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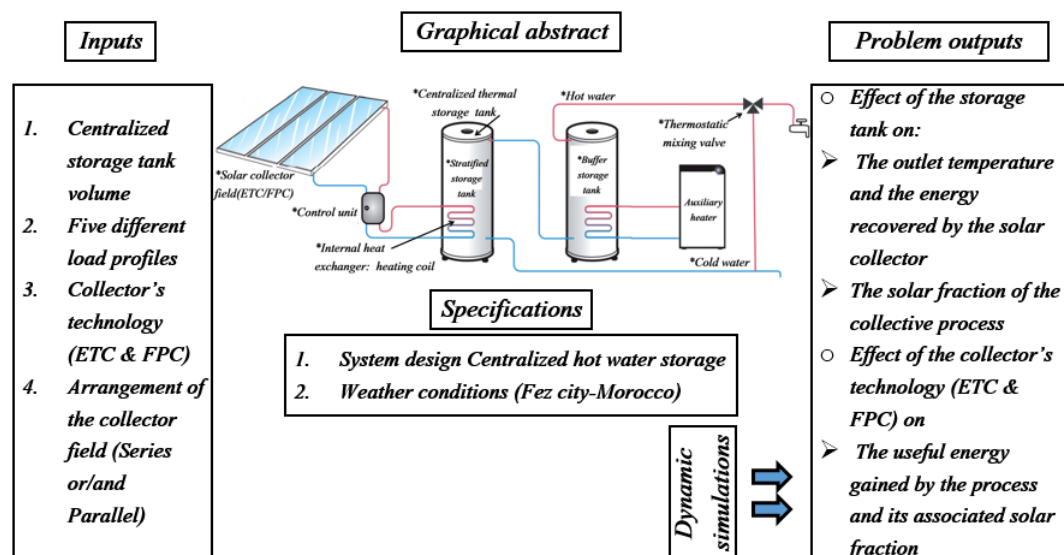
Energy performance enhancement of a collective hot water production process equipped with a centralized storage tank

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Abstract



This paper investigates the thermal performance of a forced circulation collective solar water heater (SWH) equipped with a centralized storage tank, throughout hourly dynamic simulations. The main purpose of this study is to identify the parameters affecting the overall efficiency of the collective process, because the literature review focuses on individual SWHs, rather than collective hot water systems that are extensively integrated in the tertiary sector, such hotels, hospitals, university residences, etc. Hence, being able to suggest general recommendations that would be helpful to guide hot water system designers. A typical residence located in Fes city (Morocco) that shelters 60 occupants was considered as a realistic case study, for which the thermal performances of the collective hot water production system were simulated. Several performance indicators were defined and miscellaneous dynamic simulations were carried out to enhance the process's efficiency. For instance, the incident energy on the solar collector panel, the supplementary consumptions for different storage tank volumes and load profiles, the useful energy gain from the collector's field and the solar fraction of the collective hot water process. The results showed that the Evacuated Tube Technology (ETC) is suitable for this collective hot water production application, because the solar fraction of the process remains higher with ETC, as opposed to the use of Flat Plate

Collectors (*FPC*). Moreover, increasing the centralized storage tank volume enhances the annual solar fraction of the collective hot water process. Last but not least, the maximal annual averaged solar fraction was achieved by the *ETC* technology (78%). However, it is equal to 68% for (*FPC*) while maintaining 3000 liters as a centralized storage capacity.

Keywords: Collective *SWH* process; Centralized storage; Hourly dynamic simulations; Efficiency enhancement.

1 Highlights

- 2 • An energetic comparative study for *SWHs* integration in a collective Moroccan building
- 3 • Thermal performance assessment of a collective hot water system
- 4 • Optimization of the collective hot water process for low energy consumption
- 5 • The tank's volume and the collector's configurations affect the yield of the process
- 6 • The solar fraction of the collective process is enhanced with *ETC* technologies

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7 Nomenclature

a_0	zero loss efficiency [-]	T_{out}	outlet temperature [K]
a_1	first order heat loss coefficients [W/K.m ²]	T_{load}	temperature to load [K]
a_2	second order heat loss coefficients [W/K ² .m ²]	T_{top}	top tank temperature [K]
A_c	collector area [m ²]	T_u	useful temperature [K]
A	lateral surface of the tank [m ²]	U_T	heat exchange coefficient [W/K.m ²]
C_p	specific heat at constant pressure [J/kg.K]	V	storage tank volume [l]
CFN	correction factor corresponding to N collectors connected in series	Greek symbols	
C_2	is the slope ($F_R U_L$) of a single collector efficiency curve	ρ	density [kg.m ⁻³]
(GC _p)	the fluid capacitance rate for a single collector	η	collector efficiency [-]
f	solar fraction [-]	ϕ_{tank}	diameter of the tank [m]
I_T	the total solar irradiance on the tilted surfaces of the collectors [W/m ²]	abbreviations	
m_T	storage tank's mass [kg]	AM	Arab Maghreb
\dot{m}_{load}	mass flow rate to load [kg/s]	CFD	Computational Fluid Dynamics
N	number of collectors	CPC	Compound Parabolic Collector
$Q_{auxiliary}$	energy of the booster system [W]	CSTB	Centre Scientifique et Technique du Bâtiment
Q_{load}	hot water energy to load [W]	DHW	Daily Hot water
Q_{loss}	convection losses to the surrounding environment [W]	DSHW	Domestic Solar Water heating
\dot{m}_u	useful mass flow rate [kg/s]	ETC	Evacuated Tube Collector
Q_u	the useful energy to heat the water mass [W]	FPC	Flat Plate Collector
Q_t	the flow module into the test circuit [l/h.m ²]	HTF	Heat Transfer Fluid
Q_{tank}	stored energy inside the tank [W]	ICSSWH	Integrated Collector Storage Solar Water Heater
t	time [s]	IRESEN	Institut de Recherche en Energie Solaire et Energies Nouvelles
T	temperature [K]	ISFH	Institute for Solar Energy Research
T_a, T_{amb}	ambient temperature [K]	PTC	Parabolic Trough Collector
T_{in}	inlet temperature [K]	SWHs	Solar Water Heaters
T_m	mean temperature [K]		

8 1. Introduction

9 1.1. Background research

10 Nowadays, the building sector consumes more than 40% of the primary energy, which is con-
11 sidered as the main contributor to the world energy consumption [1]. Moreover, the requirements
12 for thermal comfort are increasing, which has involved a considerable energy consumption leading
13 to environmental issues, such as emissions, pollution and global warming [2].

14 *SWHs* have become a challenging solar thermal application in Morocco [3]. The Moroccan gov-
15 ernment is aware of the socio-economic impact of Domestic Hot Water (*DHW*) production systems.
16 Therefore, an important financial support is provided to research and development universities to
17 promote research activities on *SWHs*, such as “*SOL’R SHEMA*” project funded by *IRESEN-*
18 *Morocco* [4], which aims to design and commercialize the first *SWH*, made in Morocco, and which
19 is going to be accessible to a large social scale of users. Currently, collective hot water production
20 in residential buildings is an important issue, which must be taken seriously while applying energy
21 efficiency in the building sector regulations [5]. Solar water heaters (*SWHs*) are useful solar en-
22 ergy systems that help to achieve this purpose, due to their technological feasibility and economic
23 attraction compared to other energy devices commonly used to heat water. It should be noted

that the main components of any solar hot water system are the stratified storage tank, besides to the collectors that absorb the radiation from the sun and transform it to heat. Three types of collectors are widely used in *SWHs* systems namely, Flat Plate Collectors (*FPC*) [6], Evacuated Tube Collectors with heat pipes (*ETC*) [7] and Compound Parabolic Collectors (*CPC*) [8].

1.2. State of the art research

As reported in the literature, experimental and simulation studies were performed by the scientific community on individual *SWHs* to assess and enhance their performances. For instance, in Canada, Evarts and his team [9] conducted a survey to evaluate the consumed hot water volume, which is necessary to design *SWHs*. In addition, in Saudi Arabia, Rehman et al. [10] conducted a techno-economic feasibility study on the integration of *SWHs* for the domestic sector through an optimum selection criteria. Their findings showed that the payback period would be decreased with a higher cost-ratio benefit, if the number of residents is important. In China, He et al. [11] reviewed the policy, the potential and the recommendations followed in the urbanized areas to promote the buildings that are integrating *SWHs*.

Ayompe et al. [12] validated a *TRNSYS* model for forced circulation *SWHs* under two collector's types, namely *FPC* and *ETC*. In addition, Too et al. [13] evaluated the thermal performance of *SWHs* with narrow mantle heat exchangers using *TRNSYS*. They developed heat transfer correlations, in order to model the mantle sides of the storage tank, while Colle et al. [14] analyzed the performances of *SWHs*, which are controlled by weather forecast information. The authors used hourly dynamic simulations to decrease the electric energy peak demand due to the extensive use of electric showerheads (*ESH*) in households. Moreover, Passos et al. [15] studied the feasibility of using domestic *SWHs* as alternative solution to decrease the electricity peak demand in Brazil. Their simulations were performed on an hourly basis.

Martinez et al. [16] elaborated different design approaches and specifications to enhance the thermal performances of *SWH*'s solar network structure. The authors concluded that the number of the collectors in a row and the number of rows in parallel connection would affect the thermal performances of *SWHs*. Similarly, Abdunnabi et al. [17] carried out numerical simulations to predict with accuracy the performances of forced circulation *SWHs*. Meanwhile, in Yunnan province-China, Zhou et al. [18] analyzed the performance of a collective solar domestic water-heating system. They defined several thermal performance indicators to conduct this performance analysis. More than that, Li et al. [19] presented an integrated approach to evaluate the performance of *SWH* in the urban environment, because the effect of nearby buildings on their behavior is currently not yet well characterized.

A review regarding the integration of solar water heating system in the building sector has been recently released [20]. Various collectors' types were studied and their efficiencies were compared. The collector's integration possibilities in the building sector were also investigated. Moreover, the review covered important issues concerning the system design, implementation and architectural barriers. Jamar et al. [21] presented a review on different commercial collectors. Their review focused on three principal collectors technologies (*FPC*, *ETC* and *PTC*), comparing the working fluid and the optical characteristics, in order to enhance their thermal performances.

Vasquez et al. [22] worked on residential and hotel buildings as a case study to assess the environmental effect of *SWHs*. As for, Chao et al. [23], they identified the characteristics of hot water consumption at a sustainable residential building with rainwater-sourced hot water supply. Moreover, Koroneos et al. [24] assessed the impact of *SWHs* on the environmental life cycle. Furthermore, Kordana et al. [25] set up a strategy to rationalize water and energy consumption

in shower systems of a single-family dwelling houses. On the one hand, Tanha [26] investigated experimentally and simulated the performance of two domestic *SWHs*. Two collector's types were used in their analysis (*FPC* and *ETC*). On the other hand, Benoni et al. [27] conducted an optimization analysis of a thermal storage tank and a *FPC* used by a single-family households, in order to ensure an economic efficiency.

Recently, an experimental study has been carried out by Reza et al. [28] to assess the destruction of thermal stratification occurring inside the storage tank of a conventional thermosyphon *SWH*. Thermal stratification destruction is considered as one of the main causes that would affect the performance of the solar collector panel [29]. The main author's result indicated that decreasing the tank's bottom temperature layer would increase the performance of the solar collector panel. Consequently, the overall efficiency of the individual *SWH* system is enhanced. Besides, Alfaro et al. [30] conducted *CFD* simulations to optimize the thermal yield of a commercial solar collector based on the *ETC* technology. The authors performed 3D *CFD* simulations, taking into consideration the laminar case and the steady state assumption to design and construct 259 different collector geometries that were simultaneously modeled and assessed. This research team identified the parameters that affect the thermal performance of the solar collector. They listed them as follows: the internal diameter of the *ETC* tubes, the absorber area and the mass flow rate. Moreover, their optimization's results showed that the minimum absorber area has to be 2.49m^2 , besides the internal diameter of the tubes should be increased by 30%, while their length have to be decreased by 40%. To conclude with, Alfaro et al. [30] enhanced the thermal yield of *ETCs* using *CFD* simulations with a notable decrease in their cost evaluated at 38.9%.

Furthermore, Garnier et al. [31] carried out numerical and empirical assessments of a novel integrated collector storage solar water heater (*ICSSWH*), which can be used in individual household applications. For instance, their *CFD* simulations showed that high draw-off rate result in increased outlet temperatures from the storage tank, which ensure an improved efficiency. The authors showed that the suggested design of the *ICSSWH* is integrating a submerged heating element that would provide the necessary energy to meet the heating requirements of the user, if solar radiations are not sufficient. Moreover, according to this research team, the *ICSSWH* can easily be embedded within a structural insulated roofing panel system.

Last but not least, several strategic studies were carried out *SWHs*. Firstly, Yan et al. [32] presented in their study a simplified method, which is based on a life-cycle energy analysis to optimize the design of *SWHs*. Secondly, Rezvani et al. [33] used Monte Carlo Analysis to estimate the techno-economic and reliability assessment of *SWHs* lifetime in Australia. Finally, Bessa et al. [34] assessed the importance of integrating *SWHs* as a passive technologies in social housing to decrease pollution and global warming.

1.3. Aim of the research paper

Heating water for various domestic applications is performed by using electric or gas devices, and this work opens up a new perspective of water heating using solar energy, an abundant resource in Morocco throughout the year [35]. In fact, the aim of this paper is to take profit from the recent climatic zoning in Morocco to assess the thermal performance of a dynamic solar collective system applied to a residency in Fez. The paper maps out the collective domestic hot water consumption throughout one state of Morocco and hints at the benefit of using solar collective heating devices as energy saver in domestic building, respectively. The literature presents a significant state of the art on individual *SWHs*, which deals with the improvement of their energy efficiency. This enhancement could be achieved through the optimization of the storage tanks, or through the

adjustment of the physical properties of the selective materials used as a coating on the solar collectors, or through the integration of the phase change materials as a latent component to increase the thermal storage of the individual solar systems. However, it should be noted that few studies have been conducted so far on a collective process of hot water production for the tertiary sector, including hotels, hospitals, university residences, restaurants etc. Therefore, up to now, it is difficult to determine the parameters that are likely to affect the solar fraction of the collective process that aims to produce hot water. Thus, this is a prime motivation for our research team to conduct hourly dynamic simulations, in order to determine the set of parameters that can affect its performance.

Two different solar devices were compared towards their thermal efficiency throughout the whole year, namely *FPC* and *ETC*. Individual personal preferences and habits regarding hot water usage were taken into account as well. The current analysis is carried out using hourly dynamic simulations, which are based on the computing platform of *TRNSYS*, in order to investigate the combined effect of load profiles, collective thermal storage tank volume, collectors technologies on the overall performances of a forced collective solar water heating system. This numerical study highlights the effect of the parameters cited above on the annual solar fraction saving of the collective hot water production process.

2. Description of the studied case

The energy performance of the collective *SWH* system, schematically presented in Fig. 1, has been assessed in a Moroccan residence located in Fez city [34°03'N 4°58'W]. The residence shelters 60 occupants and the individual consumption was estimated to 80 liters of hot water per person. Hence, the overall daily hot water need is 6000 liters.

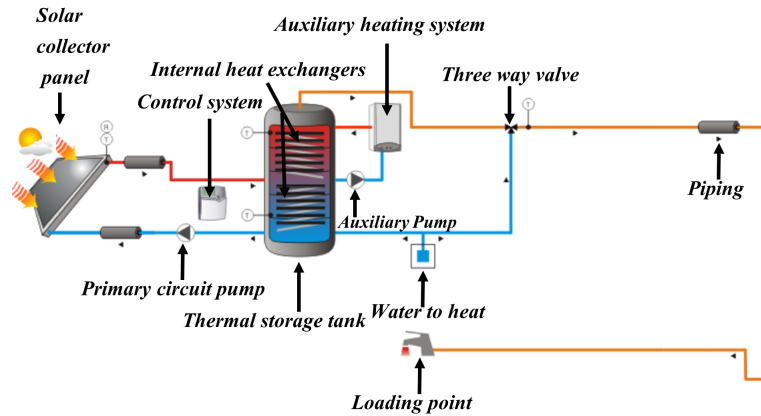


Figure 1: Simplified scheme of the collective hot water process [36].

It should be noted that the distribution of the assessed hot water volume depends on the behavior and the consumption pattern of the inhabitants [37]. The allocation of the consumed daily hot water among the various months has been taken into account for the considered household as shown in Fig. 5. Additional details will be provided and discussed further in the subsection 2.2.2 "Load profile".

2.1. Description of the collective hot water process

The collective system is composed of a solar thermal stratified storage tank, which is connected to an internal heat exchanger [38], besides to an auxiliary system which is an internal heat exchanger connected to a thermostatic temperature control valve. The *SWH* collective system consists of a set of solar thermal collectors that supply energy to the *DHW* stored in the tank (Fig. 2). Moreover, the internal heat exchanger is submerged inside the bottom zone of the tank. The energy provided to the solar tank is ensured with hydraulic or electrical auxiliary heating system, using a heat exchanger located in the top tank zone. In addition, the collective system is equipped with a recirculation circuit, in order to produce the desired *DHW* temperature by the users, using a three-way thermostatic valve, which mixes the loop's recirculation water to the warm water previously stored inside the tank. This device decreases the hot water flow from the auxiliary flask.

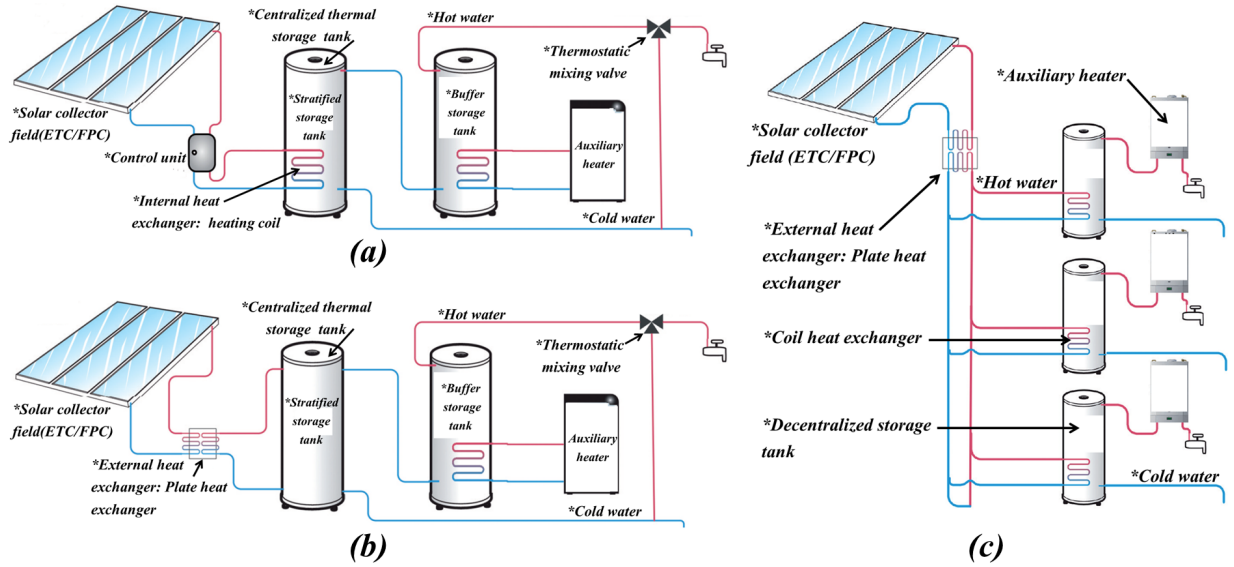


Figure 2: (a)- Centralized storage tank equipped with internal coil heat exchanger. (b)- Centralized storage tank equipped with external plate heat exchanger. (c)- Decentralized storage tank equipped with internal heat exchanger.

The auxiliary system operates if the storage tank temperature is below the set temperature defined by the consumer. This set point temperature value must be higher than the *DHW* temperature that is required for the consumption. The accurate design of the auxiliary heating system aims to ensure the hot water service in all the climatic circumstances. Consequently, to get as much benefit from solar energy. Furthermore, the control of the primary circuit is carried out by measuring the amount of the incident solar radiations or by measuring the temperature differential [12]. The pumps operate according to the radiation reaching the collectors, while the temperature differential is integrated between the collectors and the bottom side of the tank. The secondary loop can be cross-checked with the primary loop or independently by comparing the temperature of the hot side of the exchanger with the bottom temperature of the tank. In this case, the flow rate of the pumps can be fixed or variable (match-flow system). In fact, the system stops the circulation if the temperature of the storage tank or the temperature of the collector is higher than the respective maximum safety temperatures [15].

The collector technologies used during this study, in order to carry out the forced hot water collective system optimization for low energy consumption and energy storage enhancement, are presented in detail in both Tabs. 1 and 2. For instance, general information such as the manufacturer's signature, the technology's type, the test laboratory as well as technical characteristics, for example optical and thermal efficiencies are presented. Further, Tab. 3 shows the arrangement of the collector field that has been used in this hourly dynamic simulations to meet the heating requirements of hot water. Thirty-one collectors were used to constitute the solar field. They were distributed on 3 rows oriented towards the south. The first and the second rows included 10 collectors respectively, while the third row included 11 collectors. The tilt angle that has been used was 30° . According to Agrouaz et al. [39], this tilt angle value helps to enhance the efficiency of the collectors, especially in Fez city. The total apparent area covered by the collector fields is $62.124 m^2$. The arrangement suggested in Tab. 3 was used as a basic and initial configuration to evaluate the annual solar fraction of the collective process intended to produce hot water. Subsequently, a sensitivity study on the effect of the collector coupling and arrangement is proposed in the sub-section 4.1.2 "Effect of the collector field arrangement on the annual solar fraction".

ETC	Manufacturer	<i>Viessmann Werke GmbH & Co</i>	<i>Jingsu Sunrain Solar Energy</i>	<i>Bari Calefaccin</i>	<i>Thermomax-Inygen</i>
	Product	<i>VITOSOL 300-T SP3A 2 m2</i>	<i>Sunrain TZ58/1800-25R2</i>	<i>AR 20</i>	<i>Thermomax 20</i>
	Laboratory	ISFH	ISE	ISFH	CSTB
	Averaged price	284 \$ [40]			
FPC	Manufacturer	<i>Junkers</i>	<i>Chaffoteau & Maury Rendamax-MT</i>	<i>Energie Solaire S.A.</i>	<i>J. Giordano Industries</i>
	Product	<i>FKT-1s</i>	<i>2.3 V</i>	<i>XX-SEL Vertical</i>	<i>C8 modeles C8/8. S.U</i>
	Laboratory	Fraunhofer	CSTB	CSTB	CSTB
	Averaged price	227 \$ [40]			

Table 1: Database of the solar collector panel [36]

Additional technical information about the heat transfer fluid's names and types (HTF) used by the certification laboratories to assess the energy performance of various collector's technologies are available in the *Transol's* manual references [36].

	Manufacturer	a_0	a_1 ($W/K.m^2$)	a_2 ($W/K^2.m^2$)	Height (m)	Q_t ($l/h.m^2$)	C_p ($kJ/kg.K$)	Surface area (m^2)
ETC	<i>Viessmann Werke GmbH & Co</i>	0.809	1.370	0.0068	2.030	64.80	8.4830	2.004
	<i>Jingsu Sunrain Solar Energy</i>	0.734	1.529	0.0166	2.008	70.50	15.60	2.039
	<i>Bari Calefaccin</i>	0.800	1.530	0.0063	1.996	72.00	10.029	2.004
	<i>Thermomax-Inygen</i>	0.750	0.550	0.0153	1.415	72.00	10.78	2.000
FPC	<i>Junkers</i>	0.821	3.699	0.0148	2.080	72.20	10.78	2.230
	<i>Chaffoteau & Maury Rendamax-MT</i>	0.820	3.310	0.0181	2.099	72.00	10.78	2
	<i>Energie Solaire S.A.</i>	0.816	3.804	0.0176	2.40	72.00	10.78	2.020
	<i>J. Giordano Industries</i>	0.760	4.003	0.015	2.002	72.00	10.78	2

Table 2: Technical characteristics of the solar collectors panel [36].

Number of rows	Length of rows (m)	Number in series	Distance between rows (m)
3	15.6291	10	3.347

Table 3: Characteristics of the solar collectors field [36].

Fig. 2 represents two categories of the industrial process for the production of solar hot water. The first category is characterized by the centralized hot water storage, as shown in Figs. 2-(a) and (b). The stored hot water volume is important in this case and it can be sized to store 3000

liters. The second category is described in Fig. 2-(c) where the storage is individualized, in other words, it is distributed over a set of consumers having a storage tank of reduced volume compared to the centralized storage tank. The centralized production of *DHW* helps to cover the specific needs of the consumer with important volumes during short period. The configuration presented in Fig. 2-(a) allows the use of reduced auxiliary systems power according to daily hot water load profile pattern. This result is discussed further in this paper through the parametric studies that were performed on the storage tank volume of the collective process.

The benefits of a collective hot water process equipped with a centralized storage tank are the low cost of the storage solution and the enhanced performance of the process due to the use of submerged heat exchangers and large storage tank volumes, which leads to lower heat losses compared to the configuration of several tanks. Fig. 2- (c) presents a decentralized storage of a collective hot water production process.

2.2. Weather data and load profiles

2.2.1. Weather data

The Moroccan climate is both Mediterranean and Atlantic, with a dry and hot season coupled with a cold and wet season, the end of the warm period being marked by October rains. The presence of the sea attenuates the differences in temperature, tempers the seasons and increases the humidity of the air (400 to 1000 mm of rains on the coast). In the interior, the climate varies according to the altitude. Summers are hot and dry, especially when blowing the hot sirocco or the chergui, summer wind coming from the Sahara (Fig. 3). At this season, average temperatures are 22°C to 24°C. Winters are cold and rainy with frost and snow. The average temperature then varies from -2°C to 14°C. In the mountainous regions, the precipitation is very important (more than 2000 mm of rainfall in the Rif or 1800 mm in the Middle Atlas). Pre-Saharan and Saharan Morocco has a dry desert climate.

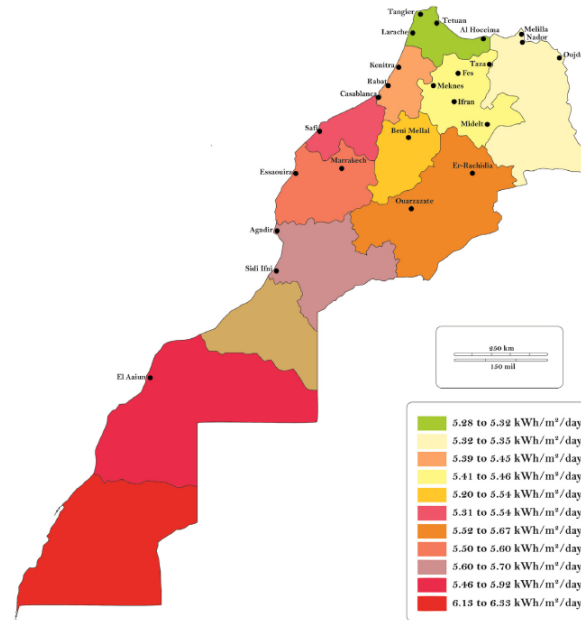


Figure 3: Various solar radiation intensities in Morocco [41].

The meteorological data of Fez city [34°03'N 4°58'W] are defined as the ambient temperature and the incident solar radiation. Moreover, the cold-water temperature refers to the cold water, which fills the tank from the bottom and goes through the hydraulic network of the residence, before it is heated by the solar radiations (Fig. 4-(a)). The incident solar radiation and the total radiation on horizontal correspond to the overall area of the solar collector field of the collective process, which is equal to 62.124 m².

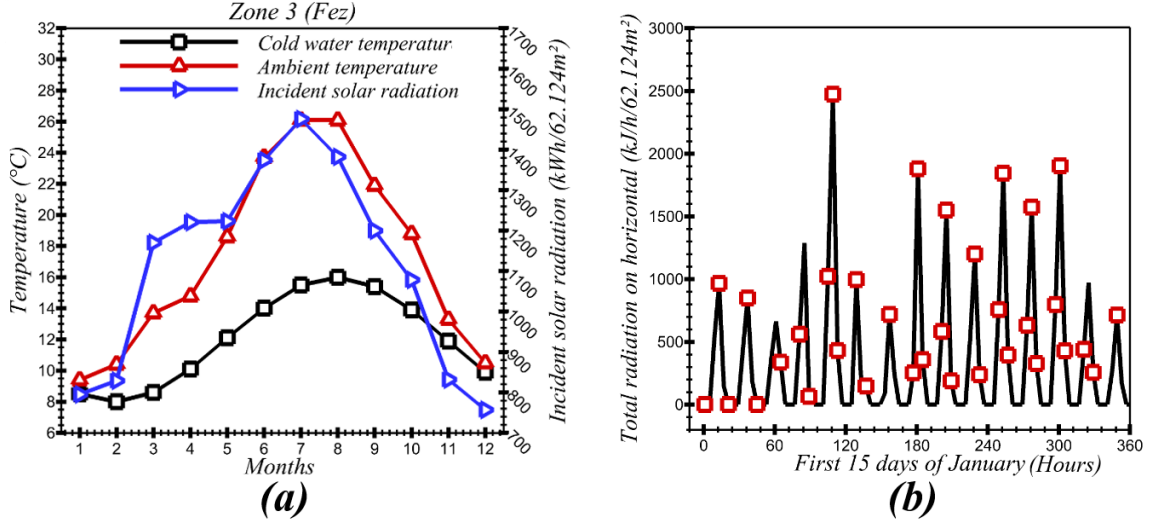


Figure 4: (a)- Fez weather data [36]. (b)- The total radiation on the collector's horizontal [36].

The weather characteristics of the climatic zone 3 (Fez) is continental [42]. Meteonorme software was used to generate the weather data that corresponds to Fez city, because the hourly dynamic simulations require a representative hourly climatic data [43]. It should be noted that the North African climate is common and can be considered as a reference for the Arab Maghreb (AM) countries. The total radiation on the solar collector is independent from the load profile as presented in Fig. 4-(b).

2.2.2. Load profiles

The daily hot water consumption and the heating load profile are considered as the most affecting parameters of the SWH's overall efficiency [44]. In the Moroccan residence, hot water is consumed according to various profiles, which are not well defined up to now, because the consumption of hot water presents a probabilistic pattern that depends on several factors. Hence, the design of the collective SWH remains a complicated issue. Five realistic load profiles were developed based on literature surveys that we have carried out, in order to compensate for this lack of information. The considered profiles per day are listed as follows: *Diario-DTIO*, *Diurno-Day*, *Europeo-European*, *Matinal-Morning* and *Tarde-Afternoon* as shown in Fig. 5. The hot water temperature commonly required by the consumer is equal to 45°C and Fig. 6 is presenting the DHW consumption flow rate, which is corresponding to each load profile throughout the first five days of January (120 hours). In addition, it should be noted that the considered load profiles present the same consumed volume of 6000 liters per day at the set temperature of 45 °C.

For example, the Matinal-Morning profile is characterized by a collective consumption of hot water in the morning and evening.

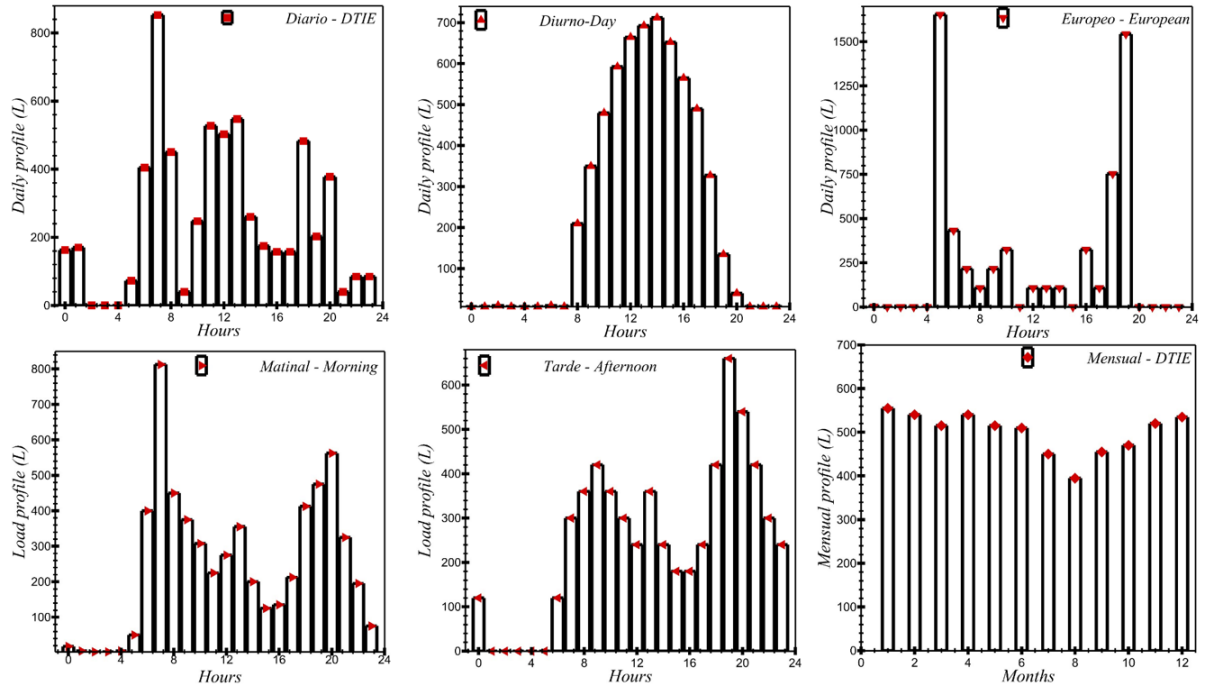


Figure 5: Typical hot water loading profiles used during the hourly dynamic simulations (daily profiles/single monthly profile) [36].

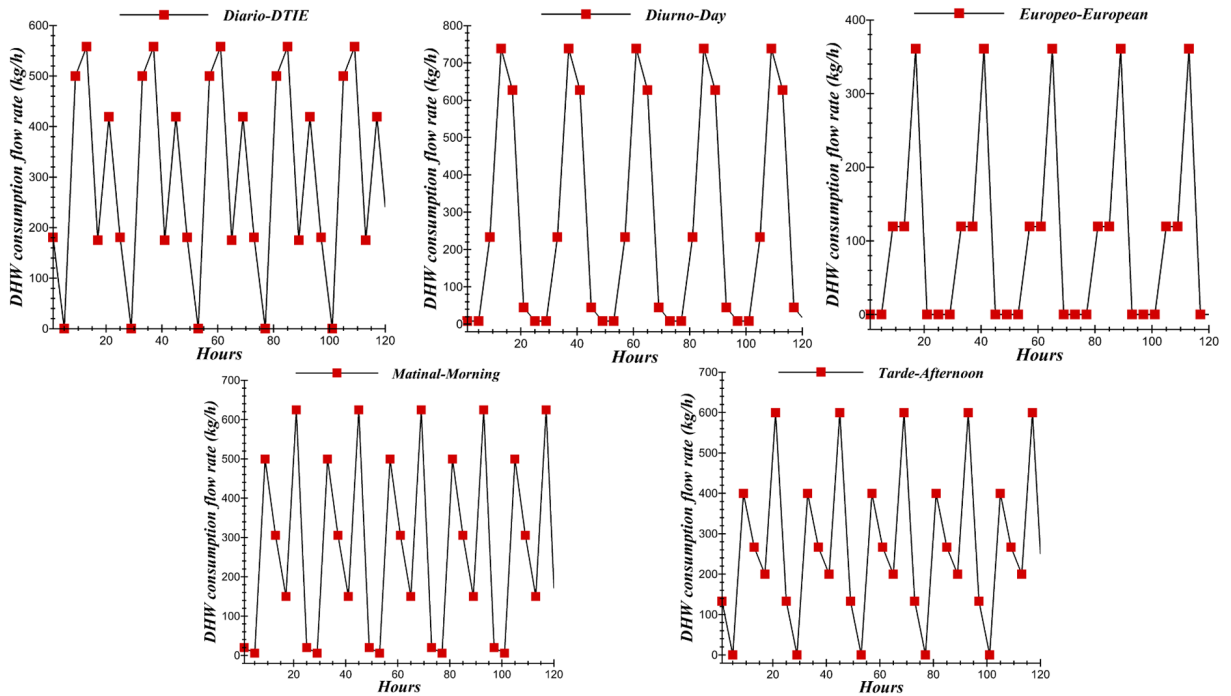


Figure 6: DHW consumption flow rate corresponding to each load profile for the first five days of January [36].

Tarde-Afternoon presents an accentuated consumption during the afternoon and the evening. In addition, the *Diurno-Day* profile describes a high consumption during the morning between 10 am and 5 pm. The profile *Europeo-European* corresponds to the countries of the European Union, where the consumer tends to use hot water between 5 am and 7 am and then in the evening between 5 pm and 7 pm. The *Diario-DTIE* has a general consumption pattern, because it describes a consumption that is spread over the whole day and it does not follow a particular trend.

3. Equation setting

3.1. Thermal collector

The thermal efficiency of a single collector is expressed in Eq. 1 [45]. Where Q_u is the useful energy to heat the water's mass \dot{m} at the inlet side of the collector's field. In addition, T_{in} is the inlet and T_{out} is the outlet temperature from the solar collector. A_c is the area of the collector, while I_T is the total solar irradiance on the tilted surfaces of the collectors. It is noted that a quadratic relation is used to define the efficiency of one single solar thermal collector as expressed in Eq. 2 [35].

$$\eta = \frac{Q_u}{A_c I_T} = \frac{\dot{m} C_p (T_{out} - T_{in})}{A_c I_T} \quad (1)$$

$$\eta = a_0 - a_1 \frac{(T_m - T_a)}{I_T} - a_2 \frac{(T_m - T_a)^2}{I_T} \quad (2)$$

where a_0 indicates the zero loss efficiency of the collector which represents its optical conversion coefficient. Moreover, a_1 and a_2 represent the first and second order heat loss coefficients by conduction and convection of the collector, respectively. The numerical values of those parameters are presented in Tabs. 1, 2. T_m is the average temperature for a single collector given by Eq. 3, where T_{out} and T_{in} are the outlet and the inlet temperatures respectively from one single collector, and T_a is the ambient temperature.

$$T_m = \frac{T_{out} + T_{in}}{2} \quad (3)$$

Our hourly dynamic simulations involve a set of collectors connected either in series or in parallel. Hence, the heated water at the outlet of the first collector module is injected slightly higher at the inlet of the adjacent collector [46]. The collective solar collectors are arranged so that the *HTF* flows through the collectors in a combined parallel and series pattern. Let us consider twelve collectors, which constitute the collector field of the collective process. In fact, as presented in Fig. 7, the *HTF* flows in a series behavior through each collector in the first row 1, 5 and 9. Moreover, the *HTF* flows in a parallel pattern between the first and the subsequent row.

As shown in Tab. 2, the data supplied by a collector manufacturer are useful to determine the performance of a single collector. However, for a large number of possible array configurations, it is required to develop an accurate method to calculate the array efficiency based on the performance data of a single collector. The first four collectors (1, 2, 3 and 4), presented in Fig. 7, are in parallel and their performance is going to be the equal to the efficiency value assessed by their manufacturer, if the flow throughout each collector is the same as the flow used in the test laboratory. In addition, the second set of the collectors (5, 6, 7 and 8) would also operate according to the manufacturer's data. However, the inlet temperatures of these collectors are equal to the outlet temperatures

of the first four collectors. Therefore, their yield would be lower than the collectors 1, 2, 3 and 4. Besides, the collectors 9, 10, 11 and 12 are going to operate at a lower performance than the previous set of collectors, since the inlet temperature is increasing [46].

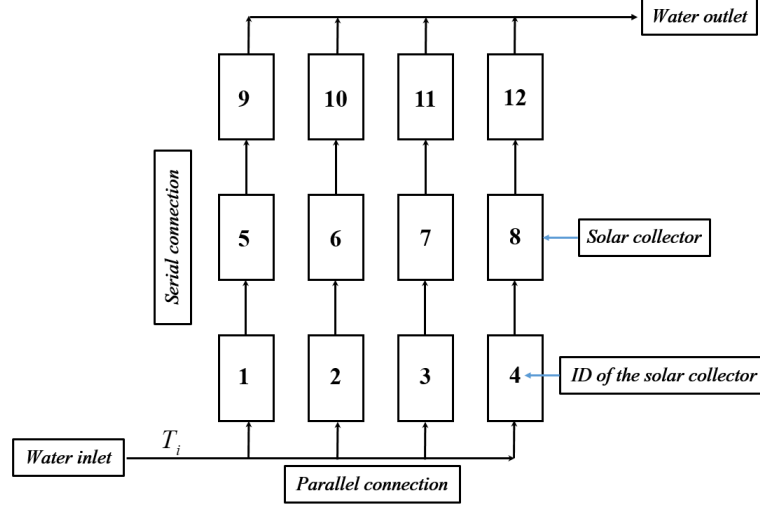


Figure 7: Combined series and parallel flow through a collector array.

An extended method, which is based on the slope/intercept test data of a single collector panel has been developed by Oonk et al. [46] to predict the performance of (N) solar collectors in series (Eq. 4). It should be noted that Eq. 4 can only be used when the fluid Reynold's Number (Re) flowing through the collector is the same as during the laboratory's tests.

$$\eta = (F_R(\tau\alpha)_e)CFN - (F_RU_L)CFN \frac{T_i - T_a}{I_T} \quad (4)$$

$$CFN = \frac{1}{N\psi}(1 - (1 - \psi)^N) \quad (5)$$

$$\psi = \frac{C_2}{GC_p} \quad (6)$$

where η is the performance of N panels in series. F_RU_L is slope of the efficiency plot of a single collector. CFN is a correction factor corresponding to N collectors connected in series. (T_i) is the inlet temperature and (T_a) is the ambient temperature. In addition, I_T is the solar radiation, GC_p is the fluid capacitance rate for a single collector, which is defined by the collector's test labs [36]. C_2 is the slope and ψ is defined as the ratio between the slope and the fluid capacitance rate of a single collector.

3.2. Storage tank

A single centralized storage tank was used for this collective application. Its volume effect on the annual solar fraction was investigated as presented in Tab. 4. Moreover, the filling and the loading tank's nozzles, besides to the inlet and the outlet positions of the exchanger are presented in Fig. 8 and in Tab. 5.

Volume (l)	H_{tank} (m)	ϕ_{tank} (m)	Internal heat exchanger area (m ²)
1000	2.21	0.76	3.25
2000	1.77	1.2	5.61
3000	2.66	1.2	7.97

Table 4: Dimensions of the centralized tank for each storage capacity [36].

Solar system inlet	Cold water inlet	Solar system outlet	Solar hot water outlet
50% L_{tank}	tank bottom (0% L_{tank})	tank bottom (0% L_{tank})	top tank (100% L_{tank})

Table 5: Location of water injection nozzles (Solar and hot water circuits)

292 The unsteady energy balance in the tank takes into account the amount of the useful energy
 293 gained by the solar collectors Q_u , the hot water energy to load Q_{load} , and the convection losses to
 294 the surrounding environment Q_{loss} .

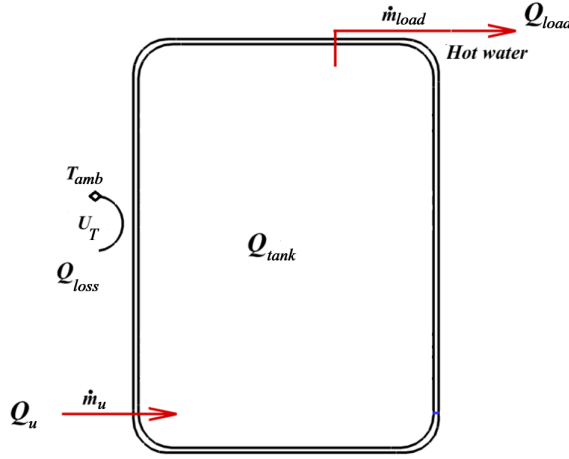


Figure 8: Schematic of the thermal storage tank's energy balance.

295 The energy balance is expressed using Eq. (7) [47]:

$$Q_{tank} = m_T C_p \frac{dT}{dt} = Q_u - Q_{load} - Q_{loss} \quad (7)$$

296 The mass stored in the tank m_T is expressed as $m_T = \rho V$. Where ρ is the water's density and
 297 V refers to the volume contained inside the centralized tank. Finally, C_p is the specific heat of
 298 water. The useful energy Q_u is calculated by Eq. (8). Where $T_{collector}$ is the outlet temperature
 299 from the collector, while T represents the temperature of a specific node of the stratified storage
 300 tank at the instant t .

$$Q_u = \dot{m}_u C_p (T_{collector} - T) \quad (8)$$

301 The draw load energy Q_{load} is written in Eq. (9)

$$Q_{load} = \dot{m}_{load} C_p (T_{top} - T_{load}) \quad (9)$$

where T_{top} refers to the top tank's temperature and T_{load} is the temperature of the hot water to load for the consumer. The heat losses from the tank (Q_{loss}) are calculated as mentioned in Eq. (10):

$$Q_{loss} = U_T A (T - T_{amb}) \quad (10)$$

where U_T represents the heat exchange coefficient from water to ambient. In addition, T_{amb} is the ambient temperature, and A is the lateral surface of the tank.

3.3. Solar fraction of the collective process

Solar fraction can be defined as the total energy provided by the solar collective system to produce hot water. It is calculated using Eq. (11) [48]. The solar fraction is the most important indicator, which is used to assess the performance of *SWHs* systems, because it takes into account the overall performance of the entire solar system and not only one single device or component [49].

$$f = 1 - \frac{Q_{Auxiliary}}{Q_{load}} \quad (11)$$

Where Q_{load} is the total energy transferred by the collective system to satisfy the heating requirements, and $Q_{Auxiliary}$ is the total auxiliary energy provided to the collective system to support the portion of the total solar energy load, which is not sufficient to produce hot water.

4. Results and discussion

In this paper, two major parametric studies were carried out to assess the energy performance of the *SWH* collective system equipped with the centralized storage tank.

To begin with, the volume of the storage tank was varied as a first study, and its effect on several performance indicators was analyzed such as: the energy recovered by the solar collectors, the outlet temperature from the collectors, the solar top tank's temperatures, the supplement consumption and the overall solar fraction of the collective process. Furthermore, the effect of the collector field arrangement on the solar fraction for different load profiles was also investigated. We emphasize that the *ETC* collector, derived from the brand *Viessmann Werke GmbH & Co* has been used to constitute the solar collector panel for the first parametric study.

The second parametric study focuses on the assessment of the collector's technology effect on the solar fraction of the collective *SWH* system. The system's efficiency was compared by using two different technologies of solar collectors, namely *ETC* and *FPC*.

4.1. First parametric study: effect of the storage tank volume

The total volume consumed per day in the collective building is equal to 6000 liters and it is divided according to the load profiles, which are previously presented in Fig. 5. The maximum volume that is consumed and recorded during a specific period of the day does not exceed 1650 liters. Hence, it is important to study the effect of the centralized tank volume on the evolution of the annual solar fraction of the collective heating water process. Three storage volumes were considered, namely $V = 1000$ liters, $V = 2000$ liters and $V = 3000$ liters. The effect of the storage tank volume for the adopted load profiles on the energy recovered by the *ETCs* panel is presented in Fig. 9.

The energy recovered by the solar collector is maximal over the year for the highest volume of the stratified storage tank volume ($V = 3000$ liters) [50]. Moreover, this recovered energy by the solar panel is affected by the load profiles, as it is shown in Fig. 9.

The energy recovered by the solar collector is enhanced, if hot water's demand is high, for example during the cold period of the year, such as February, March and April. The primary circuit pump is switched on and the heat transfer fluid is pumped from the internal exchanger located in the lower part of centralized collective storage tank towards the manifolds of the collectors. In addition, the storage tank temperature with a minimal assigned volume increases quickly compared to a higher storage volume, to finally reach the set point temperature. Therefore, the primary circuit pump is switched off, and even if the collector's field is exposed to solar radiations, the heat transfer fluid of the primary circuit loop does not pass through the series of manifolds. Hence, it is not receiving energy from the solar field panel.

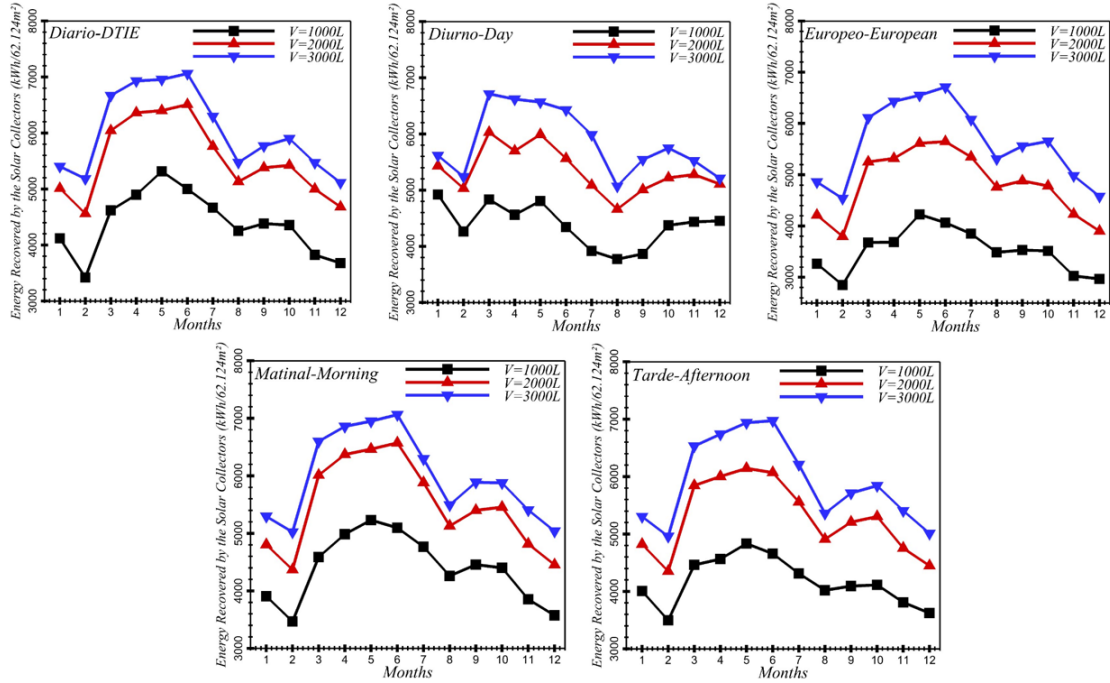


Figure 9: Effect of load profiles and storage tank volumes on the energy recovered by the solar collector.

For instance, the outlet temperature evolution from the solar collector field over the first five cold days of January is presented in Fig. 10. The outlet temperatures from the collector field are below 60°C . As can be observed, the maximal temperature at the solar collector field outlet reaches different values as time progresses. Indeed, the outlet temperature from the collector reaches its maximum peak, when the solar radiations are important. For the *Europeo-European* profile, it is noticed that during the afternoon (15h), the collector outlet temperature is 56°C and it decreases over time, to reach a minimal temperature's value of 10°C in the evening or very early in the morning (6h).

As presented in Fig. 10, the maximum temperatures occur only three times, namely at 16h, 62h and 106h for the first five considered and simulated days of January. A local maximum has been reached independently from the load profile during the second and fourth days of the first

361 week of January. Therefore, the outlet temperatures of the solar collectors were 12°C and 22°C for
 362 the *Europeo-European* profile. Since the solar radiations were insufficient to set off the operation
 363 of the primary circuit's pump, which is involved in the heating of the heat transfer fluid, thus, the
 364 outlet temperature from the collectors was not as important as the first, third and fifth days of the
 365 first week of January.

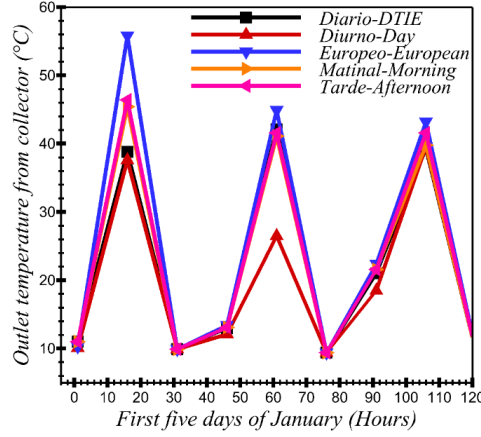


Figure 10: Outlet temperature evolution from collector over the first five days of January.

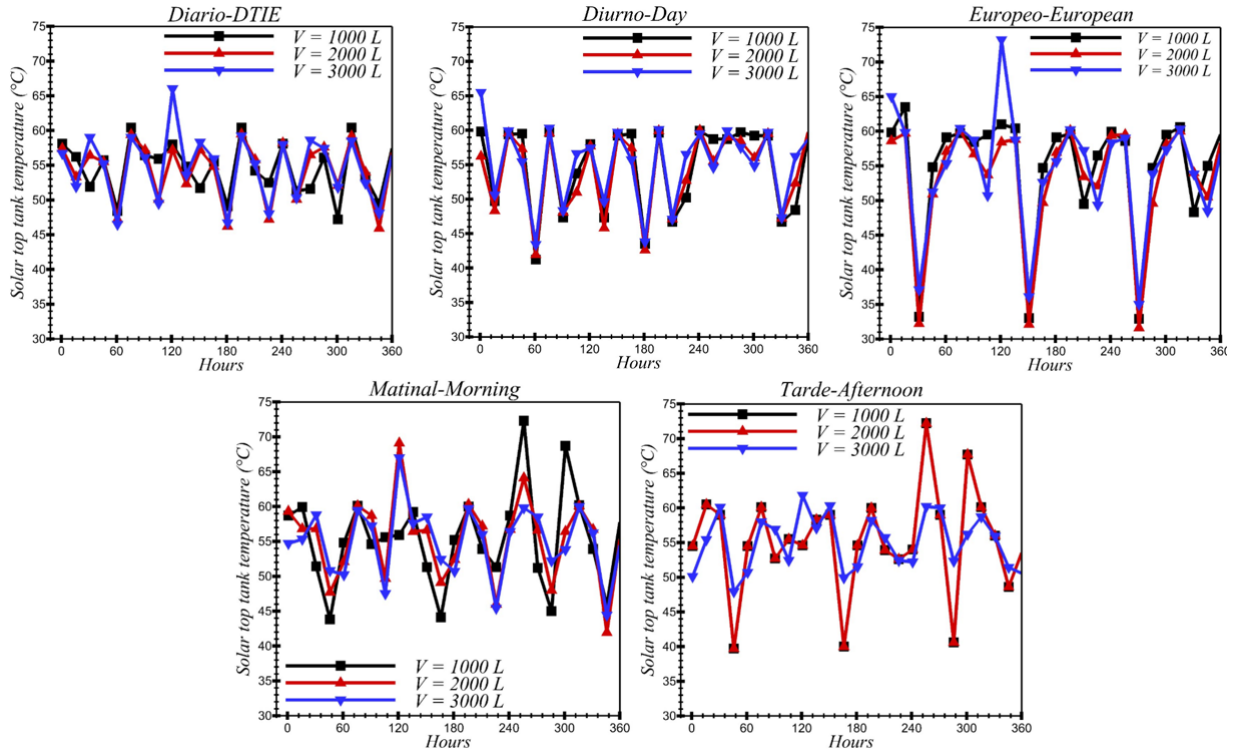


Figure 11: Solar top tank temperature evolution for three different centralized storage tank volumes and for five load profiles on a range of the first 15 cold days of January.

As shown in Fig. 5, the *Europeo-European* load profile is characterized by high *DHW* consumption between 5h and 7h (1750 liters) and between 17h and 19h (1500 liters). On the other hand, the *Tarde-Afternoon* load profile is characterized by hot water demands that varies between 200 liters and 400 liters before 17h, reaching 650 liters at 19h and 500 liters at 20h. The difference between these two profiles clearly affects the temperature at the outlet of the storage tank as shown in Fig. 11, especially if the effect of the stratified storage tank volume is taken into account. Therefore, to serve the needs of the consumer whose consumption follows the *Europeo-European* profile, the use of a large storage tank volume (3000 liters) would be the most appropriate because it would ensure the production of a hot water volume of 1750 liters without affecting the efficiency of the solar collector field, hence, improving the solar fraction of the collective process.

The supplementary consumption was assessed for different storage tank volumes and for the five considered load profiles as presented in Fig. 12. The hydraulic booster as an auxiliary energy source was used to meet the consumers' needs, which are represented by the loading profiles when solar radiations are insufficient, notably during the cold periods of the year. The technical characteristics of the hydraulic booster that has been used during the hourly dynamic simulation are presented in the Tab. 6.

Hydraulic auxiliary system	Manufacturer	Chaffoteaux
	Manufacturer	<i>PHAROS Green 18</i>
	$P_{nominal}$	18 kW
	Set-point temperature	55 °C
	Static differential	5 °C
	Supplement position	90% L_{tank}

Table 6: Technical features of the auxiliary booster [36].

The effect of the tank design is clearly noticeable, because the fact of adding an auxiliary heating source directly affects the overall efficiency of the collective system. Obviously, using a diminished volume of the tank, in this case $V = 1000$ liters, leads to the continuous operation of the auxiliary booster, even if the solar radiations are significant, because the continuous loading of the hot water at 45° C with relatively important flow rates cannot only be ensured by solar energy. Consequently, an optimized volume $V = 3000$ liters of the storage tank would stores an important solar thermal energy, which helps to fill the consumers' needs even in the case of peak demand [51].

The effect of the centralized storage tank volumes on the solar fraction of the collective process for the suggested loading profiles is presented in Fig. 13. The collective system's solar fraction was assessed for five different storage tank volumes varying from $V = 1000$ liters to $V = 3000$ liters, with an incremental volume of 500 liters. For the *Diario-DTIE* profile, the average solar fraction of November, December, January and February is equal to 50%. For April, May, June, September and October the average solar fraction is equal to 80%. The contribution of solar energy compared to the auxiliary booster is clearly enhanced for $V = 3000$ liters volume [52]. This result was generalized for the five applied load profiles. Moreover, for the *Europeo-European* profile, the solar fraction was significantly improved from a storage volume of $V = 1000$ liters to $V = 3000$ liters. An enhancement of (20% to 37% for December), (27% to 37% for January), (23% to 44% for February), (25% to 48% for March).

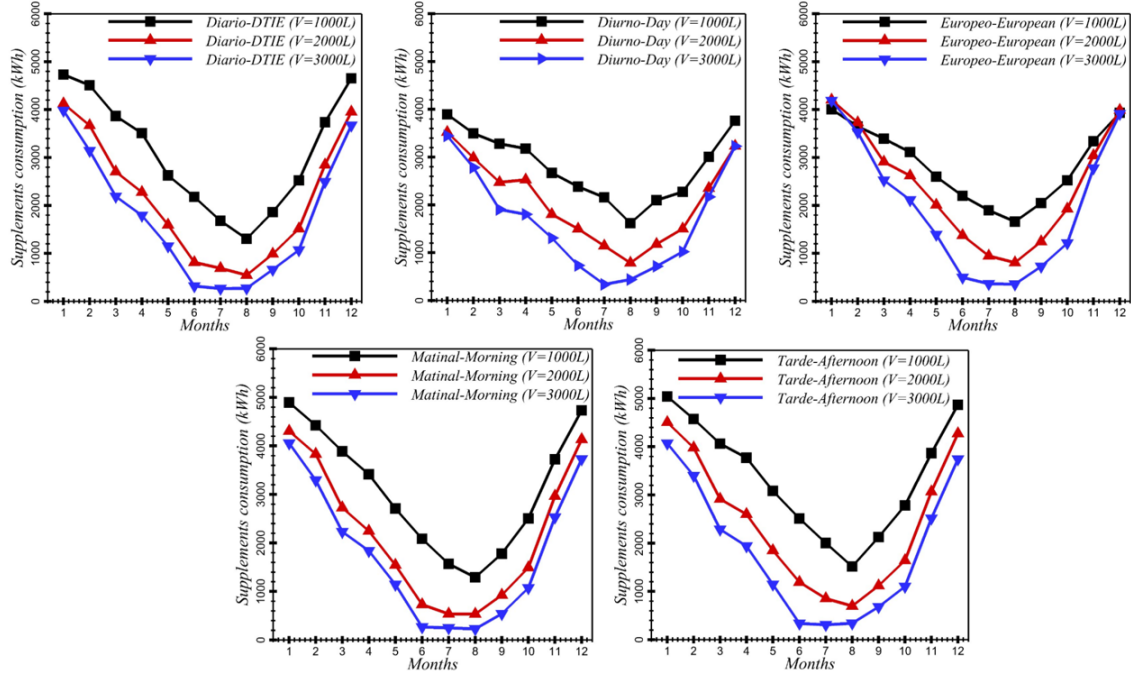


Figure 12: Effect of the load profile on the consumption of the auxiliary booster for different storage tank volumes.

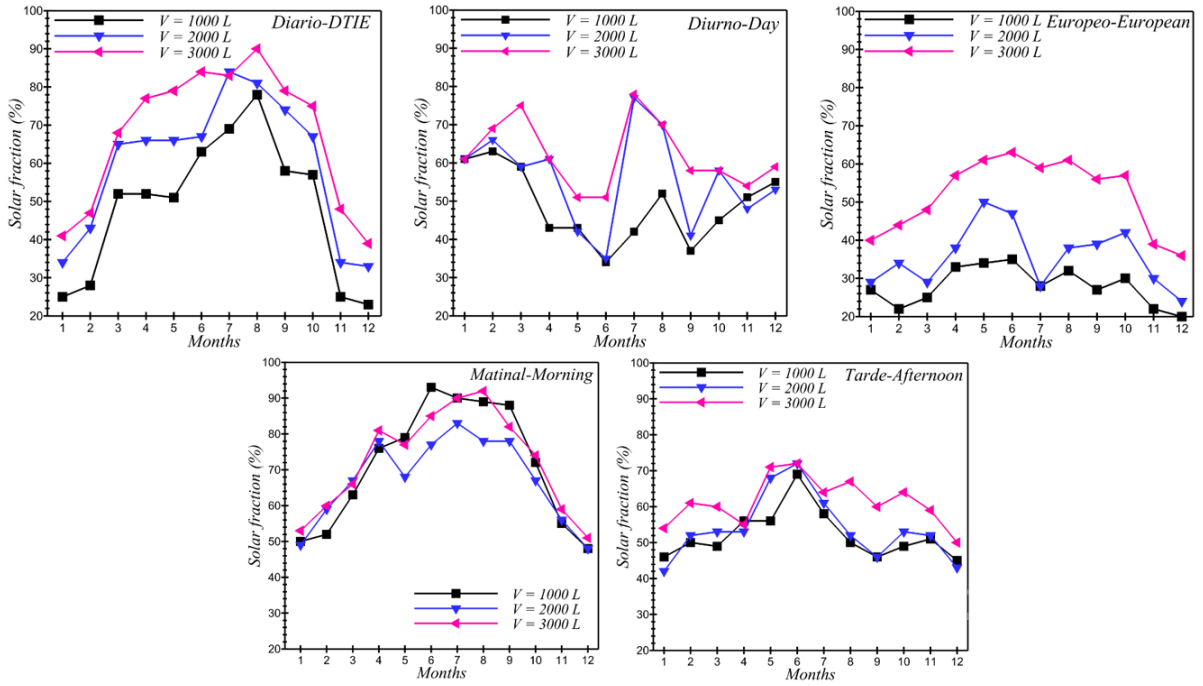


Figure 13: Effect of different storage tank volume on the solar fraction for the considered loading profiles.

4.1.1. Effect of ETC technologies on the annual solar fraction

The effect of the *ETC* collectors on the solar fraction of the collective system for different volumes of the tank are investigated in this section, according to previous defined load profiles. Four *ETCs* from different manufacturers (Tab. 2) such as *Viessmann Werke GmbH & Co*, *Jingsu Sunrain Solar Energy*, *Baxi Calefaccin* and *Thermomax-Inygen* were integrated into the collector field. Each collector product is characterized by the three intrinsic coefficients a_0 , a_1 and a_2 , which affect its operating efficiency.

It has been shown that *Jingsu Sunrain Solar Energy's ETC* collector maximizes the solar fraction of the collective hot water process. Indeed, it allows reaching a significant solar fraction average over the cold period when the hot water need is high. An average for the months of September, October, November, December, January, February, March, April and May which equals 75.23% for *Diario-DTIE*, 78.22% for *Diurno-Day*, 70.88% for *Europeo-European*, 74.15% For *Matinal-Morning* and 73.77% for *Tarde-Afternoon*.

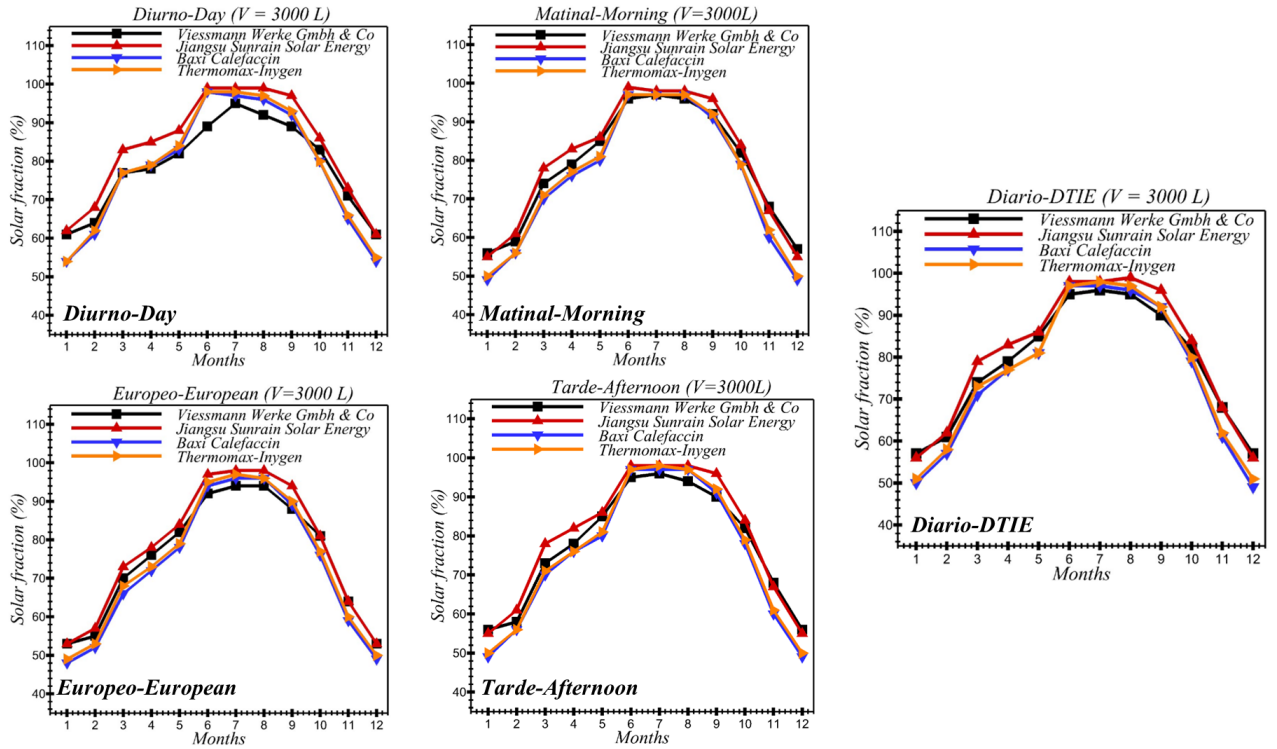


Figure 14: Effect of the *ETC* collectors designed from different manufacturers on the annual solar fraction of the collective system for a storage tank volume of 3000 liters.

The specific heat capacity (C_p) of the *HTF* used by the manufacturer "Jingsu Sunrain Solar Energy" is higher than that of the other manufacturers of the *ETC* collectors that have been considered in the different parametric studies (Tab. 2). As a result, the *HTF* transfers more energy at the integrated coil heat exchanger integrated at the bottom node the collective thermal storage tank. Consequently, the contribution of the auxiliary heating system is decreased and the solar fraction of the collective process is enhanced. The effect of the *ETC* technologies on the annual solar fraction over the year using the considered load profiles is presented in Tab. 7. In this

case the volume of the storage tank was $V = 3000$ liters.

Load Profiles		January	February	March	April	May	June	July	August	September	October	November	December
Diario-DTIE	Viessmann Werke Gmbh & Co	57	61	74	79	85	95	96	95	90	82	68	57
	Jiangsu Sunrain Solar Energy	56	62	79	83	86	98	98	99	96	84	68	56
	Baxi Calefaccin	50	57	71	77	81	97	97	96	92	79	61	49
	Thermomax-Inygen	51	58	73	77	81	97	98	97	92	80	62	51
Diurno-Day	Viessmann Werke Gmbh & Co	61	64	77	78	82	89	95	92	89	83	71	61
	Jiangsu Sunrain Solar Energy	62	68	83	85	88	99	99	99	97	86	73	61
	Baxi Calefaccin	54	61	77	79	83	98	97	96	92	80	65	54
	Thermomax-Inygen	54	62	77	79	84	98	98	97	93	80	66	55
Europeo - European	Viessmann Werke Gmbh & Co	53	55	70	76	82	92	94	94	88	81	64	53
	Jiangsu Sunrain Solar Energy	53	57	73	78	84	97	98	98	94	81	64	53
	Baxi Calefaccin	48	52	66	72	78	94	96	96	89	76	59	49
	Thermomax-Inygen	49	53	68	73	79	95	97	96	90	77	60	50
Matinal - Morning	Viessmann Werke Gmbh & Co	56	59	74	79	85	96	97	96	92	82	68	57
	Jiangsu Sunrain Solar Energy	55	61	78	83	86	99	98	98	96	84	67	55
	Baxi Calefaccin	49	56	70	76	80	97	97	97	91	79	60	49
	Thermomax-Inygen	50	56	71	77	81	97	97	97	92	79	62	50
Tarde - Afternoon	Viessmann Werke Gmbh & Co	56	58	73	78	85	95	96	94	90	82	68	56
	Jiangsu Sunrain Solar Energy	55	61	78	82	86	98	98	98	96	84	67	55
	Baxi Calefaccin	49	56	70	76	80	97	97	97	91	78	60	49
	Thermomax-Inygen	50	56	71	76	81	97	98	97	92	79	61	50

Table 7: *ETC*s collectors technologies effect on the annual solar fraction (%) for the considered load profiles.

4.1.2. Effect of the collector field arrangement on the annual solar fraction

Depending on the consumers' hot water needs and the incident solar radiation of the site, several collectors could be connected, in order to increase the collecting area of the solar field. The current parametric study was carried out for a centralized storage tank volume of 3000 liters and using *ETC*. The collector arrangement used to meet the collective hot water production has a considerable effect on its efficiency, in other words on its solar fraction (Fig. 15). Several coupling configurations between the collectors, which constitute the solar collector field, are possible. For instance, serial, parallel or mixed coupling.

If several collectors are connected in parallel, the temperature of the *HTF* at the outlet of the collector field is increased. Otherwise, an installation with several collectors connected in series has the effect of decreasing the temperature of the *HTF* at the outlet of the collector field. Parallel and serial configurations were used in this study to enhance the overall efficiency of the collective hot water production process. Thirty one *ETC* collectors, based on the manufacturer *Viessmann Werke GmbH & Co*, were spread over 2, 4, 6, 8 and 10 rows to constitute five configurations. The effect of these arrangements on the solar fraction was assessed for the considered applied load profiles. The improvements recorded regarding the system's solar fraction during the cold season are presented in Tab. 8.

Load profiles		<i>Diario-DTIE</i> (Solar fraction (%))	<i>Diurno-Day</i> (Solar fraction (%))	<i>Matinal-Morning</i> (Solar fraction (%))	<i>Europeo-European</i> (Solar fraction (%))	<i>Tarde-Afternoon</i> (Solar fraction (%))
Decembre	2 rows	37	44	40	40	40
	6 to 8 rows	58	60	54	54	56
January	2 rows	43	48	44	44	42
	6 to 8 rows	57	62	56	54	56
February	2 rows	52	42	38	36	38
	6 to 8 rows	65	68	62	68	62
March	2 rows	68	44	42	40	40
	6 to 8 rows	80	86	78	78	80

Table 8: Effect of *ETC* arrangement on the collective process solar fraction during the cold season.

Currently, the manufacturer "Viessmann Werke" conquers the Moroccan market of solar thermal collectors [35]. It has become a leader in the Moroccan market since it sells its *ETC* collectors for individual and collective solar applications, such as the production of *DHW* for households, hot water production for swimming pool centers and for other thermal applications, such as indoor space conditioning throughout integrated solar central heating and absorption cooling systems. It is for this reason that the *ETC* collectors produced from this manufacturer were used to carry out the parametric study on the arrangement of the collectors and their effect on the solar fraction of the collective process, instead of the *ETC* brand manufactured by "Jingsu Sunrain".

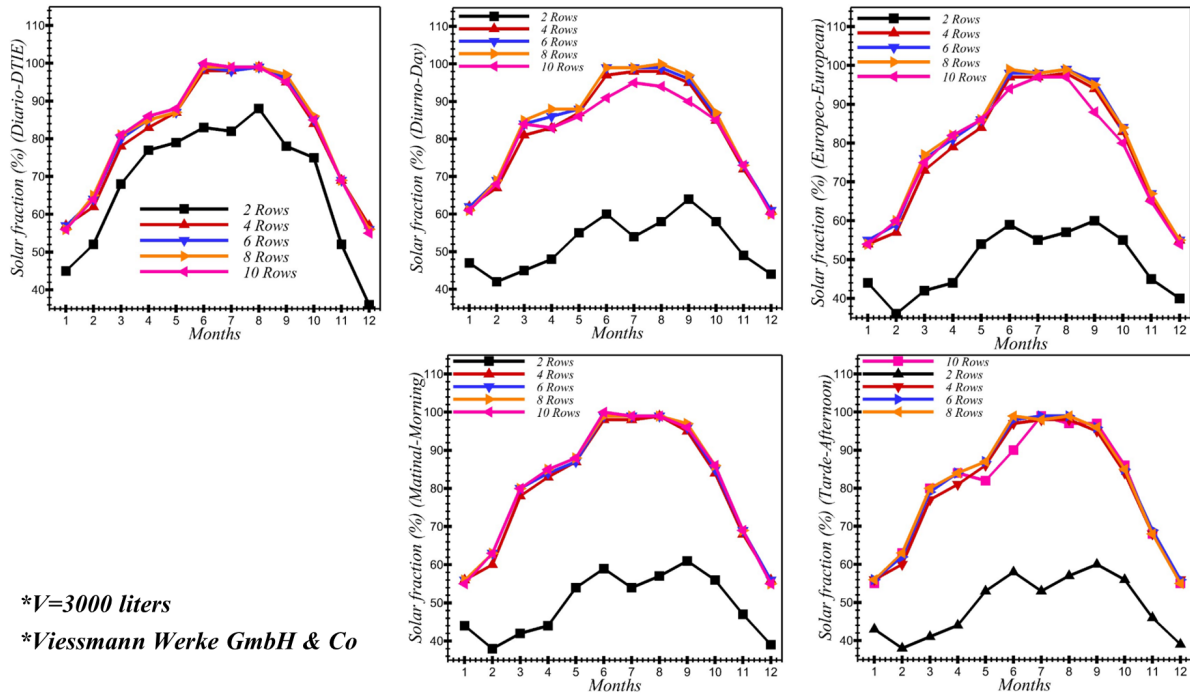


Figure 15: Effect of the collector field arrangement on the solar fraction for different load profiles.

As shown in Fig. 15, the trend of the system's solar fraction for 2 rows is below the other trends which characterize 4, 6, 8 and 10 rows. As a result, the annual solar fraction is improved by increasing the row's number. Six and eight rows enhanced the collective system's solar fraction for almost the five considered load profiles.

Increasing the number of the collectors' rows enhances the solar fraction of the *DHW* production process (Fig. 15). Above a specific number of rows, in our case 6 to 8 rows, the solar fraction does not improve by adding a new series of collectors, because the *HTF* has already received the corresponding maximum energy to its heat capacity. On the contrary, if more rows are integrated in the collector field, greater than 8 rows in this case, pressure drops in the pipes as well as thermal losses by conduction and convection could be generated, and therefore, the fraction of the process is decreased. As a conclusion, for a similar collective application of hot water production, the constitution of a solar collector field where the parallel configuration is predominant would enhance the solar fraction of the collective process. However, additional attention should be addressed to the thermal insulation of the pipes connecting the collectors.

4.2. Second parametric study: Collector effect on the annual solar fraction

The second parametric study focuses on the assessment of the collector's technology effect on the solar fraction of the collective *SWH* system. The system's efficiency was compared by using two different technologies of solar collectors, namely *ETC* and *FPC*.

4.2.1. Effect of the collector technologies on the incident energy on the solar collector plane

This section is intended to study the effect of different solar collector technologies on three performance indicators, namely the solar fraction of the collective hot water process, the useful energy gain from the collectors and the incident energy on the solar collector field. The collector's characteristics are presented in the Tabs. 1 and 2. The incident energy on the solar collector plane was assessed for the *Diario-DTIE* profile and for a centralized thermal storage tank with a volume capacity of $V = 2000$ liters. The effect of several collectors' brands, which belong to the same technology on the incident energy on the solar collector plane, is presented in Fig. 16. Tab. 9 presents the evolution of the incident energy on the solar collector plane for the cold period of the year. It is noted that the apparent solar collector surface affects the incident energy on the solar collector panel.

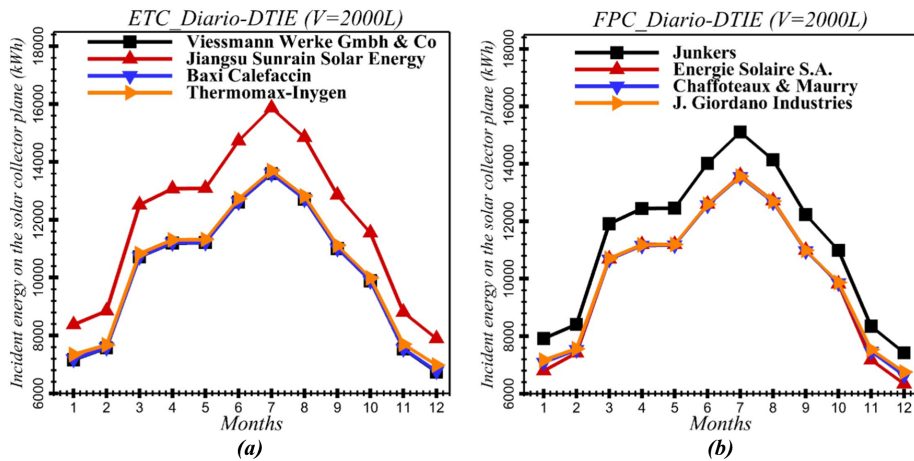


Figure 16: Effect of different collector technologies designed from different manufacturers on the incident energy on the solar collector plane for $V = 2000$ l (*Diario-DTIE* load profile). (a)- *ETC* technologies. (b)- *FPC* technologies.

Incident energy on the solar collector plane (kWh)	November	December	January	February	Mars	April
<i>ETC (Viessmann Werke GmbH & Co)</i>	8735	7790	8300	8790	12490	13000
<i>FPC (Junkers)</i>	8350	7360	7900	8400	11900	12400
Gap in the the incident energy between ETC and FPC	385	430	400	390	590	600

Table 9: Incident energy on the solar collector plane for the cold period of the year.

4.2.2. ETC effect on the useful energy gain from the collector

Two collector technologies were considered in the second parametric study to improve the thermal performance of the collective hot water process. Although the total area of the two variants of *ETC* and *FPC* collectors is equal to 2 m^2 , but the apparent surface that is exposed

to the solar radiations is different, due to the sun's momentum. The geometry of the *ETCs* that is exposed to the solar radiations is tubular [53], while the geometry of the *FPCs* exposed to the solar rays is flat [54]. It should be noted that the *ETCs* enhance the conversion of solar energy into thermal energy because of their geometrical shape that does not require a solar radiation tracking system, which is not the case for the *FPCs*. Therefore, the second parametric study has been carried out to evaluate the gains that *ETCs* technology would bring to the collective production process of domestic hot water compared to *FPCs*, while testing several certified manufacturers of solar thermal collectors.

The effect of *ETC* on the useful energy gain from the collector is presented in Fig. 17. The useful energy gain from the collectors was assessed for four products of the *ETC* collectors. Moreover, *Diario-DTIE* profile was used as a load profile input for the simulations during the first cold week of January. It has been found that the product of the *Jingsu Sunrain Solar Energy* brand maximizes this indicator to achieve the values presented in Tab. 10. Further, the useful energy gain from the collectors becomes lower in the lack of the solar radiations.

Time (h)	11	36	85	110
Useful energy gain from collector (MJ/h)	112.410	38.714	60.358	154.590

Table 10: Useful energy gain from the collector for Jingsu Sunrain Solar Energy product.

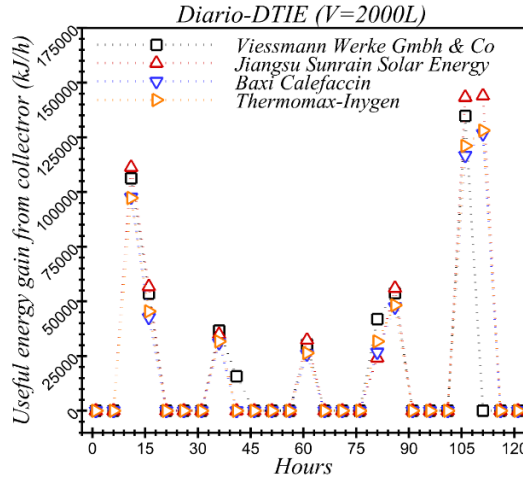


Figure 17: Effect of the *ETC* technology on the useful energy gain from collector for $V=2000$ l (*Diario-DTIE* load profile).

4.2.3. Effect of *ETC* technology on the annual solar fraction of the collective hot water process

Figs. 18 were presented to compare the energy performance of two different technologies of solar collectors, in order to justify the selection of the collector technology, which would help to meet the requirements of the present solar collective hot water production application. As a first step, a comparison between the energy performance of the *ETC* (*Viessmann Werke GmbH & Co*) and the energy performance of the other *FPCs* collectors was carried out (Fig. 18). The present study belongs to the project entitled *SOL'R SHEMA* [4], which aims to manufacture and market on the national Moroccan scale the first *SWH* equipped with *ETC* with heat pipes using as collectors the *Viessmann* product (a choice required by the project's specifications). For this reason, the

Viessmann Werke GmbH & Co ETC was selected as a reference product instead of other *ETC* collectors' products.

From one hand, the effect of the *ETC* technology on the annual solar fraction of the collective process is presented in Fig. 18. Further, the solar fraction of the collective system was assessed for three storage capacities, namely $V = 1000$ liters, $V = 2000$ liters and $V = 3000$ liters. Moreover, different products of the *ETC* collectors were compared with the *ETC* collector, notably through the integration of the Viessmann Werke GmbH & Co collector product. From the other hand, it has been shown that the solar fraction of the collective process, which uses Junkers brand, is enhanced compared to the collective process that uses other *FPC* products. However, the achieved solar fractions remain lower than that of the *ETC* Viessmann Werke GmbH & Co, especially during the cold period of the year i.e. months: October, November, December, January, February, March and April as shown in Tab. 11.

The effect of the collectors' technologies *ETC* and *FPC* on the annual solar fraction of the *SWH* collective system for three volumes of the centralized storage tank is presented in Fig. 18. The collector effect is not predictable for a small tank volume, namely $V = 1000$ liters, however it becomes noticeable as it increases to a volume of $V = 3000$ liters. In addition, the solar fraction of the collective hot water process with a solar collector field constituted with the *ETC* technology is higher than the other configuration of the collective *SWH* system with a solar field based on *FPC* (Tab. 11).

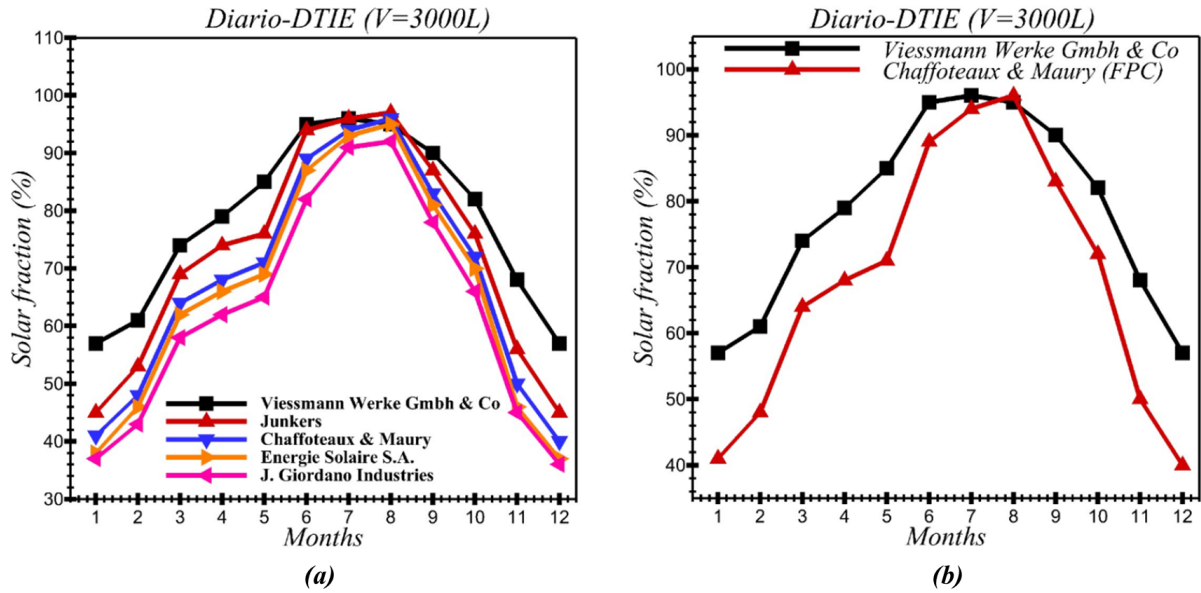


Figure 18: Effect of the *ETC* technology on the solar fraction gains for $V=3000$ l (*Diario-DTIE* load profile). (a)-Comparison between the annual solar fractions of the Viessmann brand (*ETC*) and four different *FPC* brands. (b)-Comparison between the annual solar fractions of the Viessmann brand (*ETC*) and Chaffoteaux brand (*FPC*).

The collectors' technologies effect on the annual solar fraction for a centralized storage tank with a volume of $V = 3000$ liters is presented in Tab. 11. The maximal annual averaged solar fraction is achieved by Viessmann (*ETC*) 78%. In contrast, it is equal to 68% for the Chaffoteau & Maury (*FPC*).

Solar fraction (%)	October	November	December	January	February	March
<i>FPC</i> (Junkers)	78	56	46	46	54	68
<i>FPC</i> (Chaffoteaux & Maury)	72	51	40	41	48	64
<i>ETC</i> (Viessmann Werke GmbH & Co)	85	70	58	58	61	74
The relative gains regarding <i>FPC</i> technology (Junkers)	7	14	12	12	7	6
The relative gains regarding <i>FPC</i> technology (Chaffoteaux & Maury)	13	19	18	17	13	10

Table 11: The solar fraction of the collective process during the cold periode of the year and the relative gains in terms of energy if *ETC* collectors (*Viessmann Werke GmbH & Co*) are used.

The solar fraction of the *DHW* production process largely depends on the availability of solar energy, which is captured and converted by the collector field. It is for this reason that designing properly the collective system to ensure a solar fraction higher than 50%, during the period of the year when the need for hot water is increased, remains a good achievement. As shown in Fig. 18, the solar fraction of the *DHW* process reaches important values between 80% and 95% during the summer period of the year, especially in Mai, June, July, August and September. This result is explained by the fact that during this period of the year, the contribution of solar energy is greater than that of the hydraulic/electrical booster.

It is possible to ensure a stability of the solar fraction of the collective process relative to seasonal periods of the year, which are characterized almost by similar magnitude of solar radiation. On the other hand, ensuring stability of the solar fraction throughout the year remains a very complicated issue, because the amount of solar radiation incident on the collector field is uncontrollable (it is a weather data input), unless technical devices and systems are used to hide the surface of the collector during summer periods.

5. Conclusion

In the present study, the thermal performance of a forced circulation collective *SWH* process equipped with a centralized storage tank is assessed, in order to enhance its energy efficiency. A realistic case study has been considered to carry out this analysis. Miscellaneous parametric studies were conducted to meet the collective hot water production need for a social housing (case of multiple apartment blocks) located on the city of Fez, which belongs to the climatic zone 3 in Morocco. Five typical hot water load profiles were used to assess the energy performance of this collective process.

This paper presents two main parametric studies. The first study focused on the effect of the centralized storage tank volume on the solar fraction of the process. An undersized volume generates a high consumption rate of the auxiliary system. Hence, the energy efficiency of the process decreases. Moreover, the load profile affects the energy recovered by the solar collector, the outlet temperature from the collector field, the solar top tank temperature and the solar fraction of the collective process. It was found that the parallel connection ensures enhanced solar fraction compared to the series configuration of the collectors.

The second study aimed to shed light on the effect of the collector's technology on the thermal yield of the collective process. The collector's technology affects the amount of the incident energy on the solar collector, besides to the useful energy gained. Besides, the solar collectors derived from the same technology with a_0 coefficient slightly equal to 1 and with low values of a_1 and a_2 ,

ensure enhanced annual solar fractions of the collective process. Finally, the fact of using a storage tank volume $V = 3000$ liters, connected to ETCs is a suitable choice for this process, because its solar fraction remains higher compared to the use of *FPCs*.

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