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Active solar heating system for residential building in Algeria
An energetic economic and environmental investigation

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Abstract - *In this work we used a typical single family house in Algeria as an example, the influence of building type on the energetic efficiency of an integrated solar combisystem (SCS) is determined by means of numerical simulation using TRNSYS software program. We considered two types of buildings, which have the same size and the same orientation. The first one is a low energy pilot house performed by CDER 'Centre de Développement des Energies Renouvelables' and CNERIB 'Centre National d'Etudes et Recherches Intégrées du Bâtiment' in the framework of MED-ENEC project, however, the second considered house is a virtual building; in which the walls are of the conventional type in Algeria. Based on the obtained results, it is outlined how the total system load can be decreased by adopting some solar architecture techniques. The analysis of the auxiliary energy required by the solar combi system and the average solar fraction; shows the profitability of the SCS application in Algeria, especially in the case of low energy house. Furthermore, the economic aspect and the environmental impacts of the integrated solar heating system have been investigated. The equity payback and greenhouse gas 'GHG' emissions have been estimated by means of a numerical simulation using the powerful tools of the RETScreen free software program. The obtained results showed that the equity payback is strongly dependent on the fuel used by the conventional heating system. In the case, where the heating is assured by the gasoil, the equity payback is around the half of the project lifetime. From the environmental standpoint, the solar application is entirely advantageous. In addition, the natural gas is the most favourable conventional energy resource, with a minimum yearly GHG emissions compared to electricity and gasoil.*

Résumé – *Ce travail est une étude technico-économique d'un système solaire combiné 'SSC' intégré dans un bâtiment résidentiel en Algérie. Cette étude s'appuie sur un modèle numérique élaboré avec le logiciel TRNSYS. Nous avons examiné deux types de bâtiments, qui ont les mêmes dimensions et la même orientation. Le premier est une maison pilote à faible consommation énergétique réalisée par le CDER 'Centre de Développement des Energies Renouvelables' et le CNERIB 'Centre National d'Etudes et Recherches Intégrées du Bâtiment' dans le cadre du projet MED-ENEC. Le deuxième bâtiment considéré est un logement virtuel; dans lequel les murs sont de construction classique en Algérie. Les résultats obtenus montrent que la charge totale peut être diminuée en adoptant certaines techniques d'architecture solaire. L'analyse de l'énergie auxiliaire requise par le système solaire combiné, ainsi que la fraction solaire; montre la rentabilité de l'application 'SSC' en Algérie, en particulier dans le cas d'une maison à faible consommation d'énergie. En outre, l'aspect économique et les impacts environnementaux du système de chauffage solaire intégré ont été étudiés. Le temps de retour sur les capitaux propres et les émissions de gaz à effet de serre 'GES' ont été estimées au moyen du logiciel libre RETScreen. Les résultats obtenus montrent que le temps du retour des capitaux propres dépend fortement du type de combustible utilisé pour le chauffage. Dans le cas où le chauffage est assuré par le gazole, le temps de retour des capitaux propres est d'environ la moitié de la durée de vie du projet. Du point de vue environnemental, l'application solaire est tout à fait avantageuse. En outre, le gaz naturel est la ressource la plus favorable auxiliaire parmi les ressources énergétiques*

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conventionnels, avec un minimum d'émissions annuelles de GES par rapport à l'électricité et au gazole.

Keywords: Solar energy - Solar combisystem - Energy efficiency - Economic study - Environment impacts - Building - Algeria.

1. INTRODUCTION

Solar combisystems (SCS henceforth) are solar heating systems for combined domestic hot water preparation and space heating [1]. A combisystem uses at least two energy sources to supply hot water and heating: a solar collector and an auxiliary energy source. The auxiliary energy source could be gas, biomass, oil or electricity. In Algeria, nearly 43 % of energy consumption is owed to the building sector [2].

An important part of this energy consumption is due to loads of domestic hot water (DHW) and space heating (SH). Therefore, building sector has a significant contribution in the rationalization of energy consumption. In the other hand, the country has an enormous solar potential. Therefore, a useful method to reduce the use of the fossil energy within environment protection is the integration of the solar energy in buildings to meet the needs of hot water and heating.

In order to bring out the reliability of SCS application for the residential sector in Algeria, a comparative numerical study by means TRNSYS software program [3] that focuses on the performance of a building-integrated SCS under Algerian climatic conditions is carried out, considering two types of building; namely : a low energy bioclimatic house and a classical house. To probe the economic aspects, as well as the environmental impacts of the real studied system, a numerical study by means RETScreen free software program [4] is also performed.

2. DESCRIPTION OF BOTH STUDIED HOUSES

In this work, we have studied two types of buildings. The first is a low energy pilot house realised by CDER '*Centre de Développement des Energies Renouvelables*' and CNERIB '*Centre National d'Etudes et Recherches Intégrées du Bâtiment*' in the framework of MED-ENEC project, (figure 1). The second considered house is a virtual dwelling, which has the same size and the same orientation as the prototype house, but in which the walls are of the conventional type in Algeria.

2.1 Description of the prototype bioclimatic house

The bioclimatic house has a surface of 90 m^2 and is located in the Algiers region, more precisely in the village of Souidania. This region is part of the climate zone A (latitude 36.70 N, longitude 03.20 E) characterized by relatively mild winters and hot-humid summers. The house has two bedrooms; room 1 is positioned to the south-west, room 2 is to the north-west side. The living room has a large window facing south and a window-door facing east, the kitchen is on the east side and finally the bathroom and toilets that are oriented to the north.

This prototype house has some characteristics of a passive solar house, including a large south facing window area, enhanced wall insulation and high thermal mass. The characteristics of materials constituting the different elements of the prototype house are given in **Table 1**.

2.2. Description of the classic house in Algeria

The classic house considered in this study is a virtual home that has the same orientation and the same size as the prototype house.

In addition, it is supposed to be located in the same region. However, the walls of this house are of the conventional type in Algeria. **Table 2** gives details of the composition and the thermal characteristics of various materials used in the different elements of the considered classic house.

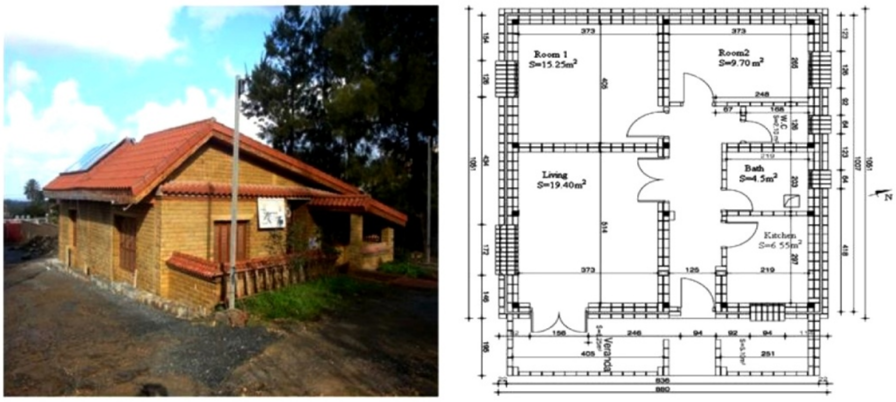

Fig. 1: The prototype residence building

Table 1: Characteristics of materials constituting the different elements of the prototype house

Element	Composition	Thickness (m)	U (W/m²K)
External wall	SEB (Stabilized Earth Blocs) Polystyrene SEB	0.14 0.09 0.29	0.36
Floor	Heavy concrete Expensed polystyrene Heavy concrete Mortar + sand Tiles	0.05 0.06 0.15 0.03 0.02	0.54
Roof	Layer of mortar Expensed polystyrene Heavy concrete Plaster	0.03 0.16 0.08 0.04	0.23
Windows	Double glazing		2.22

Table 2: Characteristics of materials constituting the different elements of the classic house

Element	Composition	Thickness (m)	U (W/m²K)
External wall	Mortar Bick Ain knife Bick Plaster	0.0 0.10 0.05 0.15 0.02	3.22
Floor	Heavy concrete Mortar + sand Tiles	0.10 0.03 0.02	1.16
Roof	Heavy concrete Plaster	0.20 0.02	2.94
Windows	Single glazed	0.004	5

3. DESCRIPTION OF THE ACTIVE SOLAR HEATING SYSTEM OR THE SCS

Figure 2 bellow shows the considered SCS. It contains the following elements:

- Solar collectors mounted on the roof of the dwelling;
- The storage tank, the solar collector field exchanges energy with the solar storage through an internal heat exchanger;
- The auxiliary energy supply maintains the upper section of the tank at a set temperature. The auxiliary heat is connected to the solar tank by an immersed heat exchanger in the top of the tank.

For the considered SCS in our study, four (04) flat-plate collectors (FPC) within parallel arrangement are adopted, which gives 8 m^2 of total collector surface. The storage tank is an insulated tank with a total volume of 300 l. The Auxiliary heat exchanger is located in the top of the tank and is of sufficient capacity that it can supply all of the DHW and SH energy needs if necessary.

Furthermore, the auxiliary energy supply maintains the upper section of the tank at 50 °C.

Five (05) persons represent the members of an Algerian family occupy the building. The need on the DHW is considered 50 l per day per occupant at 50 °C. The house set temperature is set within 20 °C at wintry period *i.e.* January, February, March, April, October, November and December. However, at outside of this period the SH system turned off.

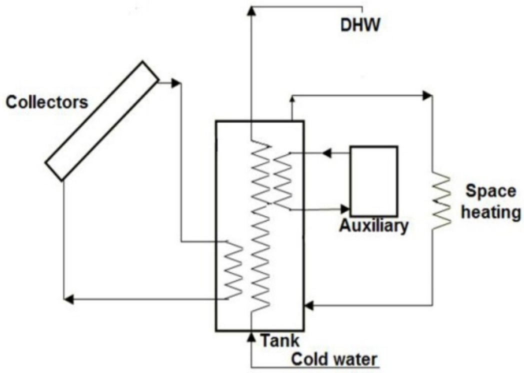

Fig. 2: Illustration of the integrated solar combisystem

4. A PROPOS DE L'ETUDE ECONOMIQUE ET ENVIRONNEMENTALE

To carry out the economic study, the RETScreen software is opted. Like any other software, RETScreen is characterized by the three functions: input, processing and output data.

Among required settings to perform an economic study, the rates of the auxiliary power and the electricity for the site.

As part of our study, the auxiliary is provided by a fossil source, namely; natural gas, electricity or gasoil, their rates are shown in **Table 3**. However, **Table 4** bellow shows the costs of main considered inputs.

Table 3: Basic pricing of a kWh, thermal and gasoil in Algeria

Currency	The first 125 kWh*	KWh beyond*	Natural gas*	Gasoil**
DZD	1.779 DZD/kWh	4.179 DZD/kWh	0.168 DZD/therm	13.7 DZD/l
USD ($)	0.0165 $/kWh	0.0388 $/kWh	0.0016 $/therm	0.1278 $/l

*Source: * Distribution Company of Electricity and Gas in Algiers, October 2015.*
*** Ministry of Commerce, October 2015.*

Table 4: The principle costs and parameters considered in the calculations

Cost/parameter	Unit	Value	Source
Initial costs	$	2240	Project owner
Solar collector	$	280	Project owner
Inflation rate*	%	5.13 (in late September 2015)	-
Yearly maintenance cost of the heating system	% of investment cost	1	[5]
Expected project life	Year	25	-

*Source: * Ministry of Finance, December 2015.*

5. RESULTS AND DISCUSSION

5.1 Estimation of the house loss coefficient

The building heat loss coefficient 'H' in W/°C summarizing the effects of transmission 'H_T' and ventilation 'H_V' [6]. It is evaluated for both houses; the estimated values are illustrated in the **Table 5**. We can note that the adoption of some passive architectural aspects in the bioclimatic prototype reduces the heat loss coefficient with a ratio of 75 % compared to the classical conception house.

Table 5: The heat loss coefficient for both considered buildings

			Heat loss coefficient (W/m^2)	
	Element	**Area**	**Bioclimatic**	**Classic**
Transmission effect "H_T"	External wall	79.43	28.6	92.2
	Floor	90	48.6	264.6
	Roof	90	20.7	289.8
	Windows	8.07	3.6	40.35
	Door	2.5	5	5
	Thermal bridges	-	10.7	69.2
Ventilation effect "H_V"		-	84.4	84.4
Building heat loss coefficient "H"		-	201.6	845.5

5.2 Energetic study

Table 6 summarizes the obtained monthly results from the performed simulation, i.e., the auxiliary required energy and the solar fraction for both considered buildings. Figure 3 shows graphically the evolution of the solar fraction.

Results show that the use of the SCS within bioclimatic conception influences enormously on the heating energy needs and the solar fraction. It appears that more than 50 % of heating energy saving is reached in the case of bioclimatic construction compared to the classic construction.

The equality between the required energy in both bioclimatic and classical cases at summery period is due to the suppression of the SH demand in summer, i.e., only the

HDW load is active in this period. It is noted also that, the solar fraction is infected with the same manner as the auxiliary energy; it shows an increasing in the case of bioclimatic construction in the wintry period compared to the classic construction.

Table 6: Monthly calculated auxiliary required energy and the solar fraction for both considered buildings.

Month		1	2	3	4	5	6	7	8	9	10	11	12
Auxiliary Energy (kWh)	Bioclimatic	989	649	598	331	1	-	-	-	-	88	428	767
	Classic	2514	1912	1837	1190	1	-	-	-	-	331	1212	2117
Solar Fraction (%)	Bioclimatic	24	42	47	62	100	100	100	100	100	81	46	36
	Classic	12	21	23	33	100	100	100	100	100	56	24	18

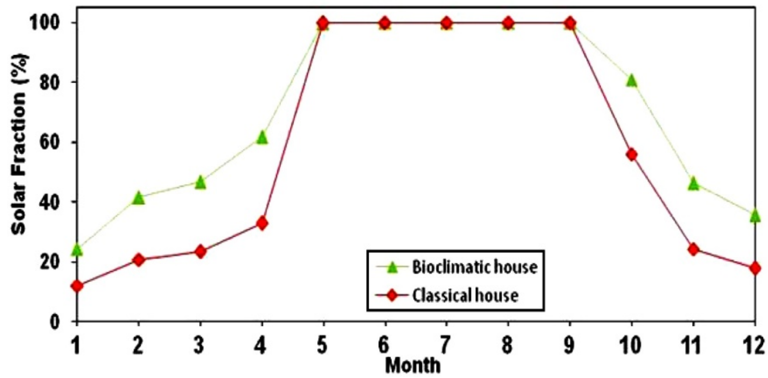

Fig. 3: Monthly solar fraction

Table 7 shows the yearly estimated energetic parameters, namely; the total system load (E_{load}), the SH load, the auxiliary energy required by the solar system (E_{aux}) and the yearly solar fraction (F_{sol}) defined by:

$$F_{sol} = 1 - \frac{E_{aux}}{E_{load}} \tag{1}$$

Figure 4 illustrates a comparative diagram of the yearly total system load (E_{load}), the SH load, the auxiliary energy required by the solar system (E_{aux}) and the yearly solar fraction (F_{sol}). The performance of the SCS is quite obvious, especially in the case of the bioclimatic dwelling, that which is in harmony with monthly obtained results.

Table 7: Loads in (kWh) and solar fraction in (%) for both studied constructions

	Bioclimatic conception (x 10^3)	Classic conception (x 10^4)
E_{load}	9.79	1.73
SH_{load}	5.01	1.25
E_{aux}	3.85	1.11
F_{sol}	60	40

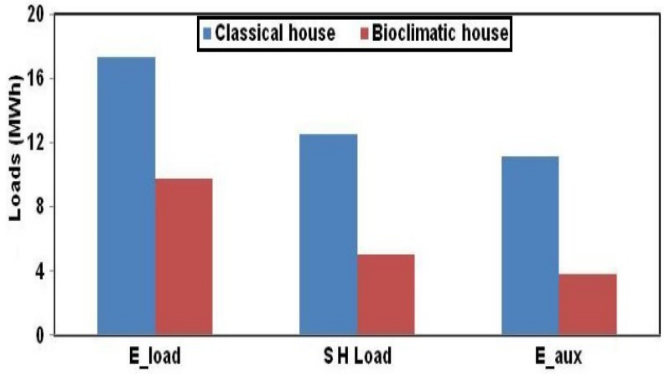

Fig. 4: Yearly total system load (E_{load}), SH load, auxiliary energy required by the solar system (E_{aux}) for both studied houses

Based on the obtained results it is bring out how the total system load can be decreased by adopting some solar architecture techniques. The reduction on the yearly-total house load is up to 50 % in the case of bioclimatic dwelling compared to the classical one. It is noted that the coherence between the obtained data from the simulation study and the calculated heat loss coefficients enhances the accuracy of present numerical investigation.

5.3 Economic aspect and environmental impacts

We note that the required energetic parameters to calculate the equity payback and the greenhouse gas emissions, namely; the total system load (E_{load}), the space heating load (SH load) and the auxiliary (E_{aux}) are provided by the energetic study (**Table 7**).

Table 8 illustrates the equity payback and the greenhouse gas (GHG) emissions for the considered installation. As **Table 8** shows, the equity payback exceeds the project lifetime in the case of natural gas or electricity auxiliary; this is due to the grant of natural gas.

In the case, where the auxiliary is provided by the gasoil, the equity payback is around 12 year. Figure 5 displays graphically the evolution of cumulative cash flow for interesting case, namely, the gasoil-based auxiliary.

Table 8: Equity Payback (EP) and emissions analysis considering three types of fuel-based auxiliary; natural gas (NG), electricity (Elec.) and gasoil (GO)

The abbreviation PL means project life

Auxiliary	NG	Elec.	GO
EP (year)	>PL	>PL	12.3
GHG emission (tCO_2)	3.2	9.3	4.5

From an environmental standpoint, the solar application is profitable in all studied cases, because the solar contribution leads to the amortization of the fossil energy usage.

In addition, the natural gas is the most favourable environmental resource as an auxiliary, with a minimum yearly GHG emissions compared to electricity and gasoil.

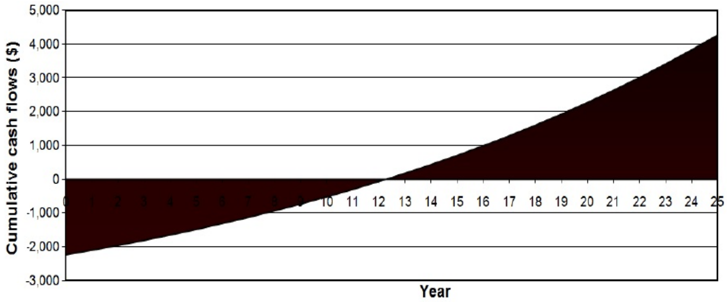

Fig. 5: Cumulative cash flows graphs for the studied installation with gasoil-based auxiliary

6. CONCLUSION

In this work, through a numerical approach using TRNSYS software program, the thermal performance of an integrated SCS on a residential building under Algerian climatic conditions was carried out. The study shows the profitability of the SCS application in Algeria, especially in the case of low energy houses. The study predicts that the use of a SCS with respect of some bioclimatic standards (orientation, materials of construction, insulation, and thermal inertia of materials…) can reduce the annual space heating energy needs by more than 50 % in wintry period.

The economic aspect and the environmental impacts of the integrated solar heating system on the bioclimatic prototype have been studied using RETScreen free software program. The obtained results outlined that the equity payback shows a strongly dependence on the auxiliary fuel-type.

In the case of the studied real system, where the auxiliary is assured by the gasoil, the equity payback is around the half of the project lifetime. From an environmental standpoint, as expected, the solar application is entirely advantageous; because, the solar system contributes to the reduction of the fossil-energy consumption.

NOMENCLATURE

H , The heat loss coefficient	F_{sol} , Solar fraction
H_T , The heat loss coefficient (transmission)	H_V , The heat loss coefficient (ventilation)
$, Dollar	DZD, Algerian dinar
U , U-factor	

REFERENCES

[1] W. Weiss, '*Solar Combisystems for a Sustainable Energy Future*', Solar Update IEA SHC Newsletter, Vol. 35, pp. 1 -3, 2000.

[2] Rapport, '*Bilan Energétique National de l'Année 2013*', Ministère de l'Energie, Algesiras, Algeria, 2014

[3] S.A. Klein, W.A. Beckman, J.W. Mitchell, J.A. Duffie, N.A. Duffie and T.L. Freeman, '*TRNSYS 16: A Transient System Simulation Program*', Madison, USA: Solar Energy Laboratory, University of Wisconsin-Madison, 2007.

[4] The RETScreen website. Available: http://www.retscreen.net/ang/home.php

[5] U. Eicker, A. Colmenar-Santos, L. Teran, M. Cotrado and D. Borge-Diez, '*Economic Evaluation of Solar Thermal and Photovoltaic Cooling Systems Through Simulation in Different Climatic Conditions: an Analysis in Three Different Cities in Europe*', Energy and Building, Vol. 70, pp. 207 – 223, 2014.

[6] M. Santamouris, '*Solar Thermal Technologies for Buildings: The State of the Art*', London, Routledge, 2003