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The possible integration of hydrogen energy for autonomy in the households for different climates in Algeria

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Abstract

The construction industry is one of the sectors whose consumption has a significant impact on the nation's total energy consumption and CO_2 emissions. It is therefore necessary to reduce the environmental impact of this sector. In this work, a renewable energy system is proposed to meet the energy requirements of a household. This household is located in seven regions of different climates in Algeria, in order to minimize energy consumption and greenhouse gas emissions. The proposed system includes photovoltaic panels combined with an electrolyzer. The results show the suggested system energy has realized energy independence for the households, and this system container avoids the emission of 7.47 tons/year of CO_2. The payback period is about 2.27 years.

Keywords: Renewable energy system, Construction sector, Hydrogen, Environmental impact.

1. Introduction

Global energy consumption will continue to grow in the coming years due to population growth and rising living standards. Greenhouse gas emissions, partly linked to all human activities, represent a growing and serious risk to the environment and society. A large part of the energy used today in the world (more than 80%) comes from deposits of carbon fossil fuels (coal, oil, gas) (IEA 2023). These deposits are limited in quantity and exhaustible.

Construction is the sector of activity that consumes the most energy, which could be significantly reduced through sustainable design, high energy efficiency and the use of renewable sources.

In 2023, the construction sector will account for 47% of the energy consumed in Algeria, far ahead of the transport sector (29%). The construction sector is responsible for 37% of greenhouse gas emissions, making it one of the vital areas in the contest against global warming and the energy transition (MEM, 2023; Recioui et al., 2016). The combination of renewable energies in buildings will reduce energy needs and improve their energy efficiency. The usage of hydrogen as an energy vector is one of the solutions considered for the energy future. The combination of hydrogen energy in buildings is an environmentally friendly solution. They make it possible to acquire a certain energy autonomy.

This study reveals the opportunity of providing the energy needs of households by means of renewable energy. The studied house is situated in seven regions of different climates in Algeria.

2. Methodology

The objective of this study is to provide the energy needs of households via a renewable energy system. The studied house is situated in seven regions of different climates in Algeria. A calculation study was carried out using an Excel calculation tool. The choice fell on an individual habitat occupied by a family of six (6) people. This hose is considered by the high energy efficiency of domestic machines and thermal insulation via phase change materials (PCM) for the house envelope ($CaCl_2.6H_2O$), as well as electricity production from hydrogen to supplement the energy needs of the construction.

As above said, the process was designed to produce an amount of energy capable of satisfying the energy demand of the building. The balance between the energy input of each source and the demand is not always achievable. This lack will be compensated by the introduction of the electrical network. If the energy produced by the electrolyzer exceeds the energy requested by the load, the surplus energy will be sent to the electrical network (Figure 1). Environmental and economic aspects are taken into account to evaluate our study.

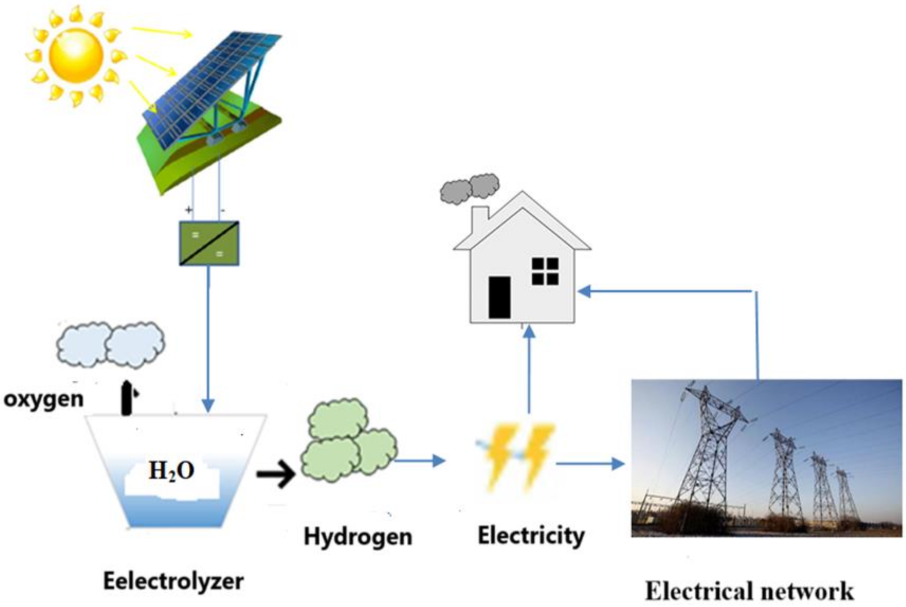


Figure 1: Proposed system.

3. Description of the case study

The building studied is an individual house; the area is 120 m^2. It is composed of a kitchen, four bedrooms, a garage, two bathrooms, and a hall. We assume that the thermophysical characteristics of opaque walls are the same for all climates. The exterior wall consists, from outside to inside, of a layer of cement, insulation (plaster/PCM), brick, air gap, brick, and plaster layer, with thicknesses of each material used, respectively, of 2 cm, 2 cm, 10 cm, 5 cm, 15 cm, and 2 cm.

The roof consists, from the outside to the inside, of a layer of slag concrete, insulation (plaster/PCM), slag concrete, and a layer of plaster, with thicknesses of each material used, respectively 5 cm, 2 cm, 5 cm, and 2 cm.

Glazed walls: Walls made of standard double glazing (4/6/4) with wooden joinery with a surface Aw = 1.44 m^2. The following table represents the thermal characteristics of opaque and glazed walls.

Table 1: Thermal characteristics of opaque and glazed walls (MHUP, 2011; Ghedamsi et al., 2014)

Building materials	Thermal conductivity (W/mk)	Thermal resistance (m^2k/W)
Cement	1.4	0.014
Plaster	0.35	0.043
Brick	0.48	0.31
Air gap	0.026	0.16
Slag concrete	0,65	/
$CaCl_2.6H_2O$	/	0.052
Double glazing (4/6/4)	/	0.34

4. Energy needs of a household

Energy needs include household appliances, lighting, heating and air conditioning.

4.1. Energy needs for heating and air conditioning

Heat gains in summer and heat losses in winter from buildings occur most often through external walls, roofs, windows, and basements and through infiltration. The annual energy needs for heating and cooling are given by (Ghedamsi et al., 2016):

$$E_H = \frac{Q_H}{(\eta_s)} \quad (1)$$

$$E_C = \frac{Q_C}{cop} \quad (2)$$

Where, η_s is the efficiency of the heating system, taken as 0.93, COP is the Coefficient of Performance of a refrigeration system, taken as 2.5 (Ghedamsi et al., 2016). Q_H is the annual heat loss for heating per unit of external wall area and Q_C is the annual heat loss for cooling per unit of external wall area are given by (Daouas et al., 2010 ; Ozel, 2011).

$$Q_H = U \times HDD \times A \quad (3)$$

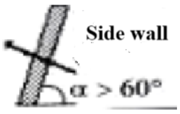
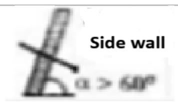
$$Q_c = U \times CDD \times A \quad (4)$$

U is the overall heat transfer coefficient in $W/m^2.k$. This coefficient is as follows (Kemal and Yüksel 2003):

$$U = \frac{1}{\left(\frac{1}{h_i} + \sum_{j=1}^{N} \frac{e_j}{k_j} + \frac{1}{h_e}\right)} \quad (5)$$

With, h_i and h_e are the convection heat transfer coefficients between air and the internal and external faces of the wall. The value of the surface thermal resistance varies with the horizontal or vertical position of the wall, as well as the direction of heat flow (Table 2). e_j and k_j are the thickness and thermal conductivity of layer j, respectively.

Table 2: Convective heat transfer coefficients between air and internal and external wall faces (MHUP, 2011).

h(W/m^2 K)	**Wall in contact with the exterior**	
	h_i	h_e
	9,09	16,66
	11,11	20
	10	25
	6,25	25

HDD and CDD are the numbers of heating and cooling degree days and are obtained as demonstrated by the following equations (Ekici: et al., 2012).

$$HDD = \sum_{days}(T_b - T_e)^+ \quad (6)$$

$$CDD = \sum_{days}(T_e - T_b)^+ \quad (7)$$

T_b is the base temperature (the base temperature in winter and summer season, 18°C and 26°C, respectively), and T_e is the average daily outdoor air temperature. The plus sign (+) beyond the parentheses shows that only positive values must be reckoned, the temperature difference should be taken as zero when the values are negative.

4.2. Energy requirements for domestic hot water

To calculate the need for domestic hot water, we need to know the number of people in the building, their age, their tasks, their lifestyle, the day of the week (work, weekend), the season and many other circumstances. The energy requirements for domestic hot water expressed in (kWh/day) are obtained from the following relationship (Yao and Steemers, 2005).

$$E_{\text{ECS}} = \frac{C_p \rho V (T_{out} - T_{in})}{3600} \qquad (8)$$

Where, C_p is the specific heat of water (4187 J/kg K), ρ is the density of water (1000 kg/m^3), Vis the Daily volume of hot water consumed for each person (m^3 /day), T_{out} is the outlet temperature of water (50°C) and T_{in} is the cold water temperature (20°C).

4.3. Household appliances

The consumption of household appliances is as follows:

$$E_{\text{app}} = n * (p * t) \qquad (9)$$

where, p is the power of each household appliance, n is the number of household appliances and t is the operating time. Table 3 gives the electrical power and operating time of each appliance (Djelloul et al., 2013).

Table 3: The electrical power and operating time of each appliance.

Appliance	Power (W)	Quantity	Daily operating time (h)
TV	45	2	13
Computer	12	1	3
Stove	21	1	7
Washing machines	135	1	1
Iron	800	1	1
Fridge	42	1	24
Freezer	40	1	24
Light-emitting diode (LED)	12	9	7

5. Modeling of the energy system

5.1. Modelling of Photovoltaic (PV)

The peak power (P_c) of modules PV (in W) is given by the following formula (Belhadj et al., 2010):

$$P_c = \frac{E_P}{H_{ens} \times \eta_{reg}} \qquad (10)$$

Where, H_{ens} is the maximum sunshine hour and η_{reg} is the efficiency of the accumulator charge regulator equal to 0.77.

From the peak power of the panel, we can determine the number of panels required for the installation (N_{PV}):

$$N_{PV} = \frac{P_c}{P_U} \quad (11)$$

Where, P_U is the unit of power (W).

The total roof surface area (S_T) required for photovoltaic panel installations is given by the following formula (Belhadj et al., 2010):

$$S_T = S_u . N_{PV} \quad (12)$$

Where, S_u is the unit area of the panels (m^2). Table 4 gives the technical characteristics of the panel used that was chosen on the basis of availability on the Algerian market, price, lifespan and energy efficiency.

Table 4: Technical characteristics of the panel used (Dimel, 2020).

Type	Unit of power (W)	Unit area (m^2)	Efficient (%)
Dimel DP300	300	1.59	16.4

5.2. Energy from the electrolyzer

The energy produced by photovoltaic will be sent to the electrolyzer to ambition the water electrolysis process to produce hydrogen. In this work, a Proton Exchange Membrane (PEM) type electrolyzer was used. Therefore, the energy produced from the electrolyzer (E_{elec}) is defined by equation 13 (Ghedamsi et al., 2024).

$$E_{elec} = \eta_{elec} E_{pv} \quad (13)$$

Where, η_{elec} is the electrolyzer efficiency and E_{pv} *is the* energy produced from Photovoltaic (kWh).The calculation of the mass of hydrogen produced from electrolyzer as follows (Chennouf et al., 2014):

$$m_{H_2} = \frac{E_{elec}}{LCV_{H2}} \quad (14)$$

Where, LCV_{H2} is the Lower Calorific Value of hydrogen (kWh/kg).

6. Environmental indicators

The avoided greenhouse gas emissions (E_{GES}) of conventional systems are evaluated according to the following equation:

$$E_{GES} = E_{con}.F_E \quad (15)$$

Where E_{con} is the energy generated by conventional systems (kWh) and F_E is the greenhouse gas emission factor that be contingent on the type of fossil fuel and the transformation technique used to generate the power. In this study, the predicted avoided CO_2 emission is based on the electricity emission factor of 0.548 kg/kWh (Ademe, 2014).

7. Economic Analysis

Logically, at the end of this work perform an economic evaluation of the project, Using commonly used indicators: are the life cycle methods (LCC) and the payback Period (RP). The equation is used for The LCC is calculated as follows (Ghedamsi et al., 2024):

$$\text{LCC} = C_T + USPW(N.d) \times C_E \quad (16)$$

Where, C_T is the total cost of a house over its entire lifetime, including initial capital costs of each system component, maintenance costs, operating costs, C_E is the annual energy cost necessary to uphold comfort inside the construction. $USPW$ is the uniform series present worth factor and is demarcated as:

$$USPW(N.d) = \begin{cases} \frac{(1+d)^N - 1}{d(1+d)^N} & \begin{cases} i > g & d = \frac{i-g}{i+g} \\ i < g & d = \frac{g-i}{1-i} \end{cases} \\ \frac{1}{1+i\prime} & i = g \end{cases} \quad (17)$$

Where, *i* is the interest rate for operations, *g* is the inflation rate and *N* is the project lifetime.

The payback Period (PR) is the primary cost of investment divided by the annual cash entry. The techno-economic characteristics of the system components are presented in Table 5.

Table 5: Techno-economic characteristics of the system components (Dimel, 2020; Mokhtara et al., 2021)

Component	**PV**	**Electrolyzer**	**Fuel cell**	**Inverter**
Capital cost (€)	130	844.7	1785.68	1222.91
O&M cost (% of capital cost)	1	2	1	0

Lifetime (year)	25	25	10	25
Interest rate (%)	4	/	/	/
Inflation rate (%)	1.1	/	/	/

8. Results and discussion

Table 6 presents the geographical data of the selected stations and the numbers of heating and cooling degree days.

Table 6: Stations and climatic characteristics.

Station	Longitude	Latitude	CDD (C°)	HDD (C°)
Alger	3.1°	36.77°	79,2	456,1
Djelfa	3.35°	34.67°	307,9	1702,8
Bechar	-2.23°	31.62°	874,1	842,1
Ouargla	5.4°	31.92°	1222,7	668,9
Illizi	8.42°	26.5°	1257,1	474,2
Adrar	-0.28°	27.88°	1558	430,9
In Salah	2.47°	27.2°	1628,1	344,3

After defining the household appliances and their conditions of use, we realize the annual energy consumption for each dwelling in each station. The following figure represents the energy consumption of a building for each station.

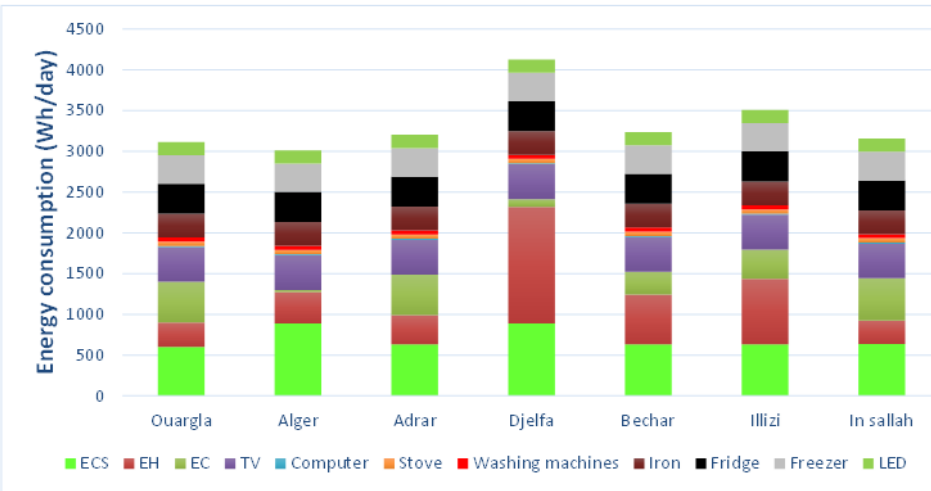


Figure 2: Energy consumption of a building for each station.

According to figure 2, the main categories of energy consumption in each region are heating, air conditioning, and domestic hot water. We observe the coldest region is the city of Djelfa, and the hottest city is In Salah. The following table presents the annual energy consumption in households, energy produced annually, and CO_2 emissions avoided for the seven stations.

Table 7: Annual energy consumption in households, energy produced annually, and CO_2 emissions avoided for the seven stations.

Station	Energy consumption (kWh/year	Energy production (kWh/year)	CO_2 avoided (tons/year)	Excess energy (kWh/year)
Ouargla	11139,8	12377,15	6.78	1 237,35
Alger	10990,15	12212,9	6.69	1 222,75
Adrar	11683,65	12979,4	7.11	1 295,75
Djelfa	15059,9	16731,6	9.16	1 671,7
Bechar	12143,55	14226,82	7.79	2 083,27
Illizi	12800,55	14224,05	7.79	1 423,5
in Salah	11515,75	12793,25	7.01	1 277,5

According to table 7, the energy produced from the electrolyser satisfied the energy requirements of households in each region of Algeria.

In this work, the average energy demand of one household in Algeria is 12190,47 kWh/year, in this situation, the average energy generated exceeds the average energy demand (13649,31 kWh/year), Thus, the goal of the study has realized. The annual surplus hydrogen energy is 1458,83 kWh/year (equivalent to 328,23 € per year), the renewable energy system avoids the emission of 7.47 tons/year of CO_2.

Figure 3 represents the quantity of hydrogen produced and the number of photovoltaic panels to meet the demand for energy building for the 07 stations.

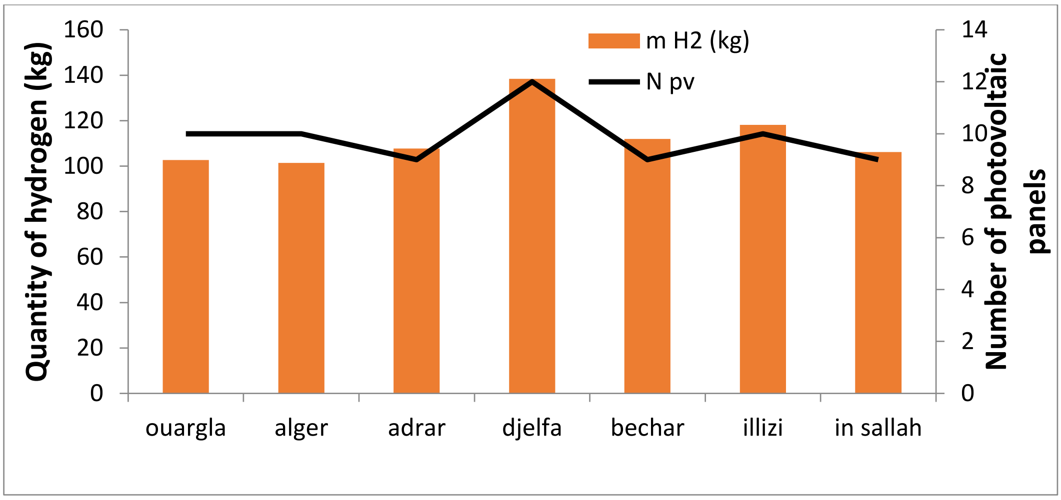


Figure 3: Quantity of hydrogen produced and the number of photovoltaic panels to meet the energy demand.

Figure 3 shows that the generation of hydrogen is followed by an increase in numbers in photovoltaic panels. The city of Djelfa produces the biggest amount of hydrogen, 138.93 kg., offset by 12 photovoltaic panels. For Illizi, Algiers, and Ouargla, produce the amount of hydrogen, respectively, 118.11 kg, 101.4 kg, and 102.76 kg, with the same number of photovoltaic panels, about 10, and this is due to the difference in global solar irradiation. The following table represents the payback period for the 07 stations.

Table 8: Payback period for the 07 stations

Station	Payback period (year)
Ouargla	2.30
Alger	2.30
Adrar	2.28
Djelfa	2.24
Bechar	2.27
Illizi	2.26
In Salah	2.29

The average payback period is 2.27 years. This period varies between each region.

9. Conclusion

This study reveals the opening of providing the energy needs of households with a renewable energy system. The studied house is located in seven regions of different climates in Algeria (Algiers, Djelfa, Bechar, Ouargla, Illizi, Adrar and In Salah). The energy requirements are delivered from the renewable energy system, which consists of the photovoltaic panel, electrolyzer, and fuel cell. When the energy produced is insufficient to supply the energy demand, the electrical network is utilized to meet the deficit energy. The results show that the suggested system has reached the energy autonomy for the households when the photovoltaic panel number is about 11, equivalent to a power of 3.3 kWp for the panel photovoltaic. This corresponds to an area of 17.49 m^2 for the studied building. The annual surplus hydrogen energy is 1458,83 kWh/year (equivalent to 328,23 € per year). The payback period is about 2.27 years. The renewable energy shuns the emission of 7.47 tons/year of CO_2. So we can conclude that hydrogen is principally the key to our future, as it will become a crucial factor warranting a secure energy supply for the building sector.

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