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Energetic study of a solar combisystem installed in Tunisia

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Abstract—**The endeavor of this study is the TRNSYS simulation of the energy long-term performances of solar combisystem used for Tunisian houses. The mainly components of the system are: flat-plate solar collector, heated floor tank (HFT), domestic hot water tank (DHWT), house and an active layer integrated inside the floor heating. A validation of the TRNSYS model was firstly achieved. Then we evaluated the long-term performances of the "combisystem" by introduction the Typical Meteorological Year data relative to Tunis, Tunisia. The results of the study showed that the annual collected energy, energy load and energy supplied to the active layer were 2940.56, 5369.52 MJ/m² and 2940.56 MJ/m² respectively. It is also seen that the annual amount of auxiliary energy represents about 36 % of total annual energy load.**

An optimization of the "combisystem" was also achieved. We noted that the "combisystem" assure an optimal function when we use about 18 m² of collector area, 400 kg h^{-1}collector mass flow rate, 1350 liters of tank capacity, 1.2 m of tank height and 2140 kg h^{-1} floor heating's mass flow rate. The results showed that assuming the previous optimal parameters the chosen solar combisystem provides a stable temperature of domestic hot water about 53°C and a temperature in the array of 20 and 26°C in the interior of the heated house with an average solar fraction of about 84%.

Keywords—

Solar combisystem, TRNSYS 16, solar fraction, long-term performances.

I. Introduction

The "Net zero energy status in residential buildings "is an aim of many authors in Canada [1, 2, 3] and in Denmark [4, 5] and in Las Vegas [6]. In 2007, G.Fraisse et al. [7] studied a combination of a photovoltaic/thermal (PV/T) collector with Direct Solar Floor installed in Mâcon area in France in order to heating systems and domestic hot water. Bornatico et al. [8] have optimized a solar combisystem for a mid-sized single-family house in Zurich, Switzerland. The optimization of all design parameters shows that to minimize the energy consumption and cost of installation, while maximizing the solar fraction, it is essential to use a collector size of 4.5 m² together with a tank volume of 498.98 l. Aivars Zandeckis [9] studied the optimization of the thermal performance of the pellet boiler integrated in a solar combisystem installed in Latvia. He concludes that the optimal performance of the boiler is a function of the amount of combustion air.

It is seen that the solar combisystem are widely used in most countries of the world. But, in Tunisia this method is not yet known. However, Tunisia is located in a relatively advantageous geographical position. It is a country in North Africa, bordered to the north and east by the Mediterranean Sea. Tunisia gets a not yet exploitable natural wealth in terms of solar energy and its energy, economic and social benefits to our country. In fact, Tunisia has a rate exceeding 3000 hours of sunshine per year [10] which allows it to develop new growth and potential niche markets such as solar thermal.

The present work draws a bead on energy performance of solar combisystem for Tunisian houses based on simulations conducted using TRNSYS software. An optimization of solar combisystem parameters was carried on in order to achieve a comfortable temperature inside single-family house in Tunisia. Then the long-term/annual performances of the optimal solar combisystem are investigated.

II. System Description

A schematic description of the building and the associated solar combisystem for space heating and domestic hot water, installed in the CRTEn in Borj Cedria (36° 379 N to 42° 029 N) situated in the North of Tunisia, is shown in Figure 1.

A. *Heating and domestic hot water*

The solar collecting device (1) consists of a series of flat plate solar collectors (2m² each), with a mixed connection, oriented N–S and tilted 45° towards the south. The storage tank

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(2) is strongly isolated and fitted with two immersion heaters placed at the bottom and middle of the storage tank. The total floor (3) area equal to 140 m², consists of concrete slab traversed by a winding system composed of copper tubes of 0.01m external diameter, pipe to pipe distance of 0.1 m, pipe wall thickness of 0.002 m, thermal conductivity pipe material of 1.26 kj/(h m K) The floor is isolated from the ground by a layer of 50mm of polystyrene; the heat transfer to the bottom was assumed to be zero. The circulation of the fluid was ensured by the primary circuit (P1) between the collecting field and the tank, and a secondary circuit (P2) located between the tank storage field and the distribution system

B. Control of the installation

The primary source of energy of the system is the sun and the auxiliary source is an electric resistance (4) which work when there is not enough energy in the storage tank to heat the space. The function of the electric heaters was controlled by a thermostats placed inside the hot water storage tank. The electric heaters were turn off once the water temperature at the top of the tank exceeded 60°C and when the temperaure inside the home exceeded 25°C.

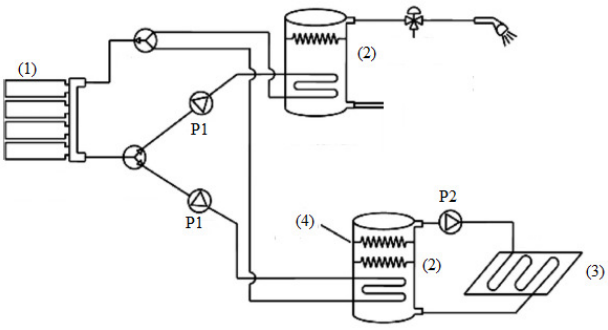

Fig.1. Descriptive diagram of the "solar combisystem"

III. Mathematical Description

A. Solar collectors:

The solar thermal efficiency of the solar collectors is calculated by using the following semi-empirical model [11].

$$\eta = \frac{Q_c}{I.A_c} = \alpha_0 - \alpha_1 \frac{T_c - T_a}{I} - \alpha_2 \frac{(T_c - T_a)^2}{I} \quad (1)$$

α_0, α_1 *and* α_2 are available for collectors rated by Hazami et al [12].

B. Storage tank:

A stratified storage tank having 2 inlets and 2 outlets. It includes an auxiliary electric heater in order to have the desired hot water temperature

Energy balance written about the ith tank segment is expressed [13]

$$M_i C_p \frac{dT_i}{dt} = \alpha_i \dot{m}_h C_p (T_h - T_i) + \beta_i \dot{m}_L C_p (T_L - T_i) + UA_i (T_{env} - T_i) + \gamma_i (T_{i-1} - T_i) C_p + Q_i \quad (2)$$

C. Domestic hot water

The rate of energy supplied for DHW, is calculated as: [14]

$$Q_{L,DHW} = \dot{m}_{DHW} . C_P . (45 - T_{city}) \quad (3)$$

D. Space heating:

The rate of energy supplied for space heating, is calculated as: [15]

$$Q_{L,SH} = \dot{m}_{SH} . C_P . (T_{supply} - T_{ref}) \quad (4)$$

The solar fraction SF of the system is equal to: [14]

$$SF = 1 - \frac{\int Q_{Aux} . dt}{\int Q_L . dt} \quad (5)$$

Where Q_{Aux} is the rate of energy supplied by tankless water heaters and Q_L is the sum of energy supplied for DHW and energy supplied for space heating [14].

$$Q_{Aux} = Q_{Aux,DHW} + Q_{Aux,SH} \quad (6)$$

$$Q_L = Q_{L,DHW} + Q_{L,SH} \quad (7)$$

The coefficient of the performance (COP) of the solar combisystem represent the ratio between consumed electrical energy and thermal energy produced, the COP takes into account the auxiliary consumption (circulation pump). The COP of the solar combisystem is calculated as follows [16, 17]:

$$COP = \frac{\int Q_L . dt}{\int (Q_{Aux} + P) . dt} \quad (8)$$

P: represents the power consumption of the circulation pumps

$$COP = \frac{\int (Q_{L,DHW} + Q_{L,SH} .) dt}{\int (Q_{Aux,DHW} + Q_{Aux,SH} + P) . dt} \quad (9)$$

IV. . Results and Discussion

A. Optimization of system parameters:

The design and optimization of the solar combisystem are described in the following section. The solar fraction of the system was used as the optimization parameter. Design parameters of the system were optimized by using the TRNSYS program.

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1) Required collector area:

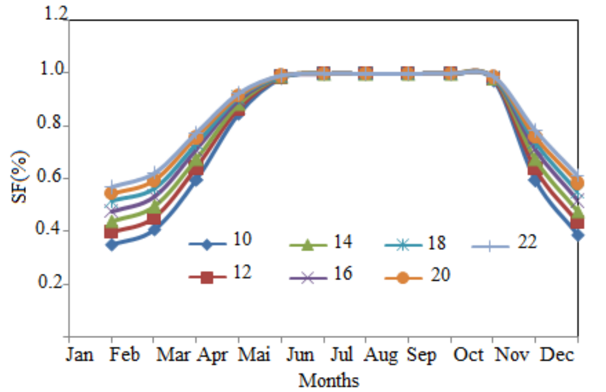

Fig. 2. Variation of monthly SF for different collector area

In order to determine the adequate collector area, I studied the monthly and the annual solar fraction for different collector areas. The modification of the collector areas is accompanied by a modification of the tank capacity according to the following relationship: V/A=75 l m^{-2} [10]. The result of the monthly solar fraction (SF) for each collector area is depicted in Fig. 2. The results show that for a system with any collector area is able to supply 100% of heating demand from May to October. Therefore the optimization of collector area is done in the cold months from November to March. Results indicate also that for 10, 12, 14, 16 and 18 m² of collector area, the SF is around 35-85%, 40-87%, 44-88%, 48-90 and 52-91% respectively during January to April. The 20 m² collector is able to supply around 54-91% during January to April. It s seen also that the curve of 22 m² is almost superposed on the curve of 20 m². Moreover, considering the cost, space requirements and reliability issues, 18 m² of collector area can be considered as the adequate size for the present application study.

2) Effect of the collector mass flow rate

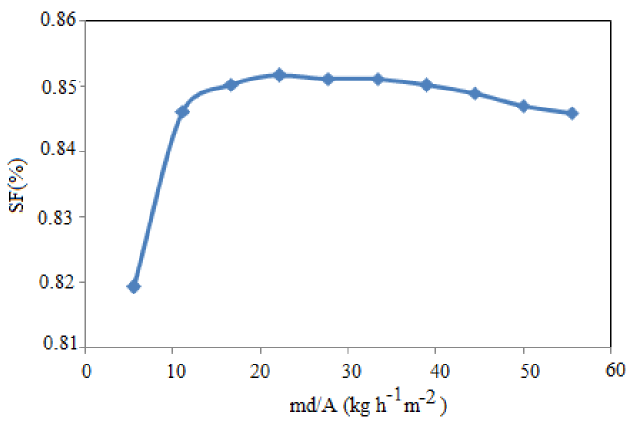

Fig. 3. Variation of the annual SF versus the collector flow rate to area ratio (md_l/A)

The second set of simulation is accomplished in order to determine the adequate solar collector's mass flow rate (md_l) relatively to the optimal collector area of 18 m². The annual SF was simulated for (md_l/A) ranging from 5 to 55 kg/ h m² (Fig.3). The plot shows that SF rises rapidly as md_l/A increases from 5 to 20 kg/ h m². Indeed SF increases from 82% at 5 kg h to a maximum value of approximately 85% at 20 kg/h.m². Then SF starts to decrease and becomes in the order of 84.6% once md1/A is about 55 kg /h m². Hence, to promise a maximum value of SF, the flow rate md 1 traversing the 18 m² of solar collector should be equal to the optimal value of about 20 kg/h m² correspond to the 400 kg / h of collector mass flow rate. The optimum values are found to be in good agreement with the previous results for the solar heating systems, 18–48 kg/h m² [18].

3) Effect of tank volume

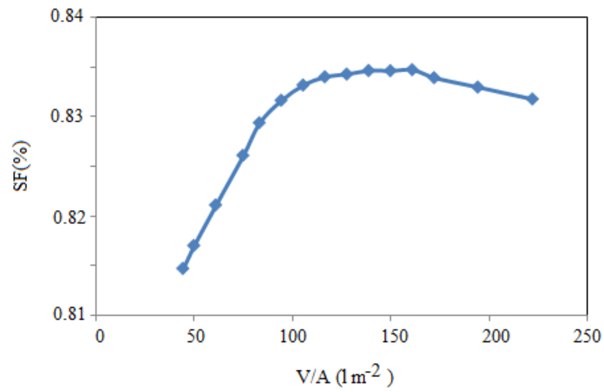

Fig.4. Variation of the annual SF of the value of the hot water tank volume to collector area ratio (V/A)

The effect of tank volume on the system performance is studied for various tank volume–to–collector area ratios (V/A) for a 18 m² collector area with 400 kg/h flow rate. During the Trnsys simulation, various ratios of (V/A) (50– 200 l m²) are investigated. The results showing the impact of the variation of (V/A) on the annual SF is presented in Fig.4. The results show that the annual SF increases rapidly as (V/A) increase from 50 to 75 l/m². Then the SF increase gradually between 75 and 130 l/m². For V/A >130 l/m² ,the SF starts to descend, which is likely due to an increase in heat losses from the storage tank, as the tank become larger. It is observed that in the range from 50 to 75l/m², the solar fraction increases of about 2%. On the other hand, the solar fraction increases by 1% between 75 and 130% (twice as larger than the first range).therefore, the value of 75 l/ m2 corresponds to 1350 l represents the optimal capacity of the storage tank. The recommended value of (V/ A) in this study is found to be in agreement with the other types of solar heating systems, 50–75 l/ m 2 for the active system [19, 20].

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4) Effect of tank height

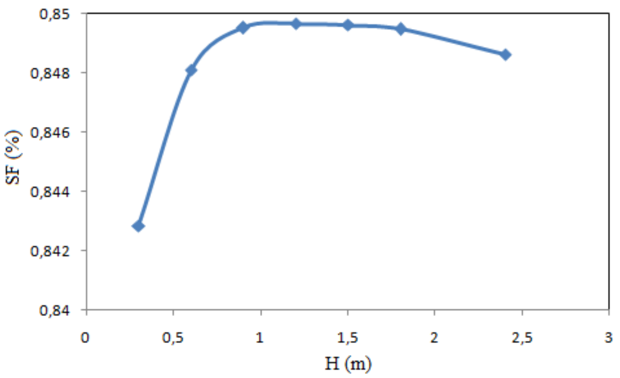

Fig.5. Variation of the total solar fraction from April to October versus tank height.

The variation of the solar fraction versus tank height was also examined in this study. The effect of the tank height (H) on the performance of the system is studied for a 18m² of collector area, 400kg/h and 1350 l of the tank volume. The annual SF was simulated for (md1/A) ranging from 0.3 to 2.5 m. Fig 5 shows that the SF increase dramatically from 20 to 60 as the tank height changes from 0.3 to 1.2. The SF achieve a maximum value about 85 % when the H=1.2, then we note a slight drop in solar fraction. Considering the space requirement of the tank, it is suggested that a tank height of 1.2 m is the most suitable.

5) The effect of floor heating's mass flow rate

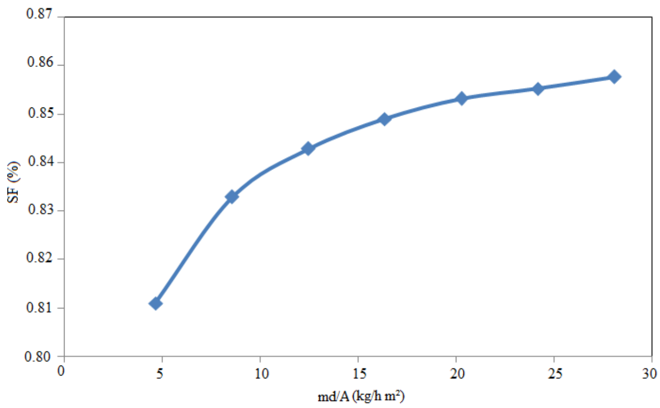

Fig.6. Variation of the annual SF versus the collector flow rate to area ratio (md_2/A)

The effect of floor heating mass flow rate (md2) on the annual SF was simulated for md_2/A ranging from 5 to 30. The trnsys results depicted in fig. 6 shows that the SF increase rapidly to achieve 84% where md2/A equal 16.12. After the SF slightly increases with md2/A increase. We conclude that 2100 kg/h can be considered as the optimal value of mass flow rate traversing the active layer. This result is verified by MEHDAOUI Farah [21].

B. energy analysis

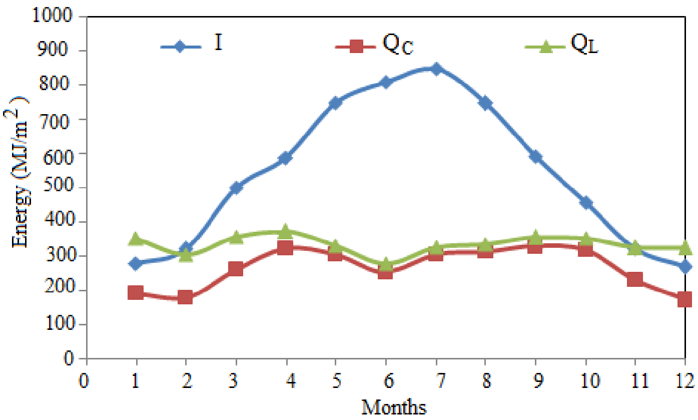

Fig.7. Solar irradiation, energy load and energy collected for a solar combisystem

Fig 7 shows results from a Trnsys simulation of a year of operation of a typical combisystem with 18 m² flat plate collectors and a 1350 liter storage tank in a Tunisian single family house. In the middle of the summer there is enough irradiation to cover the whole load, which then consists mainly of domestic water heating. The monthly variation in the amount of heat supplied by collector (Q_c) is maximized in the month of August, about 322.8 MJ/m². In winter, the system provides both space heating and domestic hot water. During the winter months the irradiation is so weak and the load (Q_L) is so large that only a small fraction of the heating load is covered by solar energy.

C. Building temperature

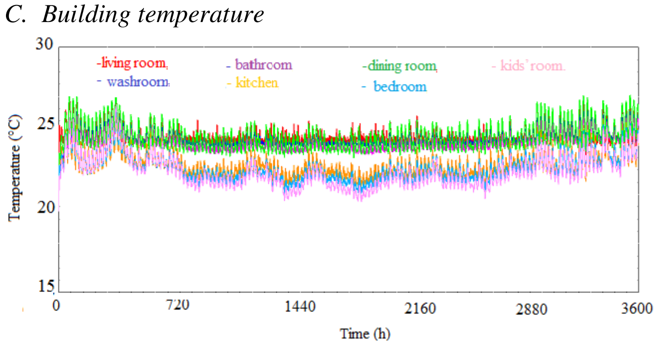

Fig.8. Temporal evolution of temperature inside the house for 3600 h operation from November to March by using a solar combisystem with one active layer.

The floor of the entire house is heated with a single coil, that passing through living room, washroom, bathroom, kitchen, dining room, bedroom and kids' room. Fig. 8 illustrates the air temperature changes inside the house for 3600 h operation from November to March. The maximum temperature achieved inside the house is the temperature inside living room and dining room about 26°C. The minimum temperature achieved is in kids 'room about 21°C. We notice that the air temperature in the house varies from a room to another according to the meaning of fluid flow in the active layer. However the increasing air temperature inside the dining room is explained not only by the energy supply by active layer to the living room but also to the increasing of heat flux supply of all windows of living room.

Fig 8 shows that the temperature difference between the different rooms ranges between 20 and 26°C. Further this gap represents the margin of temperature comfort inside a typical Tunisian house.

NOMENCLATURE

A	Total collector area, m^2
A_i	surface area of the ith tank segment, m^2
C_p	specific heat of the fluid, kJ $kg^{-1}k^{-1}$
SF	solar fraction, %
I	Global (total) horizontal radiation, kJ $h^{-1}m^{-2}$
M_i	mass of fluid in the ith section, kg h^{-1}
md_1	collector mass flow rate, kg h^{-1}
md_2	floor mass flow rate, kg h^{-1}
$\dot{m}_h$	fluid mass flow rate to tank from the heat source, kg h^{-1}
$\dot{m}_L$	fluid mass flow rate to the load and/or of the makeup fluid, kg h^{-1}
N	number of fully mixed (uniform temperature) tank segments
Q_{Aux}	auxiliary energy, MJ m^{-2}
Q_L	energy rate to load, MJ m^{-2}
Q_c	Useful energy gain, MJ m^{-2}
Q_i	rate of energy input by the heating element to the i^{th} segment, MJ m^{-2}
S_h	Number of the tank segment to which the fluid from the heat source enters $1\leq S_h \leq N$
S_L	Number of the tank segment to which the fluid replacing that extracted to supply the load enters $1\leq S_L \leq N$
U	loss coefficient between the i^{th} tank node and its environment, kJ h^{-1} m^{-2} k^{-1}
T_a	Ambient (air) temperature, K
T_c	Inlet temperature of fluid to collector, K
T_i	temperature of the i^{th} tank segment, K
T_h	temperature of the fluid entering the storage tank from the heat source, K
T_{env}	temperature of the environment surrounding the tank, K
T_L	temperature of the fluid replacing that extracted to supply the load, K

Greek symbols

α_i	a control function defined by $\alpha_i = 1$ if $i=S_h$;0 otherwise
β_i	a control function defined by $\beta_i = 1$ if $i=S_L$;0 otherwise
γ_i	a control function defined by $\gamma_i = \dot{m}_h \sum_{j=1}^{j=i-1} \alpha_j - \dot{m}_L \sum_{j=i+1}^{j=N} \beta_j$, kg h^{-1}
η	collector efficiency, %

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