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Variable-volume storage systems for solar heating and cooling system: a case study for different Italian climates

Annamaria Buonomano[a], Francesco Calise[a]*, Gabriele Ferruzzi[b], LauraVanoli[b]

[a]*DII- Univ. of Naples Federico II, P.leTecchio 80, 80125 Naples, Italy*
[b]*DiT- Univ. of Naples Parthenope, Centro Direz. IS.C4, 80143 Naples, Italy,*

Abstract

This paper analyzes different control strategies for the thermal storage management in Solar Heating and Cooling systems (SHC) for different Italian climates. This novel thermal storage system consists in a variable volume storage tank system, which includes three separate tanks and a number of mixers and diverters. Such devices are managed through two different control strategies, based on combinations of series/parallel charging and discharging approaches. Thus, it is possible to vary the thermal storage capacity as a function of the combinations of solar radiation availability and user thermal/cooling energy demands. The system allows one to either increase or reduce the number of active tanks when the occurring mismatch between the solar energy supply and the user demand is either high or low, respectively. In addition, the surplus of solar energy is used through a heat exchanger included in the solar loop for the production of Domestic Hot Water (DHW). This novel variable-volume storage system, in all the proposed configurations, is also compared with a constant-volume storage system from the energetic and economic points of view. In addition, in order to determine the set of the synthesis/design variables which maximize the system profitability, a parametric analysis is implemented. A case study developed for an office building located in different Italian climatic areas is also presented. Simulation results show that the analyzed SHC systems system configurations may be profitable for all those cases and weather locations in which a sufficiently high solar fraction is achieved.

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Keywords: Solar heating and cooling, storage system.

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* Corresponding Francesco Calise, Tel: +39-081-7682301; fax: +39-081-2390364
*E-mail address:*frcalise@unina.it

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Nomenclature

AH	Auxiliary gas fired Heater
ACH	Absorption CHiller
C	Capital Cost [€]
DHW	Domestic Hot Water
ETC	Evacuated Tube solar Collectors
F_{sol}	Solar fraction [-]
G	Global horizontal solar radiation [kW/m^2]
MTS	Multi-Tanks System
PE	Primary Energy [kWh]
PES	Primary Energy Saving [-]
Q	Heat [kWh]
SHC	Solar Heating and Cooling
SPB	Simple Pay Back
T	Temperature [°C]
TK	Tank

Subscripts

ACH	Referred to absorption chiller
AH	Referred to auxiliary heater
DHW	Referred to domestic hot water
cool	Cooling
heat	Heating
incent	Referred to public funding
SC	Referred to solar collector field
set	Referred to set point
SHC	Referred to solar heating and cooling
s	Referred to summer season
th	Referred to thermal energy
tot	Total
w	Referred to winter season

1. Introduction

In a Solar Heating and Cooling (SHC) system, the solar irradiation incident on a solar collector field is converted in both heating and cooling energy. This technology is very promising for its summer operation mode, when the cooling energy demand is often simultaneous to the availability of solar radiation. Although the international organizations efforts to promote of the use of this renewable energy technology, solar heating and cooling systems are still at the margin of the market. From this point of view, in the last decade, in order to support the implementation of SHC technologies and reducing the relative costs, many solar technology design tools have been produced. For this purpose, advanced modeling and simulation tools of SHC plants play an important role for analyzing and optimizing the system layout, the control strategy and the components operation [1]. Many authors investigated the SHC performance from the energetic, economic and environmental points of views. In particular, these analyses were performed by means of dynamic simulations and optimization procedures, performed by varying the main system design parameters (storage tank volume, collector area, etc.) [2, 3]. These simulation were developed with the help of either simulation model implemented in commercial software (such as [2, 4]) or detailed mathematical models purposely developed [5, 6]. In order to define the optimal design parameters of the SHC systems as a function of the building and climate, several analysis and multi-objective optimizations were also developed [4, 7]. While all the above mentioned works were developed implementing very similar system layouts, further research projects aim to develop innovative solar cooling systems, based on emerging technologies and innovative SHC configuration, such as concentrating solar collectors and double effect absorption chillers, fuel cells, etc., as reported in references [8-16]. All these topics have also been widely investigated by some of the authors. They presented many research works focused on the thermo economic optimization of conventional and innovative SHC system configurations for specific applications and climates [8, 9, 16, 17]. In all these studies, authors found out that a large amount of the thermal energy produced through the solar field is often not used for space heating and cooling. This occurs when the storage capacity is full and/or no thermal demand is required by the user during the supply of solar thermal energy. In general, in this case the surplus of thermal energy is used for the Domestic Hot Water (DHW) production. However, when the produced DHW is higher than the user demand, the exceeding thermal energy must be rejected. On the contrary, in case of scarce solar availability and/or of high user thermal demand, the storage tank temperature level may be not sufficient to activate the SHC system, thus auxiliary devices (boilers, heat pumps, engines, fuel cells, etc.) must provide the demanded energy. These circumstances highlight the key role of the thermal storage system and the necessity of selecting the optimal system volume and of adopting control strategy to adequately store the heat produced through solar collectors. From this point of view, performed parametric studies and optimizations showed that by only varying the tank volume during the SHC system operation a minor improvement of the system performance can be obtained. As a consequence, in several studies [9, 11, 14], some of the authors analyzed how to improve the SHC system performance by using double storage tank systems (as a function of the heating and cooling season). Therefore, in reference [18] the authors investigated and optimize the operation and performance of a SHC system with the help of a novel variable volume storage system. However, in reference [18], for the specific case study relative to an office building located in Southern Italy, authors concluded that despite this improvement, marginal savings can be achieved. From this point, in order to provide design and operating guidelines, in the presented work the performance of variable volume tank systems applied to the same SHC system configuring is analyzed as a function of the climate. Thus, with the aim at determining the set of the synthesis/design variables maximizing the system profitability, a parametric analysis for a case study concerning an office building located in four different Italian climatic areas is developed and here presented.

2. Thermal storage system

The SHC systems performances highly depend on the simultaneity between the solar availability and the heating and cooling demands. Therefore, in order to balance the energy requirements as well as to a limit the mismatch occurring between supply and demand, it is necessary to exploit as much as possible the solar energy. From this point of view, thermal storage is a very important link in any solar thermal supply network. Several studies have been carried out on Sensible Heat Storage (SHS) systems in order to improve its overall efficiency. An important role on thermal storage capacity is played by the temperature stratification phenomena, on which effective charging and discharging of the energy stored depend [19]. In a SHC system, the appropriate selection of the thermal storage systems is crucial to overcome the disadvantage of the intermittent nature of solar energy and variation of cooling demand. The enhanced utilization of solar energy and other consequences of thermal storage integrated systems have gained the attention of researchers in the recent years. In reference [20] a review in the field of solar cooling techniques, solar collectors, storage methods and their integration is presented. The selection of the storage technique depends on: energy to be stored per unit volume; the weight of the fluid; operative temperature range. In the present paper, in order to maximize the energy storage, to be supplied to a conventional SHC plant, the sensible heat storage technique is adopted. In particular, a Multi-Tanks System (MTS) has been implemented and compared to a single tank plant. Since the utilization of MTS is considered attractive in those systems where large storage tanks cannot be installed and/or the storage volume must be divided in several compact tanks [21], also depending on the winter and summer season, several case studies have been investigated. Therefore, in order to investigate the effect of the ratio between heating and cooling demands depending on the weather climate, four Italian weather locations (Bozen, Turin, Rome and Palermo) were selected. Two control strategies are implemented with the aim at managing the MTS. The results are also compared with those relative to a conventional single tank SHC system.

3. System layout

The layout of the proposed SHC system is schematically shown in Fig. 1. Such system configuration is similar to the one analyzed in reference [18], where additional details can be found. Thus, the system operating principle will be here only briefly summarized. All the components included in this system layout are diffusely presented and detailed described in previous works developed by some of the authors [8, 9, 11, 13, 14, 18]. The difference between the systems taken into account lies in the thermal storage option, such as a single SHS tank and a MTS. These systems include the following main components:

- a Solar Collector field, SC, consisting of Evacuated Tube Collectors, ETC, heating the Solar Collector Fluid (SCF);
- a LiBr-H_2O single-effect Absorption CHiller (ACH), whose generator is fed by the Hot Fluid (HF), heated up by the SC field; its condenser and absorber are cooled through the Cooling Water loop (CW) provided by the closed-circuit Cooling Tower (CT); the evaporator supplies CHilled Water (CHW) for space cooling demands;
- a gas-fired Auxiliary Heater (AH), providing auxiliary thermal energy to the HF;
- a fixed-volume Pump (P1) for the HF loop; a variable-speed Pump (P2) for the SCF loop; a fixed-volume Pump (P3) for the CW loop; a fixed-volume Pump (P4) for the CHW loop;

- two plate-fin Heat Exchangers (HE1) and (HE2) in the HF and in the solar loops, respectively. The first one transfers heat from the HF to the Hot Water (HW) to be supplied to the fan-coils during the winter, while the latter produces DHW when the solar irradiation is higher than the ACH (or HE2) thermal demand;
- Pipes, mixers, diverters, valves, and controllers required for the system operations.

Through TRNSYS the dynamic simulation of the complete model (including components for running simulations and processing data such as controllers, schedulers, weather databases, printers, integrators, etc.) of this SHC plants are performed [22]. Details regarding the operating principle and the controls strategies of the system are extensively provided in [23]. It must be also said that the same building test case (office building with thermal demand for a fitness centre) used in previous analyses [18] is here considered. The considered domestic hot water daily demand was set at 25 m^3/day at 45 °C.

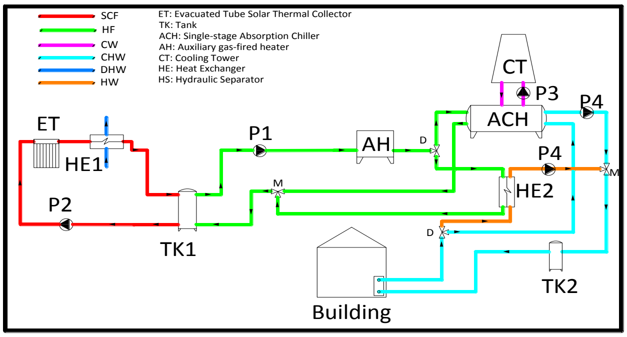


Fig. 1– System layout

4. System model

In order to simulate the proposed SHC systems the dynamic simulation software TRNSYS was used. The TRNSYS software includes a large library of built-in components, often validated by experimental data [22]. As above mentioned, the SHC system layout is the same previously developed in [18], where built-in and user-developed components, as well as the energy savings and economic models, are described in detail. Note that, the energy and economic analyses were performed evaluating the eventual savings achieved by the SHC plants vs. a conventional system, which is obtained from the layout above described by removing the solar collector field SCF, (Fig. 1). Therefore, in this section only a brief description of the strategy of the Multi-Tank System (MTS) is provided.

4.1. MTS strategy

In this SHC plant a MTS consisting of three tanks connected in different serial/parallel configurations. The interconnection between the tanks is a relevant problem. Different solutions can be selected for the charging and discharging sides, as analyzed in [24, 25]. Both the parallel and series storages connections can thermally stratify to various degrees [26].

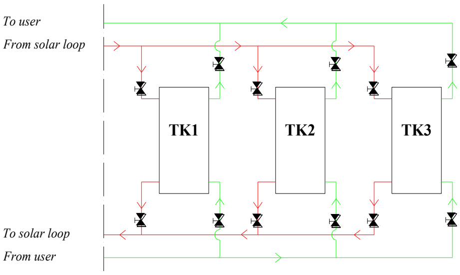


Fig. 2 - MTS proposed layout strategy

Three different working modes are described and analyzed, they are i) charging and discharging in series, ii) charging and discharging in parallel, iii) charging in series and discharging in parallel. Further details can be found in [18, 25].

In this paper the novel configuration for MTS proposed in [18] is adopted (Fig. 2). It consists in a cascade and parallel connection on the charge side, where only one tank at time can be charged, according to a fixed set-point. On the discharging side, a parallel connection is made. Here, only the tanks with a temperature higher than a fixed set point are in discharging mode. Thus, in charging mode only one tank is active, while in discharging mode all the tanks over a fixed temperature can operate. The mass flow in discharging mode is equally distributed. A comparison between our strategy and the one with charging in series and discharging in parallel is also performed.

5. Results

As above mentioned, the aim of this work is the analysis of SHC systems equipped with different types of storage systems. To this scope several case studies were developed. Here, complete energy and economic analyses were performed for the three above described SHC configurations:

A. Single Tank;
B. Multi Tank system, proposed parallel charging/discharging strategy;
C. Multi Tank system, series charging and parallel discharging strategy.

In reference [18], authors concluded that, for the investigated case study (relative to Naples climate), in terms of savings of primary energy and auxiliary heat, marginal savings were achieved by the parallel charging/discharging multi-tank system strategy compared to the other cases. However, among all the three investigated storage strategies, a marginal improvement and no significant difference were observed from the energetic and economic points of view, respectively. The aim of this paper is the analysis of the effects of the MTS on the overall SHC system performance as a function of the weather. From this point of view, the weather data are referred to four Italian cities, two of them located in the North, Bozen (Lat. 46° N, 2791 HDD, North-Est) and Turin (Lat. 45° N, 2671 HDD, North-West), and one of them in the Central, Rome (Lat. 41° N, 1415 HDD) and the last one in the South, Palermo (Lat. 38° N, 751 HDD), representative of the main Italian climates. The case studies were developed for an office building with square area of 1600 m^2 and height of 4 m. Additional data regarding the envelope, lights, equipment and scheduling are reported in reference [18]. For a better comparison, for each weather location, the same solar collector field area of 100 m^2 is used.. For all the cases the target temperature for the solar field is set at 90°C for summer (maximum allowed 93°C inside the tank) and 60 °C for winter (maximum allowed 63°C). Inside the tanks a minimum temperature of 40°C and maximum ones of 93°C (summer) and 63°C (winter) are allowed. The activation temperature of the HE1 (for DHW production) is set at 100 °C (in order to avoid the boiling temperature inside the tank), whereas the activation of the AH is set at 50 and 85°C in winter and summer, respectively. Further details as well as the economic conditions of the study presented are reported in reference [18]. For each case study, the performance of the systems Case A, B and C listed before were compared. It must be noted that all the systems are simulated by assuming the same system parameters (collector area, fluid flow rates, set point temperatures, etc.). In particular, in each case the same total storage volume is considered: the single tank included in layout A is 3 m^3, while in case of systems Case B and C two tanks (TK1 and TK2, Fig. 2) of volume 0.9 m^3 and one of 1.2 m^3 (TK3, Fig. 2) are designed. As above reported, the MTS operates a switch between the three different tanks included in the layout in order to optimize the storage system [27]. The dynamic operation of the system were detailed reported and commented in reference [18], where the MTS capability, as well as tanks average temperatures, can be clearly shown. Since dynamic trends reflect the operation of the system, all the systems studied in the presented paper report similar dynamic trends of those of reference [18]. On the other hand, depending on the weather, the variation of the results, as well as different energy and economic trends, could be expected during the year. The two parameters that mostly influence the heating and cooling demand and the productivity of the ETC solar field are the external temperature and the availability of solar radiation. They are crucial in order to achieve a good profitability of the SHC system. The availability of solar radiation varies among the selected cities and it fluctuates during the year. This is clearly shown in Fig. 3a, where the weekly average global horizontal solar radiation for the considered cities is shown. Here, it is clearly shown that, for most of the time, Palermo and Bozen are the cities with the highest and lowest radiation, respectively. Fig. 3b shows the average temperatures of each city during the system operation time. Since the external temperature highly influences the building energy demands, comparing the considered cities very different heating demands (with the exception of Bozen vs. Turin, since their winter average temperatures are similar) and comparable cooling ones are expected.

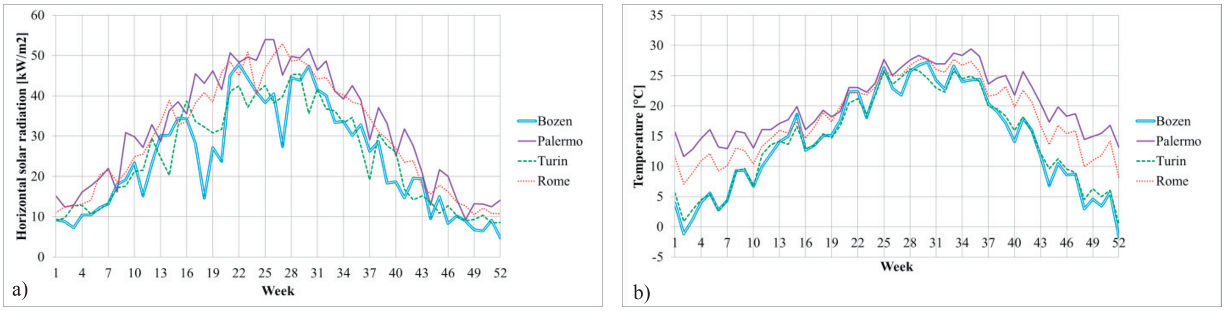
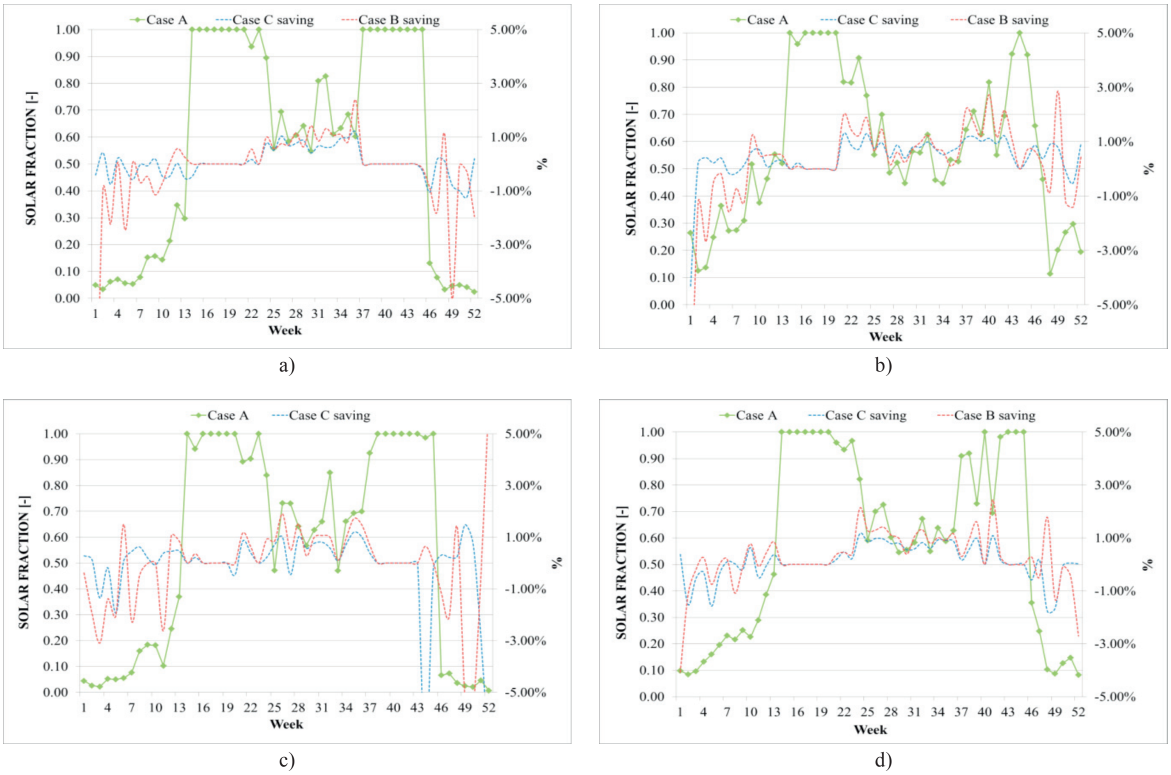


Fig. 3 - a) Average global horizontal solar radiation and b) daily average external temperatures for the selected cities

In particular, the selection of the appropriate storage system significantly affects the auxiliary heat supplied by the gas-fired boiler. The aim of this storage system configuration is the reduction of natural gas usage, for a fixed area of the solar field and for a fixed building cooling and building demand. Therefore, in this paper, the systems weekly solar fraction F_{sol} (ratio between the amount of thermal energy provided by the sun and the thermal energy demanded by the user) trends are here shown. This is shown in Fig. 4 where for the locations of a) Turin, b) Bozen, c) Palermo and d) Rome, the weekly F_{sol} obtained for the Case A and the relative deviation of the F_{sol} of Case B and Case Care shown. Fig. 4a is relative to the simulation of the Turin case study. The graph shows a very low F_{sol} during the winter weeks as a consequence of the simultaneous high space heating demand and low solar radiation. This implies that a large amount of auxiliary heat is provided during these weeks. A significant amount of auxiliary heat is also provided during the summer, where the F_{sol} is about 0.65, as a consequence of the increasing space cooling demands. Conversely, during the middle seasons (April, May, September and October), the F_{sol} is almost always equal to 1.00, thus the amount of auxiliary heat is almost always negligible. The graph also shows that the MTS strategy C allows the system to averagely reach similar F_{sol} of strategy A during the winter weeks. A slight better performance (deviation about 1.00%) of strategy C compared to strategy A is obtained during the summer weeks. Case B shows worse performance (compared to those of Case C) during the cold weeks and better performance during the those of the summer season, especially from the 27th to the 38th week of the year. Thus, for Case C the saving of auxiliary heat compared to that one of Case A is higher during the summer season, whereas it is marginal during the cold weeks. Conversely, during the cold weeks of the winter the storage system of Case B determines a slight increase in natural gas consumption with respect to the case A. Therefore, it can be concluded that the strategy B is efficient only during the weeks where the F_{sol} is high. On the other hand, strategy C, which is claimed in literature being more profitable in case of solar thermal systems, shows a slight worse performance when compared with the fixed volume storage tank, Case A. A very comparable trend is observed in Bozen, Fig. 4b, due to the similar weather. The results before discussed can be also applied to all the warmer weather locations here analyzed. In particular, passing from a cold climate (Turin, Fig. 4a) to a warm one, e.g. Palermo of Fig. 4c and Rome of Fig. 4d, it is possible to observe that during the summer weeks, where the F_{sol} decreases due to the high thermal energy demand, Case B performs better than all the other cases, as before observed for the colder weather locations. However, in Palermo, Fig. 4c, during the winter weeks the strategy of Case C results to be the more advantageous among those compared; the contrary occurs in Rome, Fig. 4d, where Case B performs better than Case C. However, in Rome, for both Cases B and C, the winter F_{sol}s are averagely lower than the one achieved through the single tank strategy of Case A. Strategy B allows one to achieve a slightly better performance than Case A and C during the summer. For all the investigated locations, as expected, solar thermal production significantly increases during the summer weeks as a consequence of the simultaneous increase of the solar radiation and of the collector efficiency (higher radiation, lower temperature difference between collector and environment). Both strategies B and C allow one to improve the performance of the solar collector. As a consequence, an higher solar collector efficiency is observed. This circumstance occurs often during summer for Case B where the solar thermal production is slightly higher than the one produced in Case C. Thus, for all the weather locations Case B strategy shows the best performance in terms of higher solar fraction and solar thermal energy production.



a) b) c) d)

Fig. 4 - Solar fractions of Case A and deviation of Case B and Case C in a) Turin b) Bozen c) Palermo d) Rome

This conclusion can be also observed by analyzing the annual energy and economic results. They are reported in Table 1 for all the system configurations and weather locations. In this table, it is possible to see that for the considered office building the heating requirements ($Q_{th,tot}$) are always higher than the cooling ones ($Q_{cool,tot}$). As a consequence, although the better performance of Case B strategy during summer, the differences among all the three investigated system are marginal. The better performance of Case B can be observed for all the weather locations, through the lower annual auxiliary thermal energy productions (Q_{AH}) (only relative to space heating and cooling scopes) always obtained. It must be said that the marginal Q_{AH} differences among the three cases mostly depend on the average winter solar fractions ($F_{sol,w}$) achieved by the Case B strategy, that are always lower than those obtained with Cases A and C strategies. It must be noted that, as before reported, for each weather locations investigated, although the summer solar fraction $F_{sol,s}$ of Case B is higher than those of Cases A and C, the demand of cooling energy is remarkable lower than the heating one. An interesting result concerns the DHW production. As discussed in reference [18], DHW is produced only when the storage systems reaches the set point temperature and no other way to store the thermal energy produced by the solar field exists. In this case the surplus of solar energy is used to produce DHW. DHW production is used in replacement of the conventional dissipative cooling coil used in solar systems. Therefore, the eventual heat in excess is nor dissipated but it is used for DHW production. As a consequence, it is expected that solar DHW production increases in all the locations where the need of Q_{AH} is scarce, i.e. where solar thermal energy availability is averagely higher than the user demand. Here, the use of MTS significantly reduces the solar production of DHW. In fact, the use of both strategies B and C reduces the maximum temperature of the fluid exiting from the solar field, reducing also the possibility of storing it for DHW scopes [18].

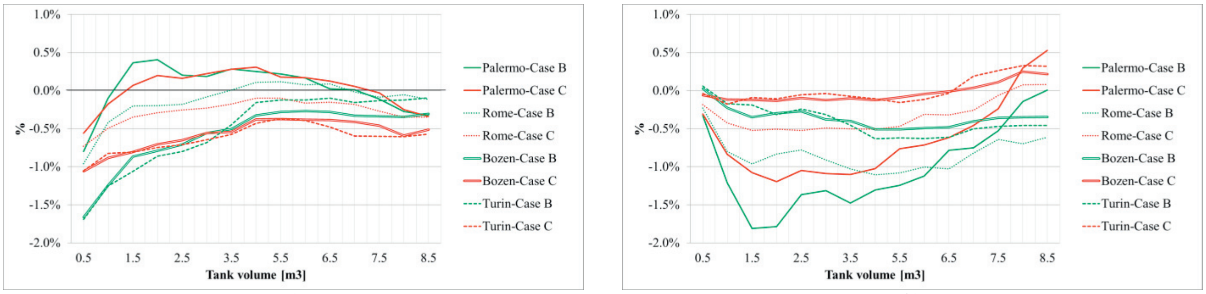
Thus, the heat that is not used for DHW production will be more efficiently delivered for space heating and cooling purposes, also determining a simultaneous reduction of the natural gas consumed by the AH. Both MTS systems of Cases B and C determine a significant decrease of the ratio between the thermal energy delivered to the DHW (Q_{DHW}) and the thermal energy produced by the solar collector ($F_{DHW} = Q_{DHW} / Q_{SC}$). However, the production of DHW requires additional thermal energy, therefore, Case B compared with the reference system Case A does not determine any improvement in terms of overall savings of primary energy (PES) for the reasons above discussed. As a consequence, it must be considered that system B produces a lower amount of DHW with respect to the both Cases B and C, counterbalancing the savings in terms of primary energy (PE), which is only relative to space heating and cooling. Thus, in terms of PES, the savings obtained during the middle and the summer seasons are partly counterbalanced by the higher consumptions achieved during the winter and the DHW production.

Table 1. Energy and economic annual results

	Rome			*Palermo*			*Bozen*			*Turin*			
Case	A	C	B	A	C	B	A	C	B	A	C	B	
$Q_{th\ tot}$	207628	207553	207569	138494	138485	138497	273557	273495	273515	270133	270202	270112	*kWh/year*
$Q_{cool\ tot}$	-127937	-127934	-127902	-124841	-124838	-124841	-115066	-115068	-115068	-117829	-117828	-117824	*kWh/year*
G	196563	196563	196563	204586	204586	204586	155830	155830	155830	159552	159552	159552	*kWh/year*
PE	138290	137601	137021	102105	101000	100765	215341	215060	214514	201557	201468	200912	*kWh/year*
Q_{SC}	85434	84675	84540	91218	90628	90355	61147	60612	60476	62078	61510	61312	*kWh/year*
Q_{AH}	118925	118333	117834	87806	86856	86654	185189	184947	184477	173334	173258	172780	*kWh/year*
$Q_{th\ ACH}$	39394	39394	39394	64027	64027	64027	26523	26523	26523	23720	23720	23720	*kWh/year*
$Q_{cool\ ACH}$	32149	32149	32149	52131	52131	52131	21654	21654	21654	19364	19364	19364	*kWh/year*
Q_{DHW}	46551	43033	42536	42543	38829	38400	33326	30453	30115	33668	30762	30447	*kWh/year*
$F_{sol,s}$	0.7473	0.7505	0.7524	0.6570	0.6604	0.6614	0.7604	0.7629	0.7650	0.7775	0.7803	0.7818	-
$F_{sol,w}$	0.1786	0.1781	0.1781	0.3081	0.3079	0.3062	0.0746	0.0745	0.0741	0.0881	0.0878	0.0871	-
F_{DHW}	0.5449	0.5082	0.5032	0.4664	0.4284	0.4250	0.5450	0.5024	0.4980	0.5423	0.5001	0.4966	-
PES	0.6396	0.6538	0.6394	0.6850	0.7019	0.6835	0.3785	0.3897	0.3789	0.4250	0.4368	0.4254	-
ΔC	17237	17471	17226	14124	14348	14103	15679	15883	15681	16364	16573	16362	*€/year*
ΔC_{inc}	51879	52891	51854	43747	44703	43663	39047	39944	39076	42605	43536	42620	*€*
SPB	14.38	14.19	14.39	17.55	17.27	17.57	15.81	15.60	15.81	15.15	14.95	15.15	*years*
SPB_{inc}	4.777	4.686	4.780	5.665	5.544	5.676	6.347	6.205	6.343	5.817	5.693	5.815	*years*

From the economic point of view, no significant difference is observed among Cases A, B and C. In fact, variations of the main energetic and economic parameters are marginal and do not determine any important improvement. Therefore, these results suggest that for the specific case study developed in this paper, the MTS systems do not determine significant improvements in economic and energy efficiencies.

In other words, as for the considered case study, the proposed MTS system may be efficient only when the solar fraction is sufficiently high (during summer for this case study), whereas when the solar fraction is low (during winter) the usefulness of the proposed MTS is marginal. Furthermore, this paper also includes a sensitivity analysis performed with the scope to evaluate the effects of the variations of the main synthesis/design parameters on the performances of the three considered system layouts. This analysis has been performed for systems A, B and C, varying the total storage volume. In reference [18] to higher tank volume corresponds an higher solar fraction. In these studied climates the trend is confirmed. In the following figures the Case B and C variation by Case A of the solar fraction (Fig. 5a) and the auxiliary thermal energy production (Fig. 5b) due to the variation of the tank volume are reported. In all the cases system B determines the higher F_{sol}, Fig. 5a. In Fig. 5b the variation of the Q_{AH} vs. the tank volume is also reported. As expected, given a tank volume, the higher the F_{sol}, the lower the Q_{AH}. However, this sensitivity analysis shows the very slight dependence of the auxiliary energy production on the tank volume. In particular, in the considered range of variation, a maximum saving of about 2 % can be achieved. These results suggest that a MTS system may be profitable, from the energetic point of view, for all those building-plant systems located in climates where high solar fractions can be obtained.



a) b)

Fig. 5 - F_{sol}s (a.) and Q_{AH} (b.) sensitivity analyses: Case B and Case C vs. Case A

6. Conclusions

In this paper the investigation of different control strategies for the thermal storage management in Solar Heating and Cooling systems (SHC) as a function of the weather is presented. The dynamic simulation of the system behavior is performed by means of a zero-dimensional transient simulation model developed in TRNSYS. A novel thermal storage system, consisting in a multi-tanks system (MTS), is investigated and compared to a single tank plant. In particular, three multi-tanks SHC configurations, with the same overall storage volume, are considered: i) single tank, ii) multi-tank system consisting of three tanks working in a parallel charging/discharging mode; iii) multi-tank system consisting of three tanks working in a series charging and parallel discharging mode. The SHC system under investigation is based on a field of evacuated solar collectors coupled with a single-stage LiBr-H_2O absorption chiller; the auxiliary thermal energy is supplied by a gas-fired boiler.

In this paper, two novel multi-tanks system strategies are evaluated with the aim at managing the MTS thermal storage capacity as a function of the combinations of solar radiation availability and user thermal/cooling energy demands. In order to provide design and operating guidelines, case studies for four Southern and Northern Italy locations are presented. Simulation results show that, in terms of primary energy, which only includes the consumptions due to heating and cooling scopes, a better management of the storage volume is achieved by adopting the parallel charging/discharging operation strategy compared to the single tank of the first configuration. On the contrary, the adoption of a series charging and parallel discharging operation strategy does not determine any significant difference in the operation with respect to the single tank layout. Results also show that by the innovative storage systems a reduction of the auxiliary heat supplied by the natural gas heater can be achieved. However, this system resulted to be efficient only during the weeks where the ratio between the amount of thermal energy provided by the sun and the thermal energy demanded by the user is high. This finding is also connected to the increase of the solar collector efficiency, due to the slight reduction of the solar collector fluid inlet temperature achieved by using a MTS. The adoption of parallel or series MTS strategies also reduces the maximum temperature of the fluid exiting from the solar field, determining a more efficient use of heat produced by the solar field and a simultaneous reduction of the natural gas consumed by the auxiliary heater. On the other hand, lower consumptions of natural gas for the heating and cooling demands are partly counterbalanced by higher ones for the domestic hot water production.

In conclusion, simulation results show that in terms of savings of primary energy and auxiliary heat, a MTS system may be profitable for all those cases and weather locations in which a sufficiently high solar fraction can be achieved. No significant differences are observed among all the three investigated cases and locations from the economic point of view. In particular, besides the installation advantages that this modular system offers, the analyzed MTS systems do not determine significant improvements in terms of economic and energetic SHC system efficiencies.

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