



HAL
open science

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

Saïf Ed-Dîn Fertahi, A. Jamil, Tarik Kousksou, A. Benbassou

► **To cite this version:**

Saïf Ed-Dîn Fertahi, A. Jamil, Tarik Kousksou, A. Benbassou. Energy performance enhancement of a collective hot water production process equipped with a centralized storage tank. *Journal of Energy Storage*, 2019, 25, pp.100849 -. 10.1016/j.est.2019.100849 . hal-03488285

HAL Id: hal-03488285

<https://hal.science/hal-03488285>

Submitted on 20 Dec 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

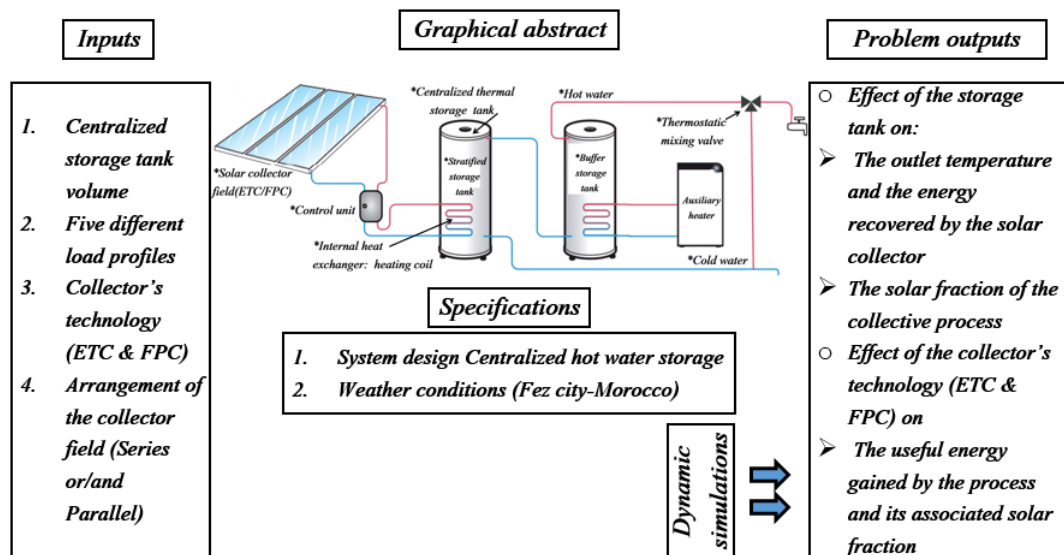
Energy performance enhancement of a collective hot water production process equipped with a centralized storage tank

Saïf ed-Dîn Fertahi^{a,b,*}, A. Jamil^a, T. Kousksou^b, A. Benbassou^a

^a Université Sidi Mohamed Ben Abdellah (U.S.M.A), École Supérieure de Technologie de Fès, Route d'Imouzzer BP 2427, Morocco

^b Université de Pau et des Pays de l'Adour (UPPA), Laboratoire des Sciences pour l'Ingénieur Appliquées à la Mécanique et au Génie Electrique (SIAME), IFR, Av. Jules Ferry, 64000 Pau France

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

*Corresponding author. Tel.: +212-668-365-373

Email address: fertahi.sayfdin@gmail.com (Saïf ed-Dîn Fertahi)

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 titled 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 SHEMSY*” 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

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

28 1.2. State of the art research

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

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

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

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

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

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

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

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

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

104 1.3. Aim of the research paper

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

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

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

131 2. Description of the studied case

132 The energy performance of the collective *SWH* system, schematically presented in Fig. 1, has
 133 been assessed in a Moroccan residence located in Fez city [34°03'N 4°58'W]. The residence shelters
 134 60 occupants and the individual consumption was estimated to 80 liters of hot water per person.
 135 Hence, the overall daily hot water need is 6000 liters.

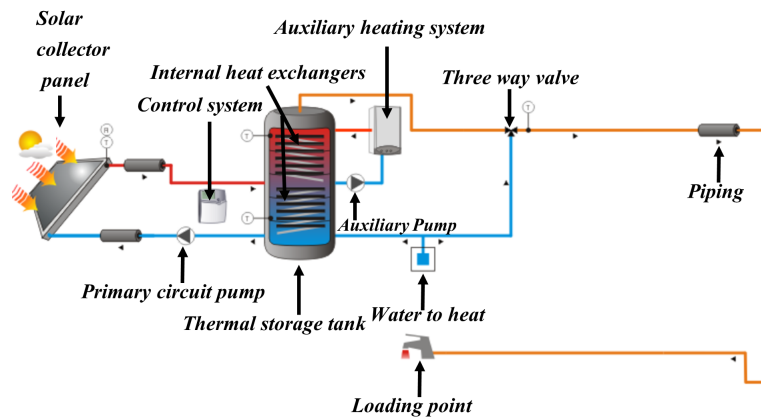


Figure 1: Simplified scheme of the collective hot water process [36].

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

141 2.1. Description of the collective hot water process

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

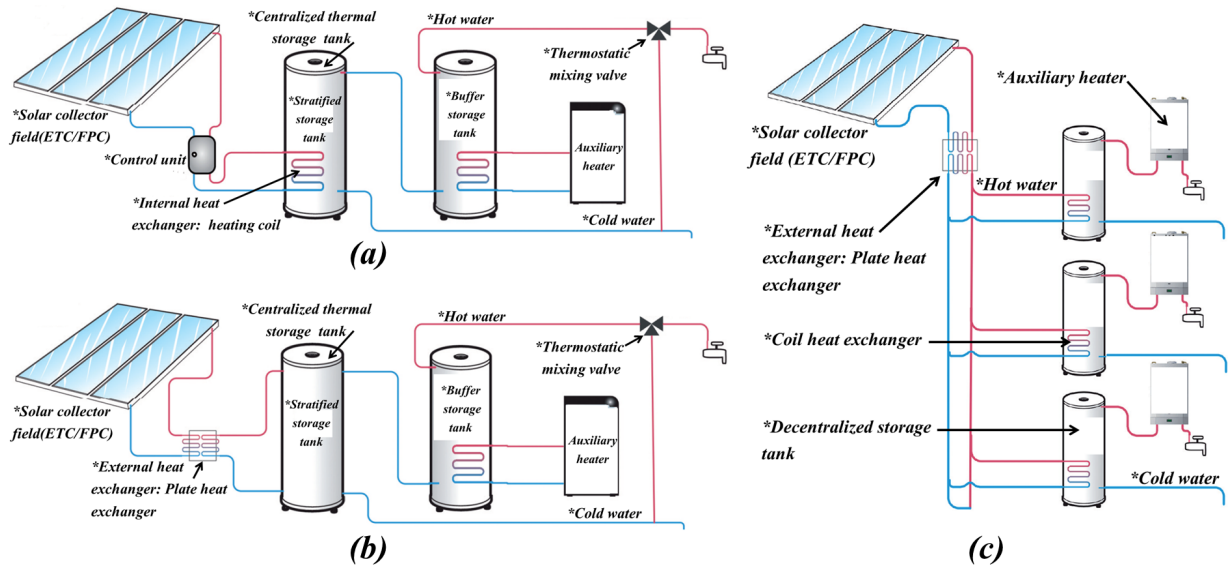


Figure 2: (a)- Centralized storage tank equipped with internal coil heat exchanger. (b)- Centralized storage tank equipped with external plate heat exchanger. (c)- Decentralized storage tank equipped with internal heat exchanger.

153 The auxiliary system operates if the storage tank temperature is below the set temperature
 154 defined by the consumer. This set point temperature value must be higher than the *DHW* tem-
 155 perature that is required for the consumption. The accurate design of the auxiliary heating system
 156 aims to ensure the hot water service in all the climatic circumstances. Consequently, to get as
 157 much benefit from solar energy. Furthermore, the control of the primary circuit is carried out by
 158 measuring the amount of the incident solar radiations or by measuring the temperature differential
 159 [12]. The pumps operate according to the radiation reaching the collectors, while the temperature
 160 differential is integrated between the collectors and the bottom side of the tank. The secondary
 161 loop can be cross-checked with the primary loop or independently by comparing the temperature
 162 of the hot side of the exchanger with the bottom temperature of the tank. In this case, the flow
 163 rate of the pumps can be fixed or variable (match-flow system). In fact, the system stops the
 164 circulation if the temperature of the storage tank or the temperature of the collector is higher than
 165 the respective maximum safety temperatures [15].

166 The collector technologies used during this study, in order to carry out the forced hot water
167 collective system optimization for low energy consumption and energy storage enhancement, are
168 presented in detail in both Tabs. 1 and 2. For instance, general information such as the manu-
169 facturer’s signature, the technology’s type, the test laboratory as well as technical characteristics,
170 for example optical and thermal efficiencies are presented. Further, Tab. 3 shows the arrangement
171 of the collector field that has been used in this hourly dynamic simulations to meet the heating
172 requirements of hot water. Thirty-one collectors were used to constitute the solar field. They
173 were distributed on 3 rows oriented towards the south. The first and the second rows included
174 10 collectors respectively, while the third row included 11 collectors. The tilt angle that has been
175 used was 30° . According to Agrouaz et al. [39], this tilt angle value helps to enhance the efficiency
176 of the collectors, especially in Fez city. The total apparent area covered by the collector fields is
177 $62.124 m^2$. The arrangement suggested in Tab. 3 was used as a basic and initial configuration to
178 evaluate the annual solar fraction of the collective process intended to produce hot water. Subse-
179 quently, a sensitivity study on the effect of the collector coupling and arrangement is proposed in
180 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>Baxi 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]

181 Additional technical information about the heat transfer fluid’s names and types (HTF) used
182 by the certification laboratories to assess the energy performance of various collector’s technologies
183 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>Baxi 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 & MauryRendamax-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].

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

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

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

199 2.2. Weather data and load profiles

200 2.2.1. Weather data

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

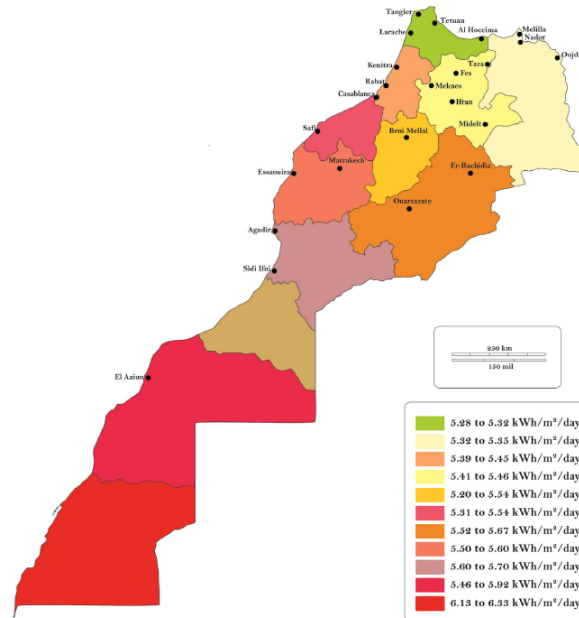


Figure 3: Various solar radiation intensities in Morocco [41].

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

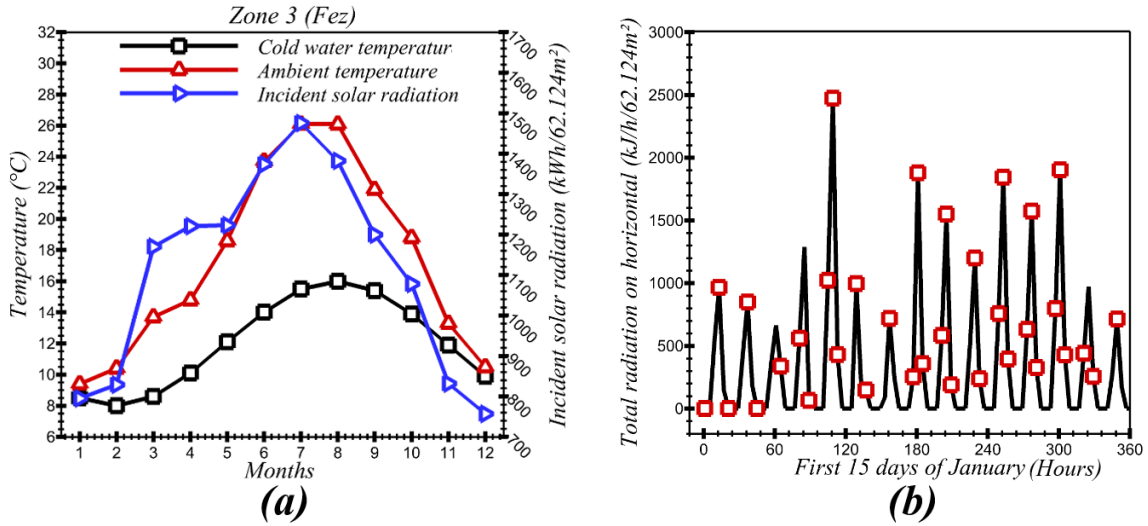


Figure 4: (a)- Fez weather data [36]. (b)- The total radiation on the collector's horizontal [36].

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

223 2.2.2. Load profiles

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

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

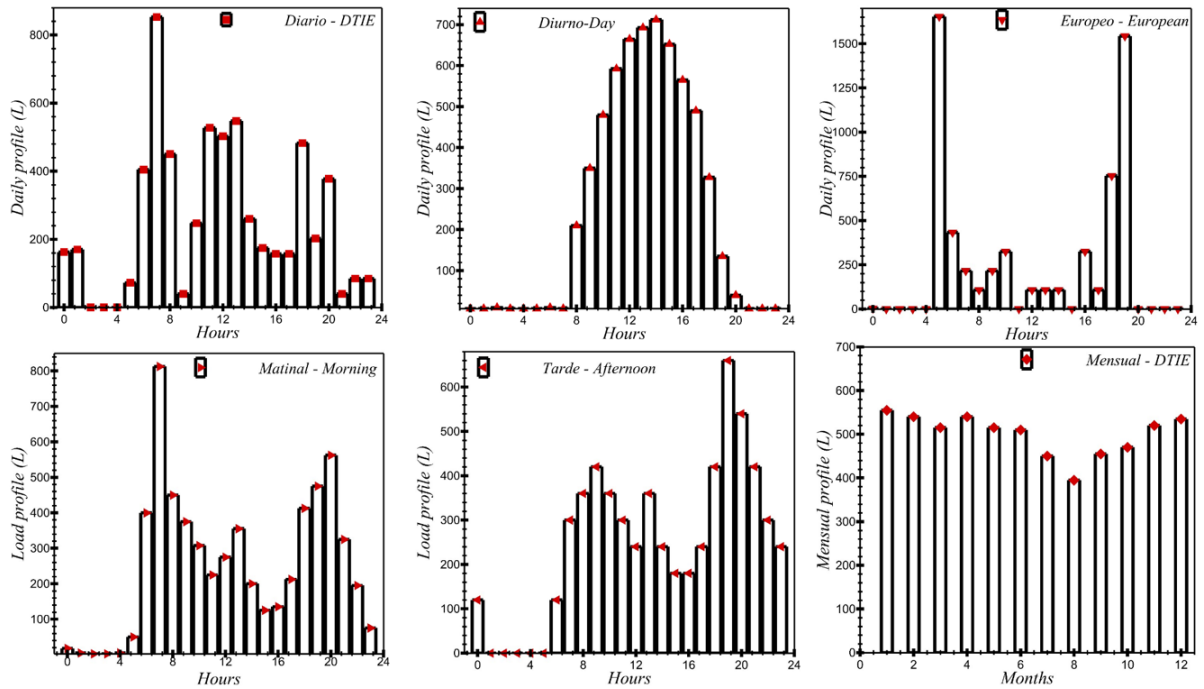


Figure 5: Typical hot water loading profiles used during the hourly dynamic simulations (daily profiles/single monthly profile) [36].

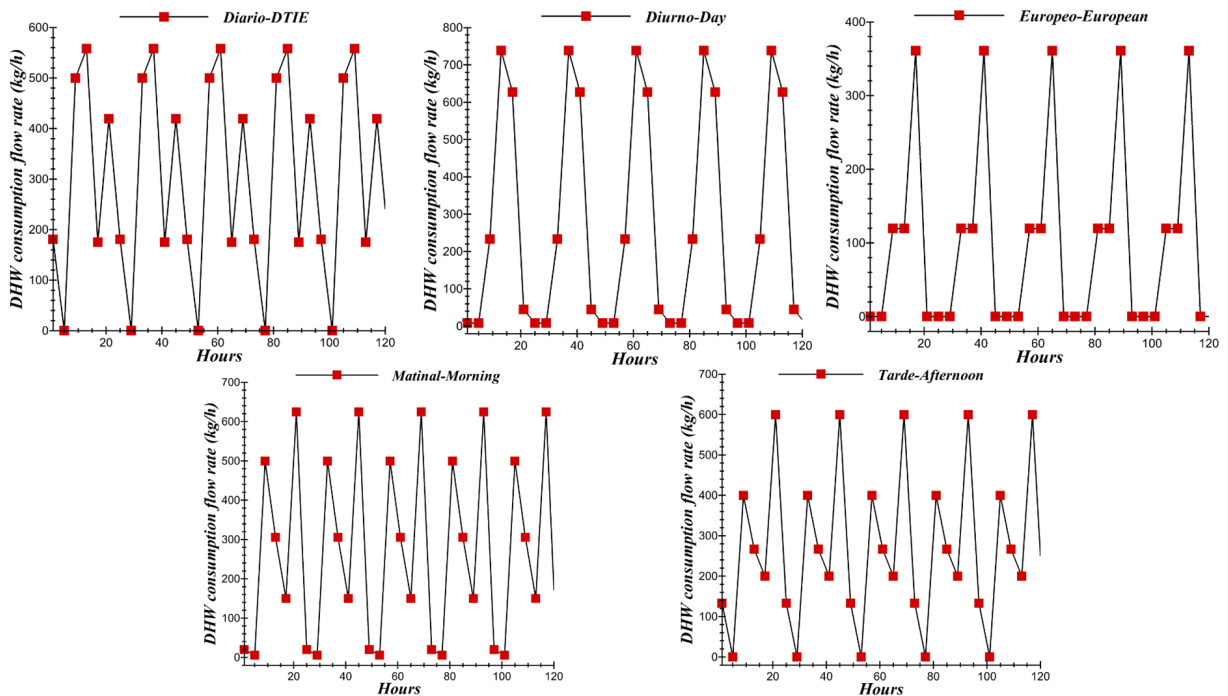


Figure 6: *DHW* consumption flow rate corresponding to each load profile for the first five days of January [36].

239 Tarde-Afternoon presents an accentuated consumption during the afternoon and the evening. In
 240 addition, the *Diurno-Day* profile describes a high consumption during the morning between 10 am
 241 and 5 pm. The profile *Europeo-European* corresponds to the countries of the European Union, where
 242 the consumer tends to use hot water between 5 am and 7 am and then in the evening between
 243 5 pm and 7 pm. The *Diario-DTIE* has a general consumption pattern, because it describes a
 244 consumption that is spread over the whole day and it does not follow a particular trend.

245 3. Equation setting

246 3.1. Thermal collector

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

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

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

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

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

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

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

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

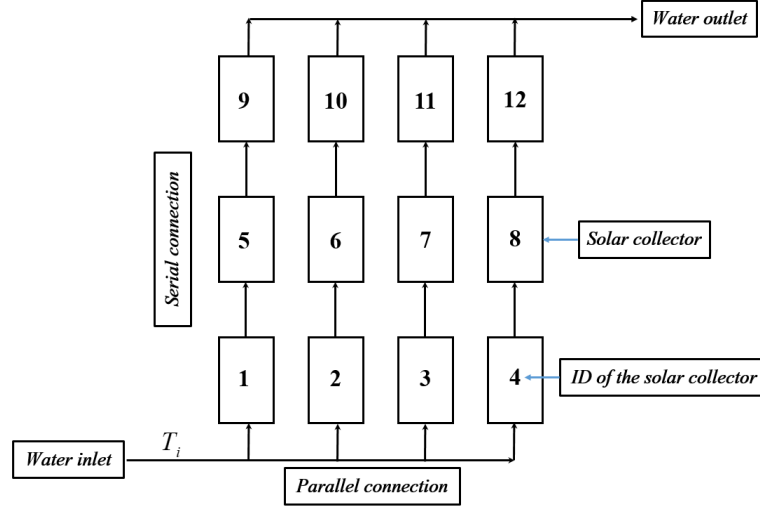


Figure 7: Combined series and parallel flow through a collector array.

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

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

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

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

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

287 3.2. Storage tank

288 A single centralized storage tank was used for this collective application. Its volume effect on
 289 the annual solar fraction was investigated as presented in Tab. 4. Moreover, the filling and the
 290 loading tank's nozzles, besides to the inlet and the outlet positions of the exchanger are presented
 291 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} .

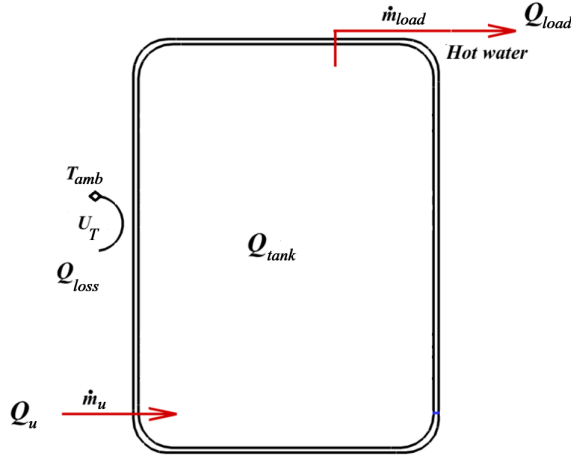


Figure 8: Schematic of the thermal storage tank's energy balance.

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)

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

302 where T_{top} refers to the top tank's temperature and T_{load} is the temperature of the hot water
 303 to load for the consumer. The heat losses from the tank (Q_{loss}) are calculated as mentioned in Eq.
 304 (10):

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

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

307 3.3. Solar fraction of the collective process

308 Solar fraction can be defined as the total energy provided by the solar collective system to
 309 produce hot water. It is calculated using Eq. (11) [48]. The solar fraction is the most important
 310 indicator, which is used to assess the performance of *SWHs* systems, because it takes into account
 311 the overall performance of the entire solar system and not only one single device or component
 312 [49].

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

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

316 4. Results and discussion

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

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

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

329 4.1. First parametric study: effect of the storage tank volume

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

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

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

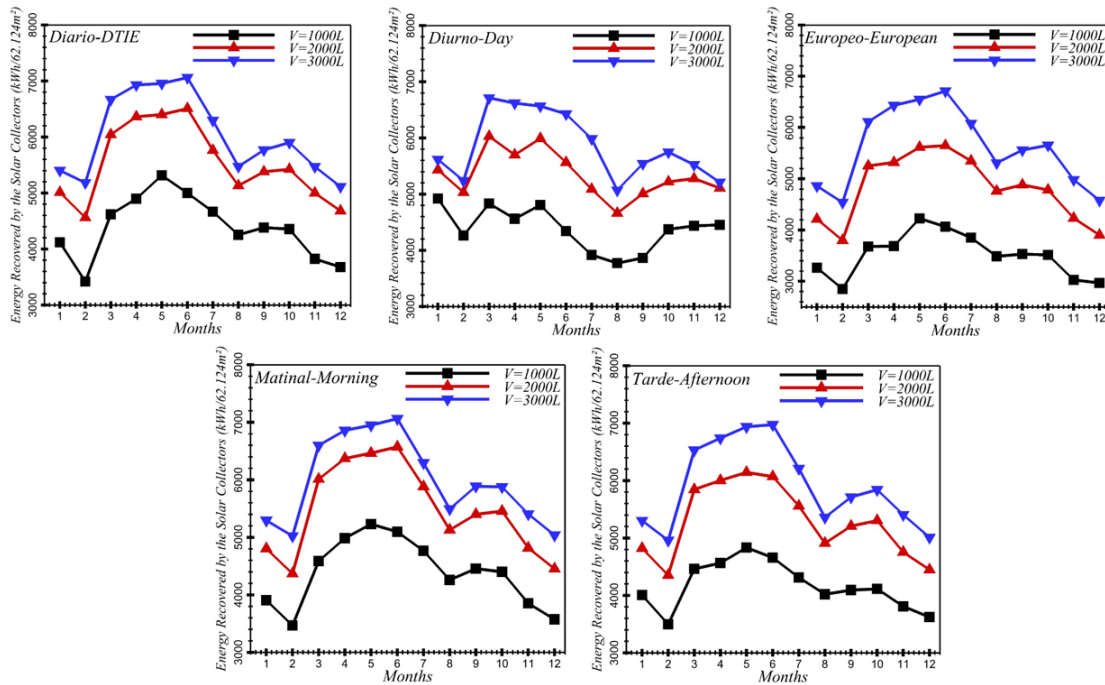


Figure 9: Effect of load profiles and storage tank volumes on the energy recovered by the solar collector.

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

358 As presented in Fig. 10, the maximum temperatures occur only three times, namely at 16h,
 359 62h and 106h for the first five considered and simulated days of January. A local maximum has
 360 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.

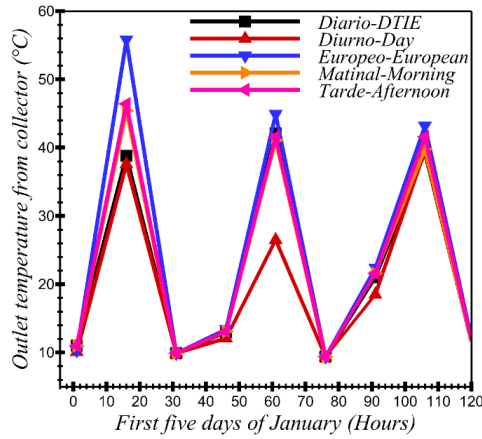


Figure 10: Outlet temperature evolution from collector over the first five days of January.

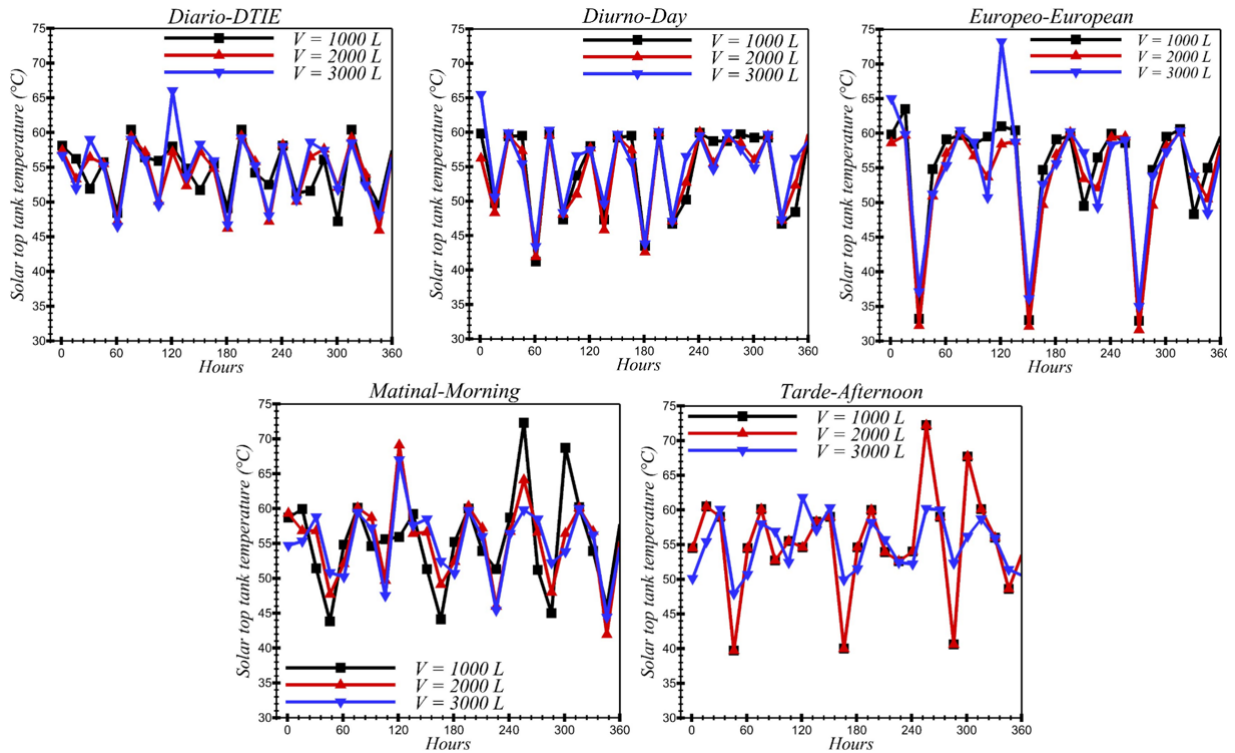


Figure 11: Solar top tank temperature evolution for three different centralized storage tank volumes and for five load profiles on a range of the first 15 cold days of January.

366 As shown in Fig. 5, the *Europeo-European* load profile is characterized by high *DHW* consump-
367 tion between 5h and 7h (1750 liters) and between 17h and 19h (1500 liters). On the other hand, the
368 *Tarde-Afternoon* load profile is characterized by hot water demands that varies between 200 liters
369 and 400 liters before 17h, reaching 650 liters at 19h and 500 liters at 20h. The difference between
370 these two profiles clearly affects the temperature at the outlet of the storage tank as shown in Fig.
371 11, especially if the effect of the stratified storage tank volume is taken into account. Therefore,
372 to serve the needs of the consumer whose consumption follows the *Europeo-European* profile, the
373 use of a large storage tank volume (3000 liters) would be the most appropriate because it would
374 ensure the production of a hot water volume of 1750 liters without affecting the efficiency of the
375 solar collector field, hence, improving the solar fraction of the collective process.

376 The supplementary consumption was assessed for different storage tank volumes and for the five
377 considered load profiles as presented in Fig. 12. The hydraulic booster as an auxiliary energy source
378 was used to meet the consumers' needs, which are represented by the loading profiles when solar
379 radiations are insufficient, notably during the cold periods of the year. The technical characteristics
380 of the hydraulic booster that has been used during the hourly dynamic simulation are presented
381 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].

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

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

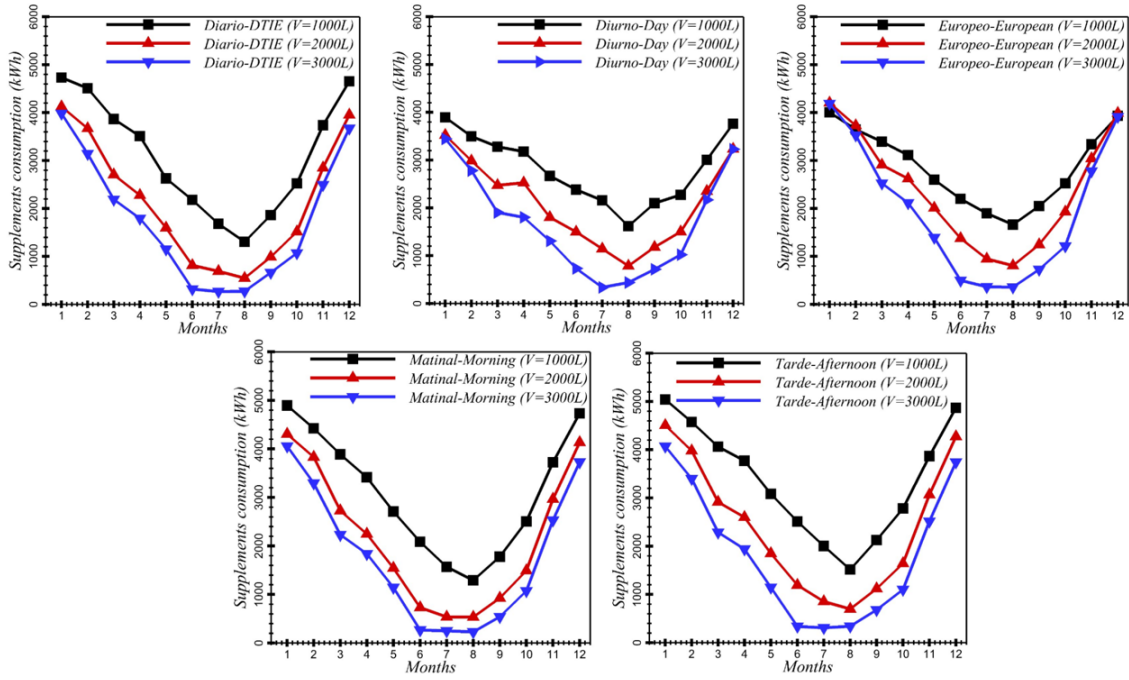


Figure 12: Effect of the load profile on the consumption of the auxiliary booster for different storage tank volumes.

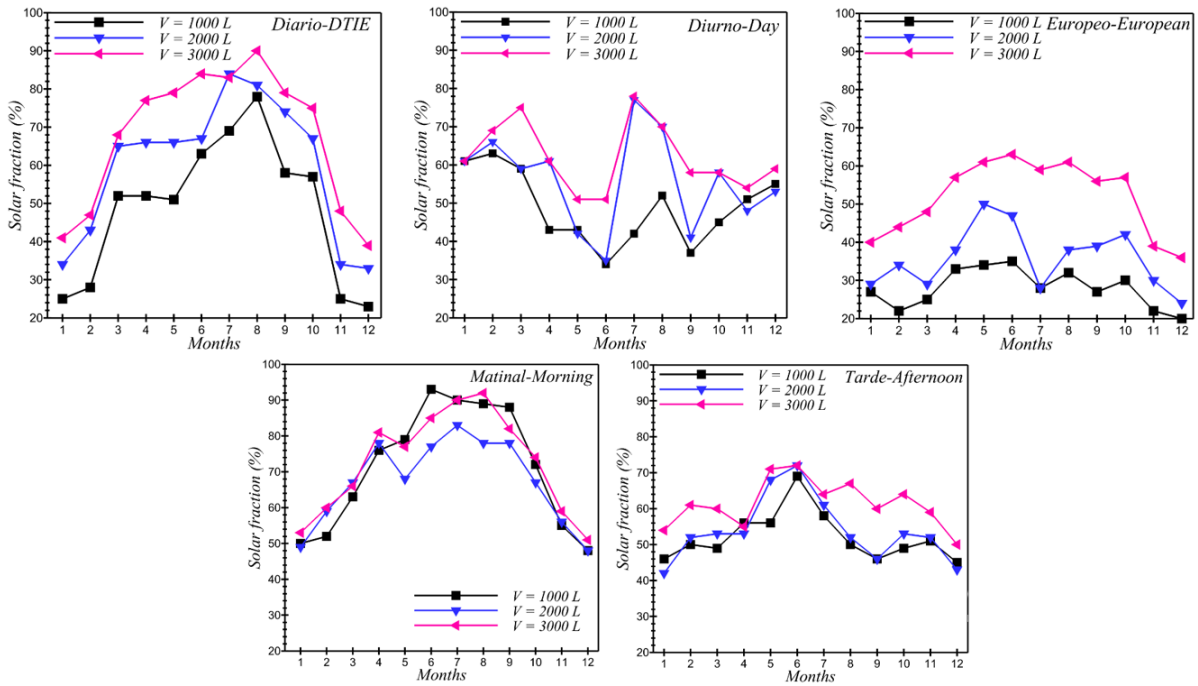


Figure 13: Effect of different storage tank volume on the solar fraction for the considered loading profiles.

400 4.1.1. Effect of ETC technologies on the annual solar fraction

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

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

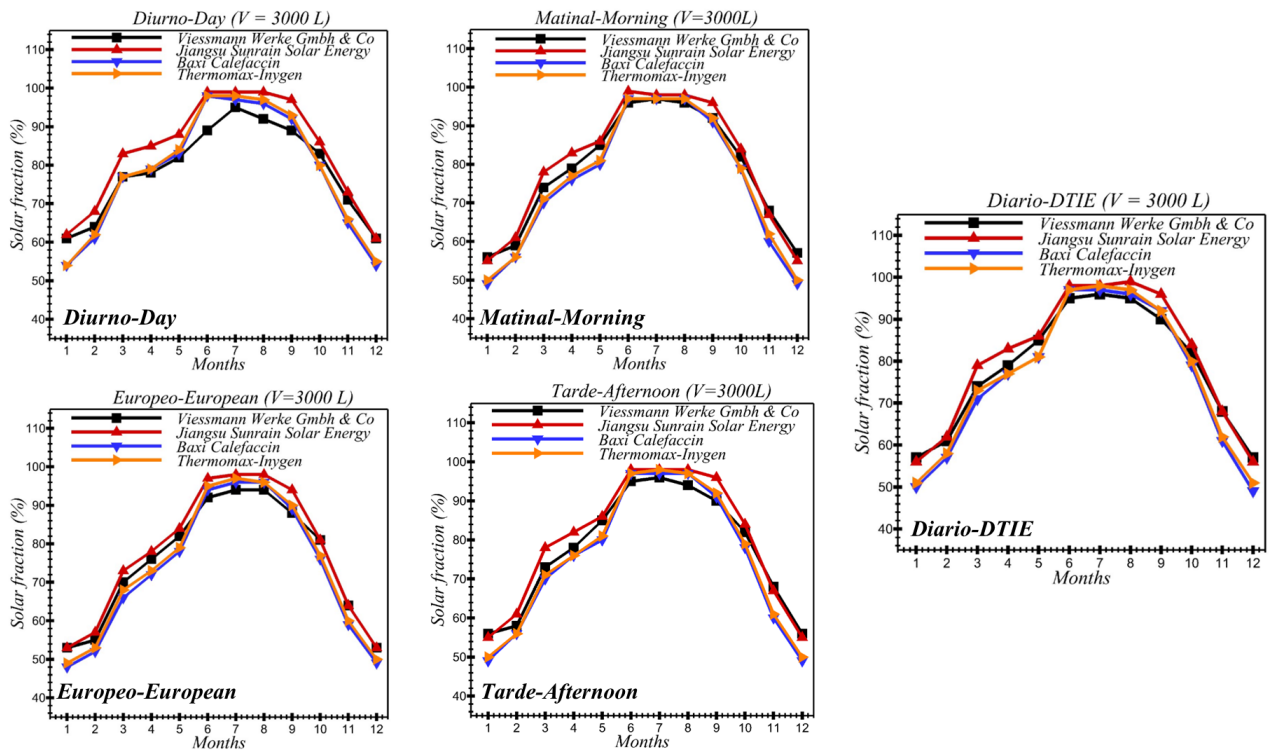


Figure 14: Effect of the ETC collectors designed from different manufacturers on the annual solar fraction of the collective system for a storage tank volume of 3000 liters.

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

420 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 Calefacin	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 Calefacin	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 Calefacin	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 Calefacin	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 Calefacin	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.

421 *4.1.2. Effect of the collector field arrangement on the annual solar fraction*

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

429 If several collectors are connected in parallel, the temperature of the *HTF* at the outlet of the
 430 collector field is increased. Otherwise, an installation with several collectors connected in series
 431 has the effect of decreasing the temperature of the *HTF* at the outlet of the collector field. Parallel
 432 and serial configurations were used in this study to enhance the overall efficiency of the collective
 433 hot water production process. Thirty one *ETC* collectors, based on the manufacturer *Viessmann*
 434 *Werke GmbH & Co*, were spread over 2, 4, 6, 8 and 10 rows to constitute five configurations.
 435 The effect of these arrangements on the solar fraction was assessed for the considered applied load
 436 profiles. The improvements recorded regarding the system's solar fraction during the cold season
 437 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.

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

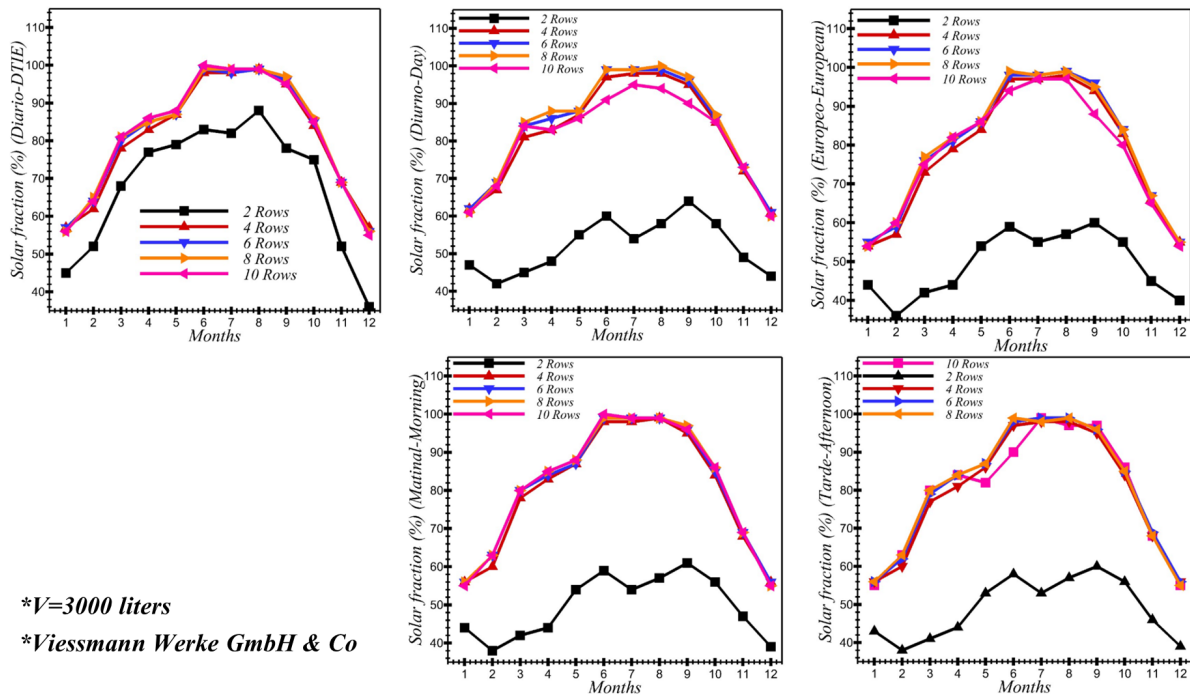


Figure 15: Effect of the collector field arrangement on the solar fraction for different load profiles.

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

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

460 4.2. Second parametric study: Collector effect on the annual solar fraction

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

464 4.2.1. Effect of the collector technologies on the incident energy on the solar collector plane

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

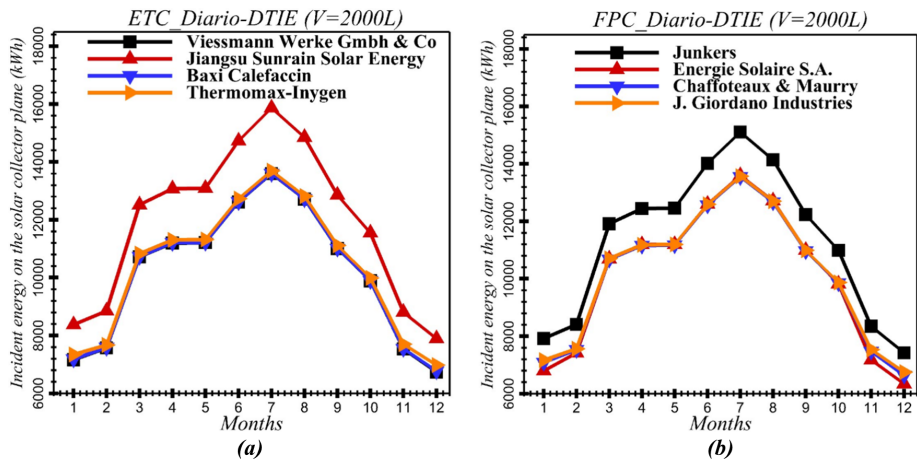


Figure 16: Effect of different collector technologies designed from different manufacturers on the incident energy on the solar collector plane for $V = 2000$ l (*Diario-DTIE* load profile). (a)- *ETC* technologies. (b)- *FPC* technologies.

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

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

475 4.2.2. *ETC* effect on the useful energy gain from the collector

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

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

487 The effect of *ETC* on the useful energy gain from the collector is presented in Fig. 17. The useful
 488 energy gain from the collectors was assessed for four products of the *ETC* collectors. Moreover,
 489 *Diario-DTIE* profile was used as a load profile input for the simulations during the first cold week of
 490 January. It has been found that the product of the *Jingsu Sunrain Solar Energy* brand maximizes
 491 this indicator to achieve the values presented in Tab. 10. Further, the useful energy gain from the
 492 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.

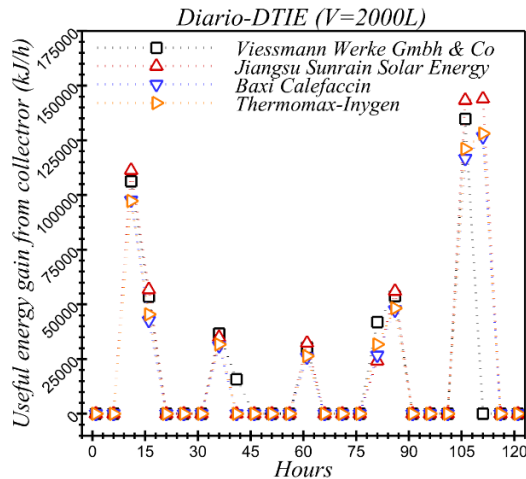


Figure 17: Effect of the *ETC* technology on the useful energy gain from collector for $V=2000$ l (*Diario-DTIE* load profile).

493 4.2.3. Effect of *ETC* technology on the annual solar fraction of the collective hot water process

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

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

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

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

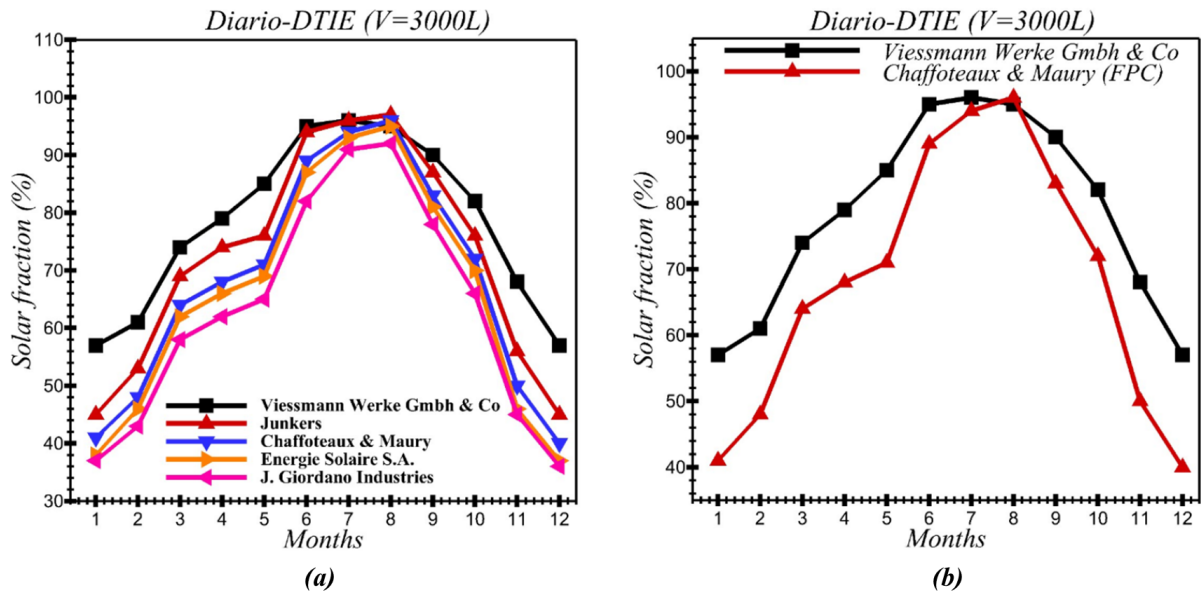


Figure 18: Effect of the *ETC* technology on the solar fraction gains for $V=3000$ l (*Diario-DTIE* load profile).
 (a)-Comparison between the annual solar fractions of the Viessmann brand (*ETC*) and four different *FPC* brands.
 (b)-Comparison between the annual solar fractions of the Viessmann brand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

521 The collectors' technologies effect on the annual solar fraction for a centralized storage tank
 522 with a volume of $V = 3000$ liters is presented in Tab. 11. The maximal annual averaged solar
 523 fraction is achieved by Viessmann (*ETC*) 78%. In contrast, it is equal to 68% for the Chaffoteau
 524 & 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.

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

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

539 5. Conclusion

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

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

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

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

561 6. Acknowledgment

562 The authors are grateful for the funding support provided by the Institut de Recherche en
563 Energie Solaire et Energies Nouvelles (*IRESEN-Morocco*) under the project *SOL'R SHEMSY*.

564 7. References

565 References

- 566 [1] X. Zhang, F. Wang, Hybrid input-output analysis for life-cycle energy consumption and carbon emissions of
567 china's building sector, *Building and Environment* 104 (2016) 188 – 197. doi:[http://dx.doi.org/10.1016/j.
568 buildenv.2016.05.018](http://dx.doi.org/10.1016/j.buildenv.2016.05.018).
569 URL [//www.sciencedirect.com/science/article/pii/S0360132316301706](http://www.sciencedirect.com/science/article/pii/S0360132316301706)
- 570 [2] T. Ming, W. Liu, S. Caillol, et al., Fighting global warming by climate engineering: Is the earth radiation
571 management and the solar radiation management any option for fighting climate change?, *Renewable and
572 Sustainable Energy Reviews* 31 (2014) 792–834.
- 573 [3] S. ed Dîn Fertahi, T. Bouhal, F. Gargab, A. Jamil, T. Kousksou, A. Benbassou, Design and thermal performance
574 optimization of a forced collective solar hot water production system in morocco for energy saving in residential
575 buildings, *Solar Energy* 160 (2018) 260 – 274. doi:<https://doi.org/10.1016/j.solener.2017.12.015>.
576 URL <http://www.sciencedirect.com/science/article/pii/S0038092X17310873>
- 577 [4] Institut de recherche en energie solaire et energies nouvelles(iresen).
578 URL <http://www.iresen.org>
- 579 [5] B. Greening, A. Azapagic, Domestic solar thermal water heating: A sustainable option for the uk?, *Renewable
580 Energy* 63 (2014) 23 – 36. doi:<https://doi.org/10.1016/j.renene.2013.07.048>.
581 URL <http://www.sciencedirect.com/science/article/pii/S0960148113004576>
- 582 [6] W. M. Hashim, A. T. Shomran, H. A. Jurmut, T. S. Gaaz, A. A. H. Kadhum, A. A. Al-Amiery, Case study on
583 solar water heating for flat plate collector, *Case studies in thermal engineering* 12 (2018) 666–671.
- 584 [7] S. ed Dîn Fertahi, T. Bouhal, Y. Agrouaz, T. Kousksou, T. E. Rhafiki, Y. Zeraouli, Performance optimization of
585 a two-phase closed thermosyphon through cfd numerical simulations, *Applied Thermal Engineering* 128 (2018)
586 551 – 563. doi:<https://doi.org/10.1016/j.applthermaleng.2017.09.049>.
587 URL <http://www.sciencedirect.com/science/article/pii/S1359431117339558>
- 588 [8] M. Hadjiat, M. Hazmoune, S. Ouali, A. Gama, M. Yaiche, Design and analysis of a novel ics solar water heater
589 with cpc reflectors, *Journal of Energy Storage* 16 (2018) 203–210.
- 590 [9] J. C. Evarts, L. G. Swan, Domestic hot water consumption estimates for solar thermal system sizing, *Energy
591 and Buildings* 58 (2013) 58 – 65. doi:<http://dx.doi.org/10.1016/j.enbuild.2012.11.020>.
592 URL [//www.sciencedirect.com/science/article/pii/S0378778812006238](http://www.sciencedirect.com/science/article/pii/S0378778812006238)
- 593 [10] H. M. A. ur Rehman, F. A. Al-Sulaiman, Optimum selection of solar water heating (swh) systems based on
594 their comparative techno-economic feasibility study for the domestic sector of saudi arabia, *Renewable and
595 Sustainable Energy Reviews* 62 (2016) 336 – 349. doi:<http://dx.doi.org/10.1016/j.rser.2016.04.047>.
596 URL [//www.sciencedirect.com/science/article/pii/S1364032116300806](http://www.sciencedirect.com/science/article/pii/S1364032116300806)
- 597 [11] G. He, Y. Zheng, Y. Wu, Z. Cui, K. Qian, Promotion of building-integrated solar water heaters in urbanized
598 areas in china: Experience, potential, and recommendations, *Renewable and Sustainable Energy Reviews* 42
599 (2015) 643 – 656. doi:<http://dx.doi.org/10.1016/j.rser.2014.10.044>.
600 URL [//www.sciencedirect.com/science/article/pii/S1364032114008697](http://www.sciencedirect.com/science/article/pii/S1364032114008697)
- 601 [12] L. Ayompe, A. Duffy, S. McCormack, M. Conlon, Validated {TRNSYS} model for forced circulation solar water
602 heating systems with flat plate and heat pipe evacuated tube collectors, *Applied Thermal Engineering* 31 (8–9)
603 (2011) 1536 – 1542. doi:<http://dx.doi.org/10.1016/j.applthermaleng.2011.01.046>.
604 URL [//www.sciencedirect.com/science/article/pii/S1359431111000718](http://www.sciencedirect.com/science/article/pii/S1359431111000718)
- 605 [13] Y. S. Too, G. Morrison, M. Behnia, Performance of solar water heaters with narrow mantle heat exchangers,
606 *Solar Energy* 83 (3) (2009) 350 – 362. doi:<http://dx.doi.org/10.1016/j.solener.2008.08.011>.
607 URL [//www.sciencedirect.com/science/article/pii/S0038092X08002119](http://www.sciencedirect.com/science/article/pii/S0038092X08002119)

- 608 [14] S. Colle, T. Koller, Simulation and performance analysis of a solar domestic hot water system controlled by
609 weather forecast information, *Energy Procedia* 57 (2014) 2496 – 2505, 2013 {ISES} Solar World Congress.
610 doi:<http://dx.doi.org/10.1016/j.egypro.2014.10.260>.
611 URL [//www.sciencedirect.com/science/article/pii/S1876610214016270](http://www.sciencedirect.com/science/article/pii/S1876610214016270)
- 612 [15] L. Passos, J. M. Cardemil, S. Colle, Feasibility study of using domestic solar hot water systems as alternative
613 to reduce the electricity peak demand in brazil, *Energy Procedia* 57 (2014) 2487 – 2495. doi:<http://dx.doi.org/10.1016/j.egypro.2014.10.258>.
614 URL <http://www.sciencedirect.com/science/article/pii/S1876610214016257>
- 615 [16] G. Martínez-Rodríguez, A. L. Fuentes-Silva, M. Picón-Núñez, Solar thermal networks operating with evacuated-
616 tube collectors, *Energy* (2017).
- 617 [17] M. Abdunnabi, K. Alakder, N. Alkishriwi, S. Abughres, Experimental validation of forced circulation of solar
618 water heating systems in {TRNSYS}, *Energy Procedia* 57 (2014) 2477 – 2486, 2013 {ISES} Solar World
619 Congress. doi:<http://dx.doi.org/10.1016/j.egypro.2014.10.257>.
620 URL [//www.sciencedirect.com/science/article/pii/S1876610214016245](http://www.sciencedirect.com/science/article/pii/S1876610214016245)
- 621 [18] Z. Zhou, L. Wang, C. Li, A. Ebert, Performance analysis of a collective solar domestic water-heating system
622 in the temperate zone of yunnan province, china, *Journal of Engineering Science and Technology Review* 9 (3)
623 (2016) 60–65.
- 624 [19] D. Li, S. Liao, An integrated approach to evaluate the performance of solar water heater in the urban environ-
625 ment, *Energy and Buildings* 69 (2014) 562 – 571. doi:<http://dx.doi.org/10.1016/j.enbuild.2013.11.044>.
626 URL [//www.sciencedirect.com/science/article/pii/S0378778813007512](http://www.sciencedirect.com/science/article/pii/S0378778813007512)
- 627 [20] M. S. Buker, S. B. Riffat, Building integrated solar thermal collectors—a review, *Renewable and Sustainable*
628 *Energy Reviews* 51 (2015) 327–346.
- 629 [21] A. Jamar, Z. Majid, W. Azmi, M. Norhafana, A. Razak, A review of water heating system for solar energy
630 applications, *International Communications in Heat and Mass Transfer* 76 (2016) 178–187.
- 631 [22] D. Zambrana-Vasquez, A. Aranda-Usón, I. Zabala-Bribián, A. Jañez, E. Llera-Sastresa, P. Hernandez, E. Ar-
632 rizabalaga, Environmental assessment of domestic solar hot water systems: a case study in residential and hotel
633 buildings, *Journal of Cleaner Production* 88 (2015) 29 – 42, sustainable Development of Energy, Water and
634 Environment Systems. doi:<https://doi.org/10.1016/j.jclepro.2014.06.035>.
635 URL <http://www.sciencedirect.com/science/article/pii/S0959652614006234>
- 636 [23] P. R. Chao, S. Umaphathi, W. Saman, Water consumption characteristics at a sustainable residential development
637 with rainwater-sourced hot water supply, *Journal of Cleaner Production* 109 (2015) 190 – 202, special Issue:
638 Toward a Regenerative Sustainability Paradigm for the Built Environment: from vision to reality. doi:<https://doi.org/10.1016/j.jclepro.2015.04.091>.
639 URL <http://www.sciencedirect.com/science/article/pii/S0959652615004667>
- 640 [24] C. J. Koroneos, E. A. Nanaki, Life cycle environmental impact assessment of a solar water heater, *Journal of*
641 *Cleaner Production* 37 (2012) 154 – 161. doi:<https://doi.org/10.1016/j.jclepro.2012.07.001>.
642 URL <http://www.sciencedirect.com/science/article/pii/S0959652612003289>
- 643 [25] S. Kordana, D. Słyś, J. Dziopak, Rationalization of water and energy consumption in shower systems of single-
644 family dwelling houses, *Journal of Cleaner Production* 82 (2014) 58 – 69. doi:<https://doi.org/10.1016/j.jclepro.2014.06.078>.
645 URL <http://www.sciencedirect.com/science/article/pii/S0959652614006660>
- 646 [26] K. Tanha, A. S. Fung, R. Kumar, Performance of two domestic solar water heaters with drain water heat
647 recovery units: Simulation and experimental investigation, *Applied Thermal Engineering* 90 (2015) 444 – 459.
648 doi:<http://dx.doi.org/10.1016/j.applthermaleng.2015.07.038>.
649 URL [//www.sciencedirect.com/science/article/pii/S135943111500722X](http://www.sciencedirect.com/science/article/pii/S135943111500722X)
- 650 [27] J. B. A. Lima, R. T. Prado, V. M. Taborianski, Optimization of tank and flat-plate collector of solar water
651 heating system for single-family households to assure economic efficiency through the {TRNSYS} program,
652 *Renewable Energy* 31 (10) (2006) 1581 – 1595. doi:<http://dx.doi.org/10.1016/j.renene.2005.09.006>.
653 URL [//www.sciencedirect.com/science/article/pii/S0960148105002636](http://www.sciencedirect.com/science/article/pii/S0960148105002636)
- 654 [28] M. R. Assari, H. B. Tabrizi, M. J. Movahedi, Experimental study on destruction of thermal stratification tank
655 in solar collector performance, *Journal of Energy Storage* 15 (2018) 124–132.
- 656 [29] S. ed Din Fertahi, A. Jamil, A. Benbassou, Review on solar thermal stratified storage tanks (stsst): Insight on
657 stratification studies and efficiency indicators, *Solar Energy* 176 (2018) 126 – 145. doi:<https://doi.org/10.1016/j.solener.2018.10.028>.
658 URL <http://www.sciencedirect.com/science/article/pii/S0038092X18310077>
- 659 [30] J. A. Alfaro-Ayala, O. A. López-Núñez, F. Gómez-Castro, J. Ramírez-Minguela, A. Uribe-Ramírez, J. Belman-

- 664 Flores, S. Cano-Andrade, Optimization of a solar collector with evacuated tubes using the simulated annealing
665 and computational fluid dynamics, *Energy Conversion and Management* 166 (2018) 343–355.
- 666 [31] C. Garnier, T. Muneer, J. Currie, Numerical and empirical evaluation of a novel building integrated collector
667 storage solar water heater, *Renewable Energy* 126 (2018) 281–295.
- 668 [32] C. Yan, S. Wang, Z. Ma, W. Shi, A simplified method for optimal design of solar water heating systems based on
669 life-cycle energy analysis, *Renewable Energy* 74 (2015) 271 – 278. doi:[http://dx.doi.org/10.1016/j.renene.
670 2014.08.021](http://dx.doi.org/10.1016/j.renene.2014.08.021).
671 URL [//www.sciencedirect.com/science/article/pii/S0960148114004807](http://www.sciencedirect.com/science/article/pii/S0960148114004807)
- 672 [33] S. Rezvani, P. Bahri, T. Urmee, G. Baverstock, A. Moore, Techno-economic and reliability assessment of solar
673 water heaters in australia based on monte carlo analysis, *Renewable Energy* 105 (2017) 774 – 785. doi:<http://dx.doi.org/10.1016/j.renene.2017.01.005>.
674 URL [//www.sciencedirect.com/science/article/pii/S0960148117300058](http://www.sciencedirect.com/science/article/pii/S0960148117300058)
- 675 [34] V. M. Bessa, R. T. Prado, Reduction of carbon dioxide emissions by solar water heating systems and passive
676 technologies in social housing, *Energy Policy* 83 (2015) 138–150.
- 677 [35] T. Bouhal, Y. Agrouaz, T. El Rhafiki, T. Kousksou, Y. Zeraouli, A. Jamil, et al., Technical assessment, economic
678 viability and investment risk analysis of solar heating/cooling systems in residential buildings in morocco, *Solar
679 Energy* 170 (2018) 1043–1062.
- 680 [36] Transol.
681 URL <http://boutique.cstb.fr/fr/transol-3-0.html>
- 682 [37] T. Bouhal, Y. Agrouaz, A. Allouhi, T. Kousksou, A. Jamil, T. El Rhafiki, Y. Zeraouli, Impact of load profile and
683 collector technology on the fractional savings of solar domestic water heaters under various climatic conditions,
684 *International Journal of Hydrogen Energy* 42 (18) (2017) 13245–13258.
- 685 [38] A. Jamil, A. Benbassou, et al., Review on solar thermal stratified storage tanks (stst): Insight on stratification
686 studies and efficiency indicators, *Solar Energy* 176 (2018) 126–145.
- 687 [39] Y. Agrouaz, T. Bouhal, A. Allouhi, T. Kousksou, A. Jamil, Y. Zeraouli, Energy and parametric analysis of solar
688 absorption cooling systems in various moroccan climates, *Case Studies in Thermal Engineering* 9 (2017) 28 –
689 39. doi:<https://doi.org/10.1016/j.csite.2016.11.002>.
690 URL <http://www.sciencedirect.com/science/article/pii/S2214157X16300454>
- 691 [40] E. Bellos, C. Tzivanidis, K. A. Antonopoulos, Exergetic, energetic and financial evaluation of a solar driven
692 absorption cooling system with various collector types, *Applied Thermal Engineering* 102 (2016) 749–759.
- 693 [41] Y. El Mghouchi, T. Ajzoul, A. El Bouardi, Prediction of daily solar radiation intensity by day of the year in
694 twenty-four cities of morocco, *Renewable and Sustainable Energy Reviews* 53 (2016) 823–831.
- 695 [42] T. Kousksou, A. Allouhi, M. Belattar, A. Jamil, T. E. Rhafiki, A. Arid, Y. Zeraouli, Renewable energy potential
696 and national policy directions for sustainable development in morocco, *Renewable and Sustainable Energy
697 Reviews* 47 (2015) 46 – 57. doi:<http://dx.doi.org/10.1016/j.rser.2015.02.056>.
698 URL [//www.sciencedirect.com/science/article/pii/S1364032115001458](http://www.sciencedirect.com/science/article/pii/S1364032115001458)
- 699 [43] O. Iken, M. Dlimi, R. Agounoun, I. Kadiri, S. ed Din Fertahi, A. Zoubir, K. Sbai, Numerical investigation of
700 energy performance and cost analysis of moroccan’s building smart walls integrating vanadium dioxide, *Solar
701 Energy* 179 (2019) 249 – 263.
- 702 [44] T. Bouhal, S. ed Din Fertahi, Y. Agrouaz, T. E. Rhafiki, T. Kousksou, Y. Zeraouli, A. Jamil, Technical assess-
703 ment, economic viability and investment risk analysis of solar heating/cooling systems in residential buildings
704 in morocco, *Solar Energy* 170 (2018) 1043 – 1062. doi:<https://doi.org/10.1016/j.solener.2018.06.032>.
705 URL <http://www.sciencedirect.com/science/article/pii/S0038092X18305838>
- 706 [45] J. A. Duffie, W. A. Beckman, *Solar engineering of thermal processes*, John Wiley & Sons, 2013.
- 707 [46] R. L. Oonk, D. E. Jones, B. E. Cole-Appel, Calculation of performance of n collectors in series from test data
708 on a single collector, *Solar Energy* 23 (6) (1979) 535–536.
- 709 [47] T. Kousksou, P. Bruel, G. Cherreau, V. Leousoff, T. E. Rhafiki, {PCM} storage for solar dhw: From an
710 unfulfilled promise to a real benefit, *Solar Energy* 85 (9) (2011) 2033 – 2040. doi:[https://doi.org/10.1016/
711 j.solener.2011.05.012](https://doi.org/10.1016/j.solener.2011.05.012).
712 URL <http://www.sciencedirect.com/science/article/pii/S0038092X11001927>
- 713 [48] A. Baniassadi, M. Momen, M. Amidpour, A new method for optimization of solar heat integration and solar
714 fraction targeting in low temperature process industries, *Energy* 90 (2015) 1674–1681.
- 715 [49] A. Madhlopa, C. Johnstone, Model for computation of solar fraction in a single-slope solar still, *Solar Energy*
716 83 (6) (2009) 873–882.
- 717 [50] A. Moià-Pol, V. Martínez-Moll, R. P. Nadal, J. M. R. Serra, Solar thermal potential for collective systems in
718 palma beach (balearic island’s), *Energy Procedia* 48 (2014) 1118 – 1123, proceedings of the 2nd International
719

- 720 Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2013). doi:<https://doi.org/10.1016/j.egypro.2014.02.126>.
- 721
- 722 URL <http://www.sciencedirect.com/science/article/pii/S1876610214003889>
- 723 [51] C. Fraga, F. Mermoud, P. Hollmuller, E. Pampaloni, B. Lachal, Large solar assisted heat pump systems in
724 collective housing: In-situ monitoring results for summer season, Energy Procedia 48 (2014) 1086 – 1095,
725 proceedings of the 2nd International Conference on Solar Heating and Cooling for Buildings and Industry (SHC
726 2013). doi:<https://doi.org/10.1016/j.egypro.2014.02.123>.
- 727 URL <http://www.sciencedirect.com/science/article/pii/S1876610214003853>
- 728 [52] A. Bertrand, A. Mastrucci, N. Schüler, R. Aggoune, F. Maréchal, Characterisation of domestic hot water end-
729 uses for integrated urban thermal energy assessment and optimisation, Applied Energy 186, Part 2 (2017) 152
730 – 166, energy and Urban Systems. doi:<https://doi.org/10.1016/j.apenergy.2016.02.107>.
- 731 URL <http://www.sciencedirect.com/science/article/pii/S030626191630263X>
- 732 [53] M. d. P. R. Teles, K. A. Ismail, A. Arabkoohsar, A new version of a low concentration evacuated tube solar
733 collector: Optical and thermal investigation, Solar Energy 180 (2019) 324–339.
- 734 [54] L. Zhou, Y. Wang, Q. Huang, Cfd investigation of a new flat plate collector with additional front side transparent
735 insulation for use in cold regions, Renewable Energy 138 (2019) 754–763.