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Research Article

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Design and Construction of a Solar Photovoltaic Egg Incubator for Rural Areas

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Abstract This work proposes a prototype of solar photovoltaic egg incubator adapted to the rural environment. For the realization of this device, the approach adopted is one that takes into account different aspects, namely, the number of eggs to be incubated, the choice of material for thermal insulation, the interior evaporation surface, and the time to reach the operating temperature. The prototype of solar photovoltaic incubator presented has an average capacity of 300 hen eggs for a power of 125 W. The tests carried out with the device prove to be very satisfactory with an overall hatching rate of about 70%.

Keywords incubator, eggs, solar photovoltaic

Introduction

Livestock being one of the keys to all development, it is essential to make use of all possible means to boost this promising sector, especially in the context of rural African areas which are generally disconnected from the electricity network. All the same, these regions are well sunny. If we consider the case of Senegal, the country receives about 3000 hours of sunshine per year and a global irradiation of 5.8 kWh/m^2/day [1]. We proposed to design a prototype incubator taking into account the energy efficiency component and being able to efficiently use photovoltaic solar energy. In this work, we propose a path with a new approach that takes into account the number of eggs to be incubated, the material to be chosen for the thermal insulation of the device, the adjustment of the physical parameters of the incubator (volume, evaporation surface, threshold temperature, etc.).

2. Materials and Methods

2.1. Study and design of the photovoltaic incubator

To imitate exactly the poultry, the artificial incubators must imperatively respect a certain number of parameters, mainly: temperature, hygrometry, aeration (oxygen supply) and egg turning [2], [3]. In the previous works, there are several versions, sometimes with nuances about these parameters and how to regulate them [4],

[5], [6], [7], thermal insulation [8], [6], [9], for the solar power supply we can count completely different approaches [9], [10], [11], [12].

We will apply the calculation model used in the heating of buildings [13]. The incubator will not be in direct contact with the sun's rays. It will be placed in a room to already reduce temperature variations with the outside. The calculations are made in established regime (operating mode) under extreme conditions. We do not take into account the losses and contributions due to the embryonic metabolism. The linear thermal transmission (linear thermal bridges) and the small glass window. The room temperature is set between 18° and 36°. And that in the enclosure of the incubator must be distributed and not reaching a critical limit. The air velocity through the incubator should be between 0.1 m/s and 5 m/s [5].

2.2 Sizing of the incubator

2.2.1. Sizing of the incubator body

The capacity of the prototype is 300 eggs, considering an egg of average mass equal to 60 g [2], the incubator has as dimension then $780*564*850$ mm^3.

2.2.2. Egg turning

The egg turning is semi-automatic and is designed in such a way that the tray system can be turned up to a limit of 45° on either side of the horizontal by means of a single lever**.**

2.2.3. Choice of insulating materials for the incubator

For the choice of materials, we used the approach developed by Ashby [14] and relying on a sorting software. The criteria for the selection of materials for the incubator insulation are presented by Table 1 below.

Table 1: Material Selection Criteria for Incubator Insulation

Function	Thermal insulation of the incubator enclosure
Objective	Use of renewable resources and increased energy efficiency
Constraints	Maximum operating temperature 40.5°C with a limitation of the thickness of the incubator walls for mobility reasons; availability on the local market.

At the start of operation, the walls absorb energy per unit area expressed by the following relationship:

$$E_{abs} = C_p \times \rho \times e \times \frac{\Delta T}{2} \tag{1}$$

C_p: Mass heat capacity (specific heat) of the material, ρ : density of the material, e: material wall thickness, $\frac{\Delta T}{2}$: average temperature of the material wall.

At a time t , the energy loss by conduction through the walls to the outside per unit area is given by equation (2):

$$E_c = \lambda \times \frac{\Delta T}{e} \times t \tag{2}$$

λ : Thermal conductivity of the material, ΔT : temperature difference between inside and outside.

The performance index obtained through equations (1) and (2) is expressed by equation (3):

$$I_P = (\lambda \times \rho \times C_p)^{\frac{-1}{2}} = \frac{a^{\frac{1}{2}}}{\lambda} \tag{3}$$

The sorting and classification of materials based on the performance index is given by the diagram in Figure 1

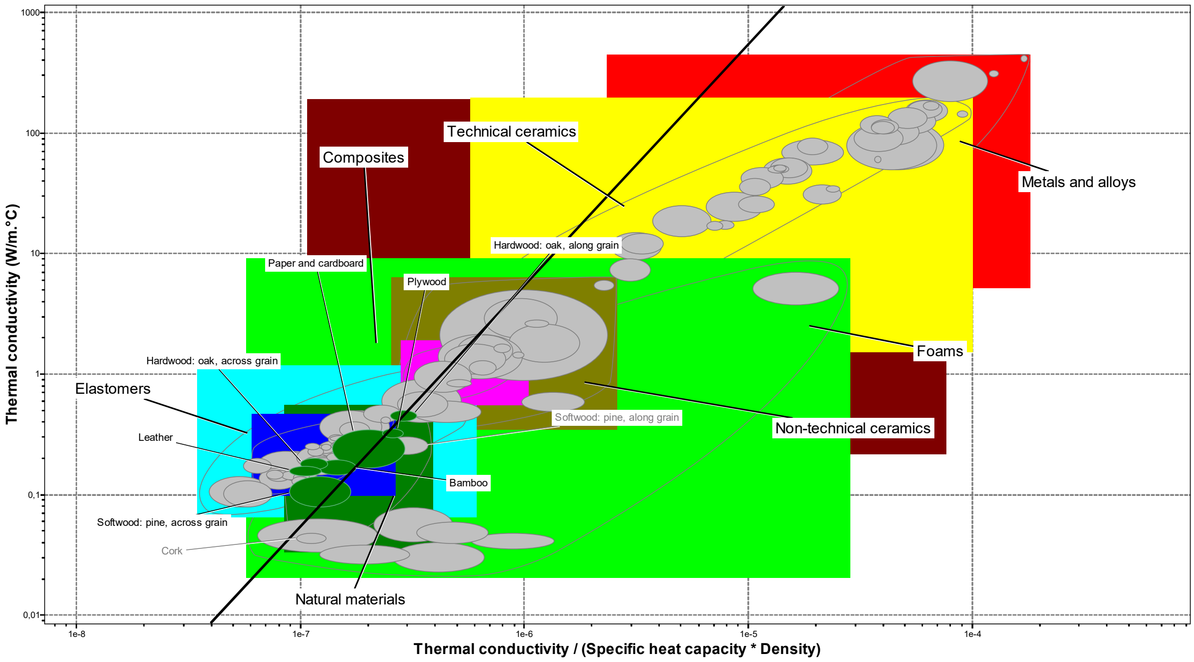

Figure 1: Sorting and grading of materials using the performance index

The diagram obtained from the processing shows that among the last seven (7) materials proposed by the software. For the realization of the device, our choice fell on the plywood. It is an air gap sandwiched between two sheets of plywood. The air gap is also an excellent insulator. Moreover, compared to the cost, air is an asset.

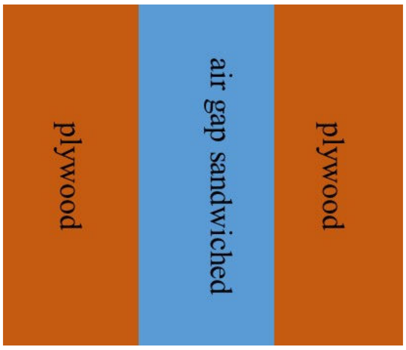

Figure 2: insulation

2.2.4. Ventilation (air quality)

At the level of the device, orifices with adjustable dimensions will ensure the continuous air renewal, because the need for oxygen is not the same throughout the incubation period. At the same time.

Passage area for air renewal:

$$A = \frac{V_i}{v} \quad (4)$$

$A_{\max}$: Maximum passage area m²; $A_{\min}$: Minimum passage area m²; $v_{\max}$: Maximum admissible speed of the area m²/s; $v_{\min}$: Minimum admissible speed of the area m²/s; V_i :is the air volume flow in m³/s.

The average amount of oxygen per hour required by an egg is 4.2*10-5m³/h [15] or about 0.0125m³/h for 297 eggs. Taking into account the air which is composed of 1/5 oxygen, we have :

$$V_i = 0.0125 \times 5 = 0.0625\, m^3/h = 1.73 \times 10^{(-5)}\, m^3/s$$

$$A_{\max} = \frac{1.73 \times 10^{-5}}{0.1} = 17.3 \times 10^{-5}\, m^2 = 173\, mm^2$$

$$A_{\min} = \frac{1.73 \times 10^{-5}}{5} = 3.46 \times 10^{-6}\, m^2 = 3.46\, mm^2$$

2.2.5. Sizing of the heating system

During the operation of the incubator, heat losses occur at the walls by conduction and convection, but also at the air renewal orifices.

The expression of the thermal balance is given by.

$$Q_T = Q_p + Q_r \tag{5}$$

Q_p is the thermal power lost by conduction and convection due to the walls; S_t : total wall area in m²; U : global thermal transmission coefficient W/ (m². °C)

$$Q_P = S_t \times U \times \Delta T \tag{6}$$

$$S_t = \sum S = 2.2848 + 0.43992 + 0.43992 = 3.2\, m^2 \tag{7}$$

$$U = \frac{1}{R_t} = \frac{1}{3.95} = 0.25 \frac{m^2 °C}{W} \tag{8}$$

R_t : total thermal resistance or thermal flux in (m².°C)/W, it is given by the relation:

$$R_t = \sum R = \sum \left(\frac{1}{h_{\text{int}}} + \frac{e_{cp}}{\lambda_{cp}} + \frac{e_{air}}{\lambda_{air}} + \frac{e_{cp}}{\lambda_{cp}} + \frac{1}{h_{ext}}\right) \tag{9}$$

h_{int} : Convection transmission coefficient on the interior wall W/ (m². °C); h_{ext} : convection transmission coefficient on the external wall W/ (m². °C); ΔT : temperature difference between inside and outside in °C.

$$Q_P = 3.2 \times 0.25 \times (40.5 - 18) = 18.5625 \approx 19\, W \tag{10}$$

Power lost by air renewal

$$Q_r = V_i \times C_v \times \Delta T \tag{11}$$

C_v = 0.34: volumetric heat capacity of air in Wh/m³. °C; V_i : Air volume flow rate in m³/h, expressed by the relation.

$$V_i = A_{MAX} \times v_{\max} = 3.84 \times 10^{-5} \times 5 = 0.000192\, m^3/s = 0.06912\, m^3/h \tag{12}$$

$$Q_r = 0.06912 \times 0.34 \times (40.5 - 18) = 5.29\, W \tag{13}$$

Power required for heating

$$P_c = Q_T = Q_p + Q_r = 19 + 5.29 = 24.29\, W \tag{14}$$

The heating power required to maintain the temperature in the incubator is then $24.29\ W$.

The device includes a fan of $P_v = 5\ W$ power to allow a mixing of the air inside, in order to avoid too much difference in temperature.

The necessary electrical power is then:

$$P_n = P_c + P_v = 24.29 + 5 = 29.29\ W \tag{15}$$

Another variable to be taken into account is the time to reach the operating temperature when the incubator is started, or if the eggs are introduced with a delay. The system must evolve in a moderate way to reach the operating temperature.

For the reasons mentioned above, we have decided on a new electrical power requirement taking into account the heating element:

$$P_n' = 120\ W \tag{16}$$

The installed electrical power is:

$$P = P_n' + P_v = 120 + 5 = 125\ W \tag{17}$$

2.2.6. Hygrometry

The humidification is ensured by a water tank installed inside the incubator, using the principle of vase communicating with another tank outside connected by a piping. Thus the interior tank has an evaporation surface corresponding to the interval required for the incubation phase and an additional tank is provided for the hatching phase, its evaporation surfaces have been determined experimentally.

2.2.7. Electrical circuit and equipment

The circuit is composed of incandescent bulbs, a fan, a thermostat model XH-W3001, a light, a switch and a thermometer-hygrometer indicator.

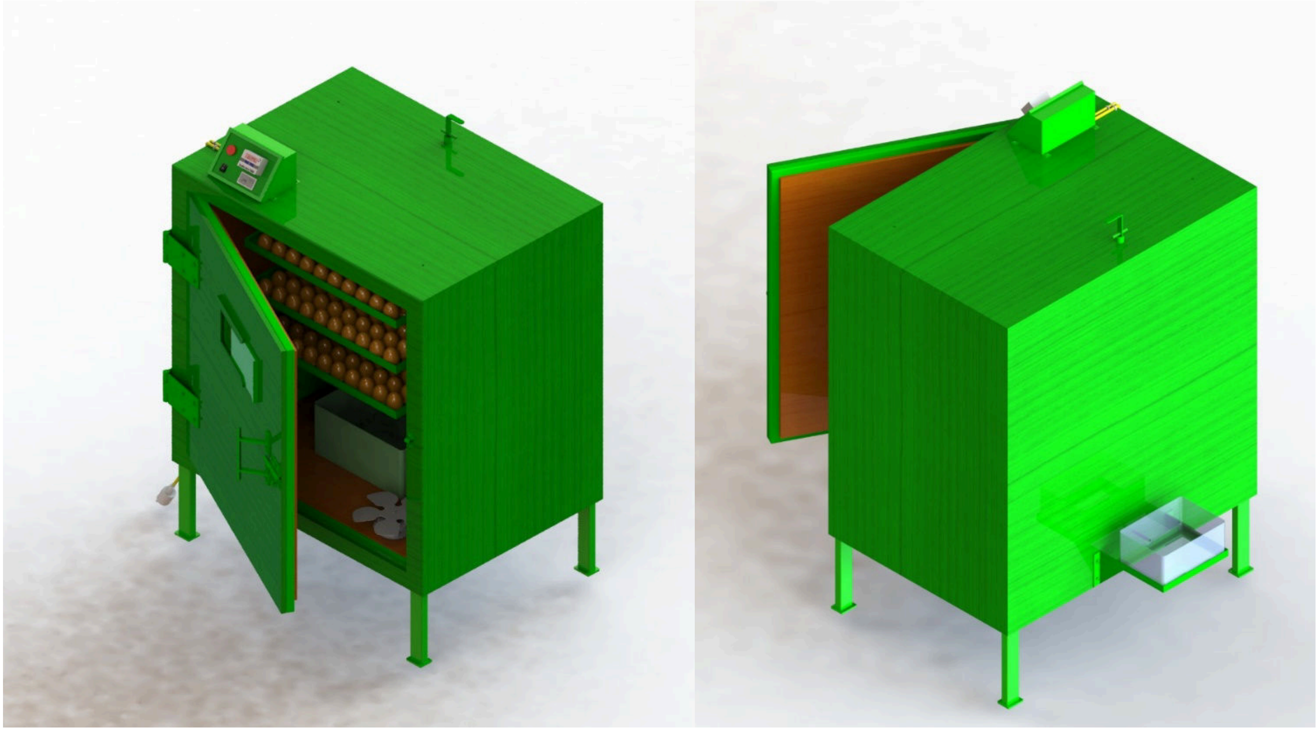

Figure 3: the prototype designed

Sizing of the photovoltaic system

System configuration

We have an off-grid configuration (stand-alone): photovoltaic generator, charge regulator, batteries and inverter.

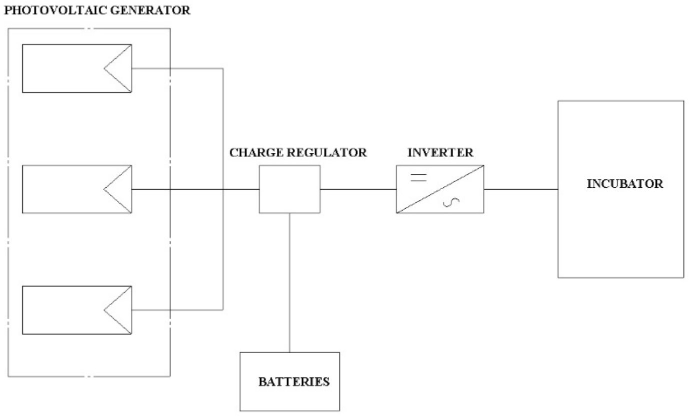

Figure 4: System configuration

Operating conditions relative to the city of Thiès (Senegal)

The operating conditions are predefined and linked to the geographical situation; the manufacturers fix others, while others are adopted by experience made on the device. Average radiation: 5.8 kWh/m²/day; overall system efficiency: 0.65; number of days of autonomy: 3; degree of deep discharge: 0.8; angle of inclination: 15° north/south; distance inverter equipment: 2 m; distance panels regulator: 4 m; distance inverter regulator and distance battery regulator: 1 m.

The insignificant consumption of the thermostat is not taken into account.

Daily energy requirement: $E_j(Wh) = 1250\,Wh$ (18)

Peak power: $P_p(Wp) = 337.38\,Wp$ (19)

The select panel is: Peak power: 120 Wp, Voltage: 12 V.

Number of panels $N_p = 3$; number of panels in series $N_{ps} = 1$; number of parallel branches $N_{bp} = 3$. (20)

Capacity of the battery: $C(Ah) = 390.625\,Ah$ (21)

Selected battery (200 Ah, 12 V)

Number of batteries $N_{ac} = 2$; number of batteries in series $N_{acs} = 1$; number of parallel battery branches $Nbp_{ac} = 2$. (22)

Rated current of the regulator: $I_e \geq 21.57\,A$ (23)

Selected controller 12/24 V, 25 A

Apparent power of the system $S_{inv} = 180\,W$ (24)

Selected inverter 12 V, 200 W

Cable sections: $S_{inv/inc} = 0.75\,mm^2$; $S_{pan/con} = 6\,mm^2$; $S_{con/bat} = 2.5\,mm^2$; $S_{con/inv} = 2.5\,mm^2$ (25)

3. Results & Discussion

3.1. Realization and testing

3.1.1 Realization of the incubator

The realization includes mainly two great parts: That of the incubator and its electric supply. It is about the metal construction to realize the framework, the shelves with their supports, the wood joinery for the thermal insulation, the installation of the electric circuit, the heating, the hydraulic circuit for the humidification, the aeration holes and the finishing.

Figure 5: Different stages of realization and testing

3.1.2. Setting the incubator parameters

After the realization of the incubator, we passed to the test of parameter setting to determine certain characteristics such as: the heating necessary to reach the temperature of operation in the interval of 30 minutes to 1 hour, the time of daily operation to be used for sizing photovoltaic , the surface of evaporations necessary to keep the hygrometry in the required interval.

3.1.3 Device test

To conduct the test properly, you should:

Mark the date of egg introduction, ensure turning 4 to 5 times a day until three days before hatching, monitor the water level from the outer tank and increase the evaporation surface during the hatching phase, perform egg candling to discard unfertilized eggs from the 7th day of brooding.

3.2. Analysis of the results

For the heating, we opted for 2 incandescent bulbs of a power of 60 watts each, the incandescent bulbs have a luminous output of approximately 20% to 25%, the remainder of the power is dissipated in heat what makes us 90 to 96 watts as power of heating allowing us to remain in the interval.

The operating time of the heater is about 10 h / day.

The corresponding evaporation surface for our volume which is V = 0.31m^3 with a temperature fluctuating between 37.7 and 38°C and an average air speed between 0 and 4 m/s is :

Table 2: Correspondence between evaporation surface and hygrometry

	incubation phase	**hatching phase**
Evaporation surface (m^2)	0.080 to 0.085	0.098 to 0.12
Humidity (%)	58 to 65	65 to 85

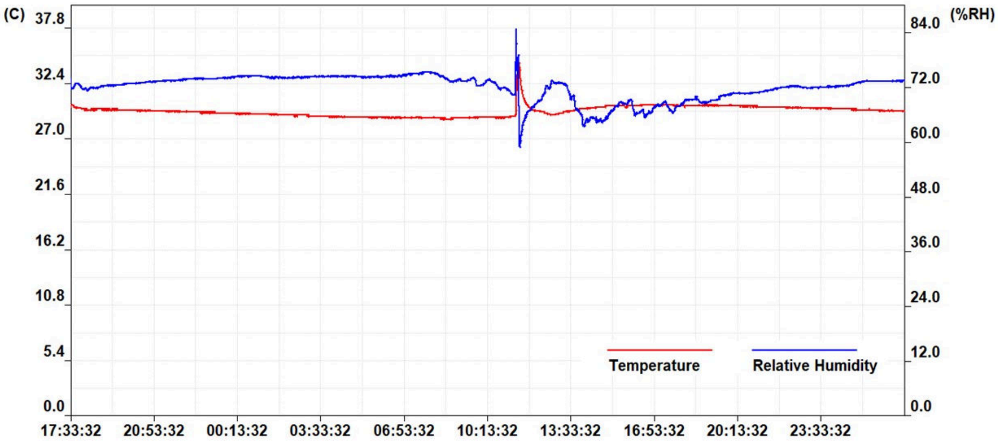

Figure 6: Temperature and humidity as a function of time in the incubator room

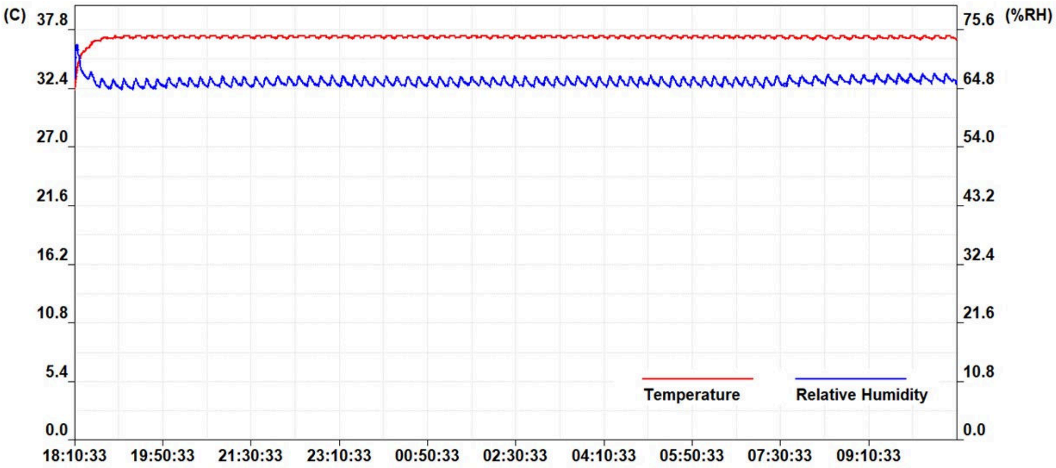

Figure 7: Evolution of temperature and humidity as a function of time in the incubator

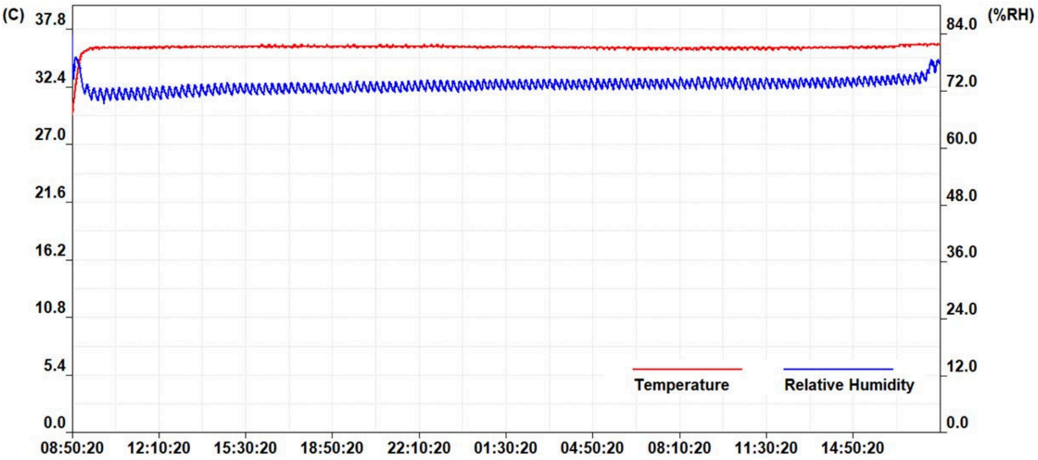

Figure 8: Evolution of temperature and humidity as a function of time in the incubator during the hatching phase

Figure 9: Hatching

4. Conclusion

In this work, we have designed, realized and tested a solar photovoltaic incubator intended for the rural environment very energy efficient compared to the existing incubators on the market, indeed we have taken into account the realities and the locally available materials. The results of the test are 70% satisfactory despite the constraints of egg supply and mechanical monitoring.

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