K	+/- 0.1 K
Δ (Ta-Te)	+/- 0.05 K	+/- 0.1 K
ΔTa	+/- 1 K	+/- 1.5 %
Δ Ig	-	+/- 50 W/m^2
Δ m/m	+/- 1 %	+/- 1%

They have been done with the following inlet (input) temperatures:

Ti = 20°C, Ti = 30C Ti = 40°C et Ti = 50°C

Four measurement points are considered (two before 12:00H and two after that). The fthe ollowing tests conditions are verified:

1. Global solar irradiation : 840 $W/m^2 < Ig < 950$ W/m^2
2. Diffused irradiation : 130 $W/m^2 < I_d < 220$ W/m^2
3. Ambient temperature : 20°C $< T_a <$ 25°C
4. Wind speed : 1 m/s $< V < 3$ m/s

4.4 Time constant computation

Test concerning time constant is carried out in accordance with the considered recommendations (heating and cooling period). Test conditions are verified since sky is clear (diffused irradiation < 20% of global irradiation), temperature varies slightly around 25°C global irradiation is greater than 800W/m^2. By adjusting theses points, the following exponential form curve is obtained :

$$\Delta T = A\,(1\text{-}e^{-Kt}). \qquad (7)$$

ΔT variation of outlet (output) temperature and ambient temperatures.

4.5 Calculation of the instantaneous efficiency of the solar collector

4.5.1 The instantaneous efficiency of the solar collector according to ASHRAE norm:

The expression of instantaneous efficiency is presented in the form of first degree polynomial, and it is reported to the global surface of the collector. It is a function of inlet (input) temperature of the fluid. It can be expressed as :

$$\eta = \eta_0 - a_1 T_m^* \qquad (8)$$

Where

η_o Optical efficiency of the collector.
a_1 Coefficient characterizing first degree polynomial thermal losses of the collector (W/m^2K).

$$T^* = \frac{T_e - T_a}{I_g} \qquad (9)$$

Where:
Te Inlet (input) temperature of the fluid
Ta Ambient temperature.

4.5.2 The instantaneous efficiency of the solar collector according to the European norm

For the European norm EN 12975-2, the relation expressing the instantaneous efficiency of the collector is reported to the surface of the solar collector or that of the absorber. It is a function of mean temperature of the fluid (i.e. arithmetic mean value).

$$T^* = \frac{T_{mf} - T_a}{I_g}$$

The expression of efficiency is a second degree polynomial as it is presented below:

$$\eta = \eta_0 - a_1 T_m^* - a_2 T_m^{*2}$$

η_o Optical efficiency of the collector ;
a_1 Coefficient characterizing first degree polynomial thermal losses of the collector (W/m^2K) ;
a_2 Coefficient characterizing second degree polynomial thermal losses of the collector ($W/m^2\ K^2$).

5. Results and discussion

5.1 Time constant

By adjusting considered points by simulation, the curve of the Equation calculating time constant is determined. It allows the definition of the asymptotic value A and time constant 1/k.
Fig. 7. present the evolution of time constant.

$$\Delta T = 0.632\ (1 - e^{-\frac{t}{495}})$$

The denominator 1/k present the collector time constant which is equal to 495 seconds. It refers to the time taken by the quantity ΔT (initial) to reach 0.632 of ΔT(final). Time constant is considered to be 10 minutes is recommended by the norm EN 12975-2.

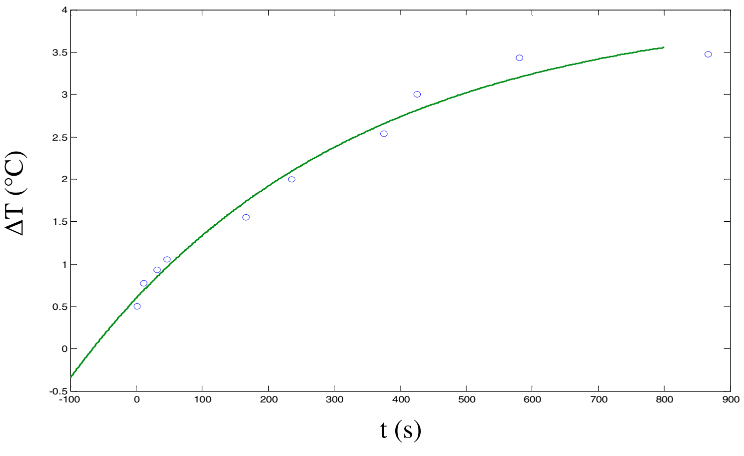

Fig.7 Time constant measurement points adjustment.

5.2 First degree polynomial instantaneous efficiency according to different norms

By smoothing the curves of measurement points and the calculated points based on mean square values method, the characteristic curve of instantaneous efficiency of the collector versus mean value of fluid and input temperatures can be obtained..

5.2.1. According to ASHRAE norm

The expression of the first degree polynomial instantaneous efficiency of the solar collector according to the ASHRAE norm is expressed as:

$$\eta_1 = 0.42 - 5.64\ T_1^* \tag{10}$$

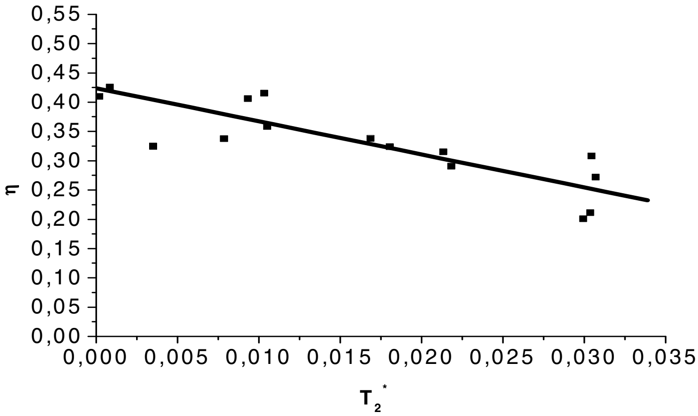

Fig.8 The instantaneous efficiency according to the ASHRAE norm

5.2.2 According to European norm EN 12975-2

By smoothing the curves of the measurement points and the calculated points based on mean square values method, the characteristic curve of instantaneous efficiency of the solar collector versus mean value of fluid temperature is written as:.

$$\eta_2 = 0.49 - 6.53\ T_2^* \tag{11}$$

It can be seen that the instantaneous efficiency according to the ASHRAE norm is slightly smaller than that calculated according to EN 12975-2 norm. This is due to the fact that global surface is greater than the aperture surface besides the difference of reduced temperature for each norm.

It is also noticed that the first degree polynomial global thermal losses coefficient is equal to 5.7 W/m2 K. This value indicate the insulation quality in the front and in the back (40 mm mineral wool back and 20 mm glass wool side). This means that the materials of the absorber and the insulation materials didn't get aged since they are protected against external hazards.

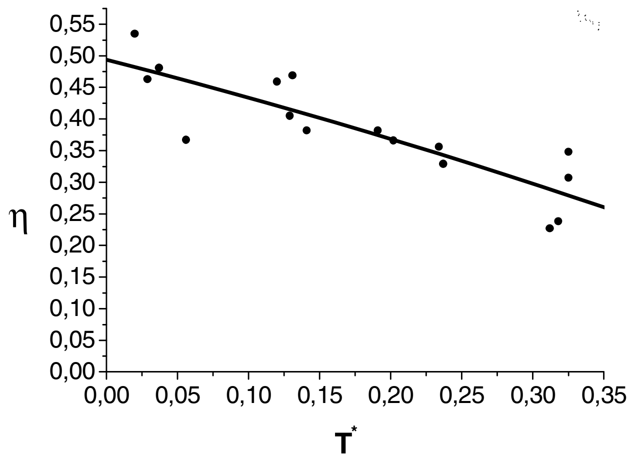

Fig.9.The instantaneous efficiency according to EN 12975-2 norm

5.2.3 Second degree polynomial instantaneous efficiency of the solar collector

By smoothing the curves of the measurement points and the calculated points based on mean square values method, we get the characteristic curve of instantaneous efficiency of the solar collector versus mean value of fluid temperature. The figure 10 Represents the instantaneous efficiency of the collector.

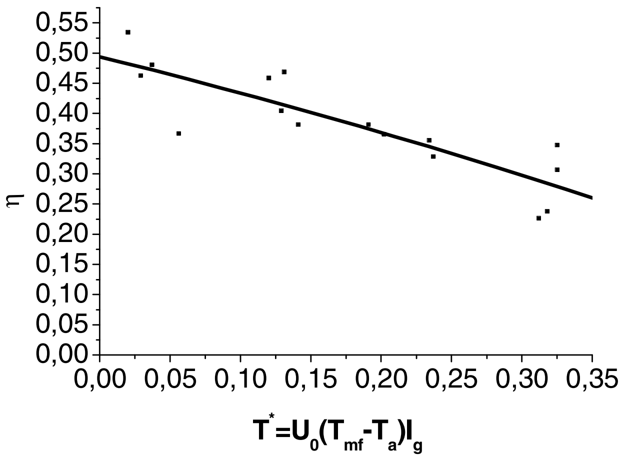

Figure 10 : Représentation of the instantaneous efficiency of the collector.

This curve fits well with the following Equation:

$$\eta 1= 0.49 - 5.7\ T^* - 0.26\ T^{*2} \tag{12}$$

This result is characterized by a good correlation coefficient that is equal to 0.84. The value 0.49 refers to the collector optical efficiency F'(τα)eff. It is defined by the intersection of the curve and the ordinates axis.

The value 5.7 refers to the solar collector global thermal losses (F'Ug). It presents the curve inclination rate (W/m^2K).

The value 0.26 refers to the dependence of irradiation thermal losses coefficient. It indicates the curvature of the curve (W/m^2K^2);
Some norms consider this coefficient insignificant (the new collectors have modern selective layers).

5.3 Uncertainty calculation

The instantaneous efficiency of the solar collector is given by :

$$\eta = \frac{\dot{m} C_p (T_s - T_e)}{A I_g} \quad (13)$$

According to th norm:

$$\frac{\Delta\eta}{\eta} = \left[\left(\frac{\Delta\dot{m}}{\dot{m}}\right)^2 + \left(\frac{\Delta C_p}{C_p}\right)^2 + \left(\frac{\Delta(\Delta T)}{\Delta T}\right)^2 + \left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta I_g}{I_g}\right)^2 \right]^{\frac{1}{2}} \quad (14)$$

The absolute errors given by the EN 12975 norm were [16]:

$$\Delta m/m = 0.01,\ \Delta(\Delta T)=0.1\ °C,\ \Delta I_g/I_g=0.06,\ \Delta T_a=0.2°C \text{ et } \Delta T_e=0.5°C \quad (15)$$

Using calculus, we get the variations ranges of errors of η et T*, according to the norm EN 12975-2 like follows:

$$\frac{\Delta\eta}{\eta} = [6.92\,\% \ - \ 9.75\%] \quad (16)$$

6. **Conclusion**

A theoretical modeling of the plate solar collector was developed in the current work. This allowed the determination of the general expression of global thermal losses coefficient, the effective heat quantity transmitted by the glass and absorbed by the absorber as well as the expression of the instantaneous efficiency according to EN 12975-2 and ASHRAE norms.
A closed loop test bench was tested in the Unit of Applied Research on Renewable Energies of Ghardaia, Algeria.
Most useful norms were studied in order to show the difference between them in the term of precision.
The obtained results of collector instantaneous efficiency calculated according to EN 12975-2 et ASHRAE were compared to the instantaneous efficiency found in different research works or solar collectors data sheets.

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