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ScienceDirect
Energy Procedia 81 (2015) 1 – 10
Energy Procedia

69th Conference of the Italian Thermal Engineering Association, ATI 2014

Dynamic simulation of outdoor swimming pool solar heating

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Abstract

This paper presents a dynamic model of a "passive" solar heating system composed by horizontal solar flat collectors coupled to an outdoor swimming pool. The numerical model has been developed by using the Matlab/Simulink environment and it allows to predict on a hourly basis the thermal energy collected by the solar panels, the inlet/outlet collector working fluid temperature, the pool water temperature and the system efficiency. As a case study, three different pools characterized by different dimensions and three different flat solar collectors (unglazed, glazed and evacuated collectors) have been considered. The Simulink model allows to estimate the warm-up period of the swimming pool as a function of the characteristics of the pool and of the solar collectors. It has been demonstrated that, by using the model, the designer can make the optimal sizing of the solar heating system in order to obtain a water pool temperature ranging within a fixed interval. The results demonstrate that unglazed collectors are appropriate for this kind of use and evacuated collectors can be useful just in case of very big swimming pools in order to reduce the absorbing area of the solar panels.

Peer-review under responsibility of the Scientific Committee of ATI 2014
Keywords: dynamic simulation; Matlab/Simulink; solar hot water system; uncovered swimming pool; solar energy; solar collectors.

1. Introduction

Nowadays, the designers of thermal plants are helped in their work by a series of software able to simulate the dynamic behavior of thermal plants following the hourly evolution of the significant status parameters. Energy+, ESP-r, TRNSYS are just some example of famous and diffuse dynamic codes for HVAC. The modeling of a thermal plant in these codes obeys to a common rule: any thermal plant can be considered as a set of simple elements and

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Peer-review under responsibility of the Scientific Committee of ATI 2014
doi:10.1016/j.egypro.2015.12.053

hence could be sub-divided into blocks (compartment approach). In this paper, a numerical model of a hydronic solar heating system coupled to an outdoor swimming pool based on a series of customized blocks made by using Matlab/Simulink is presented. This kind of approach can be a powerful tool in order to study the interactions between the containment building and the thermal plant and to calculate accurately the thermal loads, as demonstrated by Morini and Piva [1-2] and more recently in [3-6].

Outdoor swimming pools are generally used during the summer season when the outdoor temperature is larger than 22-24°C and the daily average solar radiation is high; in these conditions it is possible to use solar thermal collectors in order to compensate the heat losses of the swimming pool and to maintain the temperature of the pool water within a fixed range ($T_{sp,min}$-$T_{sp,max}$). As an example, for swimming pools used for competitive sport activities, the CONI Resolution n. 855 [7] suggests to maintain the water temperature between 26°C ($T_{sp,min}$) and 32°C ($T_{sp,max}$); this range of temperature is considered optimal in order to obtain thermal comfort for pool users and to avoid the proliferation of microorganisms. The use of Simulink, for a fixed area of solar collectors, enables to calculate the hourly trend of the swimming pool water temperature during the whole summer for a fixed location if one uses the climatic hourly data of this location as input data. This kind of result cannot be obtained by using "integral" approaches, like the F-chart method [8] suggested by the European standard UNI EN 15316-4-3 [9] and the Italian standard UNI/TS 11300-4 [10]. In fact, by using the F-chart method it is possible to obtain only monthly average data, like the average monthly value of the solar coverage factor defined as the ratio between the thermal energy provided by the solar collectors and the thermal energy load needed by the swimming pool during the fixed month.

2. The MATLAB/Simulink model

The numerical analysis of the unsteady behavior of a thermal plant becomes attractive for a designer if the computer code used for this purpose does not require any further programming. In this frame, MATLAB/Simulink presents a series of features which can be considered as ideal for this kind of work; in fact, Simulink is born as an interactive tool for modeling, simulating, and analyzing dynamic systems. It enables the designer to build graphical block diagrams in order to simulate such dynamic systems, and this approach is conceptually robust. Different systems can be studied, like linear, non-linear, continuous time, discrete time, multi-rate, conditionally-executed, and hybrid systems. A hierarchical methodology (top-down or bottom-up) facilitates an intuitive analysis of the model and of the interactions between the components of the system. Simulink is integrated with MATLAB, providing immediate access to an extensive range of analysis and design tools. Morini and Piva [1-2] demonstrated how Simulink can be proficiently used in order to build a "thermal library" for the modeling of HVAC systems. In this work it is shown how solar thermal collectors and swimming pools can be modeled in Simulink. In this way, the performances of a solar heating system composed by flat solar collectors coupled with an uncovered outdoor swimming pool are calculated.

Any given block is modeled by a lumped formulation of the conservation equations [1].

In Fig. 1 the lay-out of the solar heating system of the swimming pool built by using Simulink is shown; three blocks are employed in order to model the system:

- The *Climatic Data* block by means of which the hourly value of the outdoor temperature (T_{ext}) and of the solar radiation on a generic oriented surface (H) are calculated for a fixed location;
- The *Collector* block by means of which the performances of the selected solar thermal collectors are evaluated;
- The *Swimming Pool* block by means of which the main thermal loads (gains and losses) of the pool are calculated.

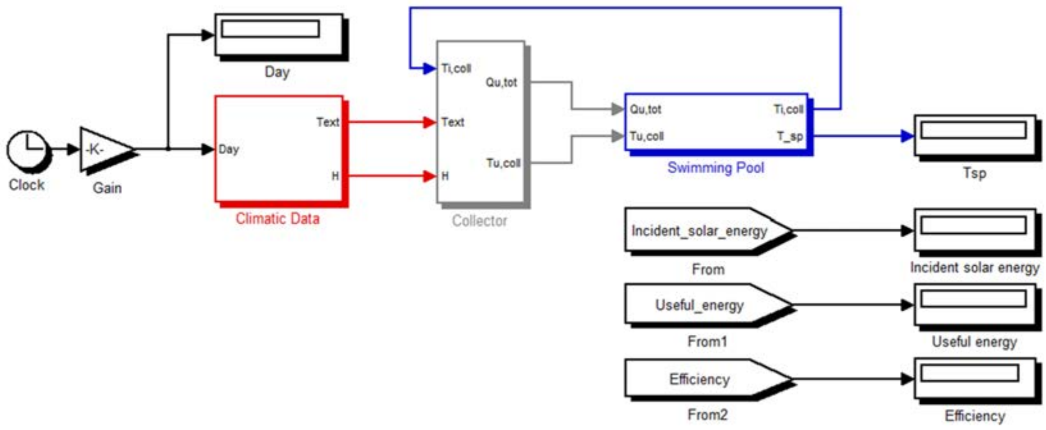


Fig. 1. Lay-out of the Matlab/Simulink developed model

More in detail, the *Climatic data* block elaborates the climatic data obtained by using the Test Reference Year defined by CTI for the main Italian locations [11] (transformed in a MATLAB worksheet) in order to obtain, for a fixed location, the hourly external temperature (T_{ext}), the hourly solar radiation on a horizontal plane (H_0), the hourly outdoor air relative humidity (*RH*) and the hourly wind speed (*W*). Starting from these data, by fixing the geometrical characteristics of the solar thermal collectors, like the azimuth ( ), latitude ( ), albedo ( ) and tilt angle ( ), one can obtain the total incident solar radiation on the collectors (*H*) by following the procedure indicated by the Italian standard UNI/TR 11328-1 [12].

The *Collector* block in Fig. 1 represents the solar thermal collectors of the heating system. Each block can model *N* collectors connected in parallel which have the same inlet temperature of the working fluid. On the contrary, in order to model *M* solar collectors connected in series, *M Collector* blocks must be connected in series in Simulink: in this way the outlet temperature of a *Collector* block is used as input temperature by the following *Collector* block. The input data for the *Collector* block are the total incident solar radiation and the outdoor temperature, both calculated by the *Climatic Data* block, and the inlet working fluid temperature.

The lay-out shown in Fig. 1 is able to model a solar heating system realized by using *N* solar collectors in parallel; in this case, each collector has an inlet working fluid temperature equal to the temperature of the fluid returning from the pool heat exchanger ($T_{i,coll}$). In order to calculate the quantity of heat transferred to the working fluid by the solar collectors ($Q_{u,tot}$) and the outlet temperature of the working fluid by the collectors ($T_{u,coll}$) the block evaluates the instantaneous collector efficiency by means of the following correlation:

$$\eta = \eta_0 - a_1\left(\frac{T_{i,coll} - T_{ext}}{H}\right) - a_2 H\left(\frac{T_{i,coll} - T_{ext}}{H}\right)^2 \quad (1)$$

in which the optical efficiency ($_0$), the first order heat loss coefficient (a_1) and the second order heat loss coefficient (a_2) are input data taken by the technical data given by the manufacturer of the solar collectors. Eq. (1) underlines that the instantaneous collector efficiency is a function of the climatic abscissa, defined as the ratio $(T_{i,coll} - T_{ext})/H$.

By fixing the number of solar collectors connected in parallel (N_c) and by knowing the absorber area of each solar collector (A_{abs}), the useful thermal power collected by solar panels $Q_{u,tot}$ is calculated as follows:

$$Q_{u,tot} = H\eta A_{abs} N_c \quad (2)$$

The outlet water temperature $T_{u,coll}$ can be evaluated by means of a simple energy balance:

$$T_{u,coll} = T_{i,coll} + \left(\frac{Q_{u,tot}}{m A_{abs} N_c C_{pb}} \right) \quad (3)$$

where m is the mass flow rate per total absorber area of the working fluid inside solar collectors (fixed on 0.015 kg/s m^2) and c_{pb} is the specific heat capacity of the working fluid.

The variables $Q_{u,tot}$ and $T_{u,coll}$ are the output of the *Collector* block and they are used as inputs in the *Swimming Pool* block. It is important to observe that, in order to calculate the climatic abscissa, the value of $T_{i,coll}$ is needed; however, the value of the temperature of the fluid returning from the pool heat exchanger ($T_{i,coll}$) is not known until the thermal loads of the swimming pool are not computed. For this reason, this input of the *Collector* block is obtained as output of the *Swimming Pool* block (see the connections among the blocks shown in Fig. 1).

The *Swimming Pool* block developed in Simulink calculates the temperature of the water of the swimming pool (T_{sp}) by means of an energy balance between the heat losses and the heat gains of the pool in which the thermal inertia of the pool water is accounted for.

According to [13] the energy balance equation of the swimming pool can be written as:

$$\frac{d\left(m_{sp} c_{pw} T_{sp}\right)}{dt} = Q_{sol,c} + Q_{sol,p} - Q_{rep} - Q_{cv} - Q_{cd} - Q_{irr} - Q_{ev} \quad (4)$$

where m_{sp} and T_{sp} are the mass and the temperature of the water contained in the pool, respectively, $Q_{sol,c}$ and $Q_{sol,p}$ are the heat gains provided by solar collectors and directly absorbed by the free surface of the swimming pool, respectively, Q_{rep} is the thermal loss due to the water renewal, by following the indications of the national Standards [14], Q_{cv} is the heat loss for convection, Q_{cd} is the heat loss for conduction towards the ground, Q_{irr} is the heat loss due to the radiative heat transfer and Q_{ev} is the thermal loss caused by the water evaporation. In order to solve the differential equation an initial condition on T_{sp} is needed (T_{sp0}). This input data is expressed in Simulink within the integrator block and it is selected by the user. In order to calculate the thermal loads it is important to fix as input the geometrical dimensions of the swimming pool, the pool walls thermal resistance (R_{th}), the ground temperature (T_g), the pool water renewal rate (RR), the aqueduct water temperature (T_{aq}) and the efficiency of the heat exchanger by means of which the working fluid of the solar collectors transfers heat to the water of the swimming pool ( ). In order to close the algebraic loop present in the model, the value of $T_{i,coll}$, that is an input data for the *Collector* block, is calculated by using the following equation:

$$T_{i,coll} = T_{u,coll} - \varepsilon\left(T_{u,coll} - T_{sp}\right) \quad (5)$$

In Fig. 2 the Simulink sub-system used in order to implement the *Swimming Pool* block is represented..

3. Case study

The developed model is used in order to evaluate the efficiency of a solar system coupled to an outdoor swimming pool by considering different kinds of solar collectors and pools. Three different models of solar panels have been selected with different thermal properties: an evacuated collector (EC), a single glazed collector (GC) and an unglazed collector (UC). As a case study three different pools are evaluated through the Simulink model presented in the previous chapter. The geometrical data of each pool are reported in Table 1. The SP1 represents a typical paddling pool, the SP2 is a modeling of a common public swimming pool and the SP3 represents a pool dedicated to competitive sport activities.

The pools are located in Bologna (Italy, 44.47 N; 11.43 E) and the Test Reference Year (TRY) provided by CTI [11] is used as climatic input data. Simulations are carried out for the interval 1st June – 30th August (92 days), considered the standard utilization period for outdoor swimming pools in Italy.

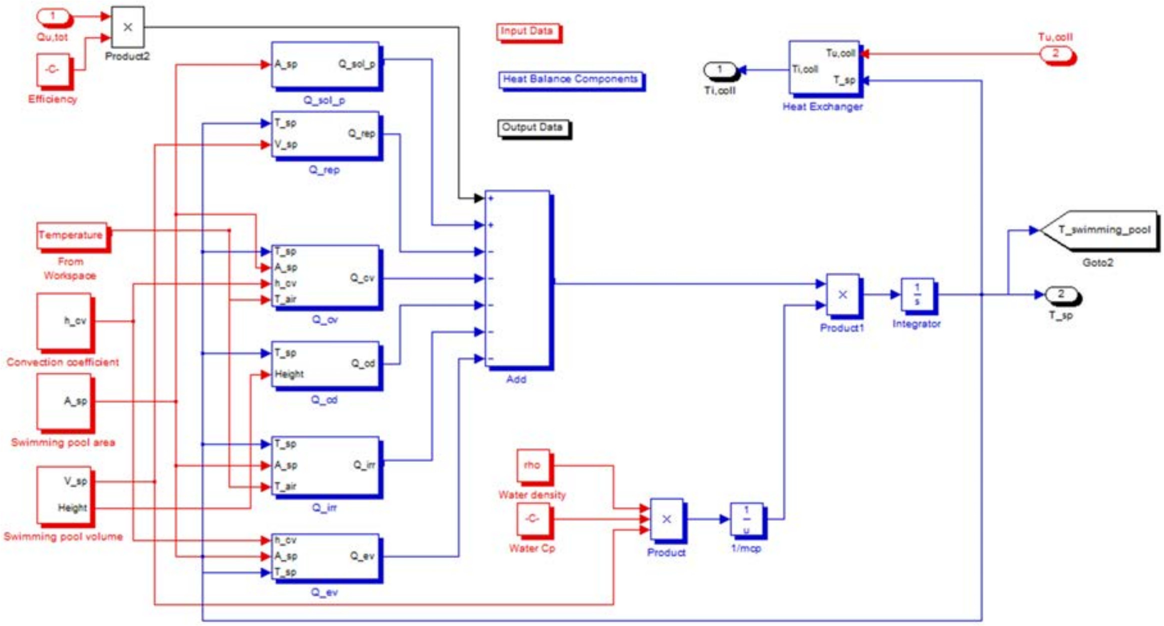
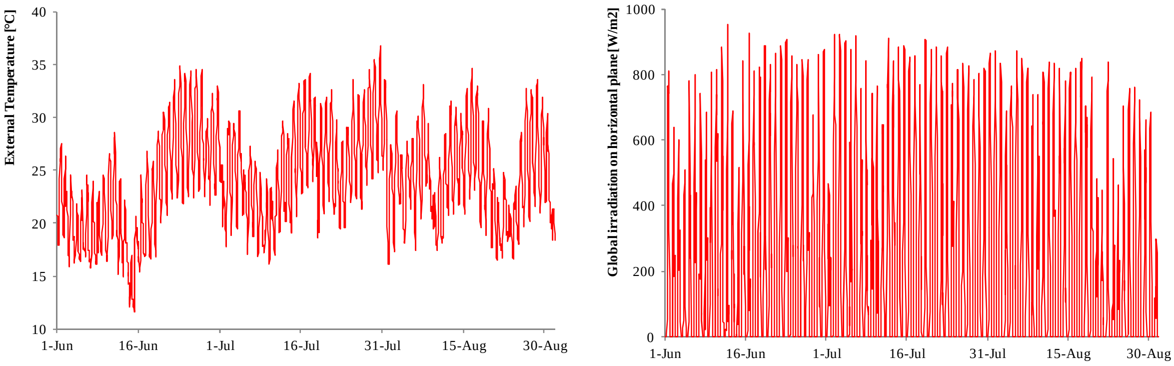


Fig. 2. Lay-out of the *Swimming Pool* block

In Fig. 3 the trends of the outdoor temperature and of the total solar radiation on a horizontal plane during the selected period in Bologna are represented. As shown in Fig. 3a, in Bologna during the summer the outdoor temperature ranges between a maximum of 36.7 °C reached on 30th July at 5PM and a minimum of 11.6 °C reached during the night of 15th June. The total irradiation on horizontal plane is characterized by a large number of days during the summer with a daily maximum peak allocated around 800 W/m^2; the seasonal peak of 954.5 W/m^2 is reached on 12th June at 2PM.

In Table 1 the main technical characteristics declared by manufacturers for the selected solar panels are quoted while in Fig. 4 the instantaneous efficiency of the different solar panels are shown as a function of the climatic abscissa.



a b

Fig. 3. Trend of hourly outdoor temperature (a) and of the total irradiation on horizontal plane (b) during the summer in Bologna.

As indicated in Fig. 4 and Table 1, the selected collectors have different thermal characteristics; the UC model presents no transparent cover and its high values of coefficients $_0$ and a_1 make it perfect for a summer use. The GC panel is typically used for DHW production: it is characterized by a cover of glass that reduces heat losses and by lower $_0$ and a_1 with respect to the UC collector. The EC panel is composed by multiple evacuated glass tubes that almost eliminate convection and conduction heat losses; this kind of collector is used in order to obtain non negligible solar contribution also for low levels of solar radiation and low outdoor temperature. The EC collector is characterized by the highest instantaneous efficiency within the whole range of climatic abscissa.

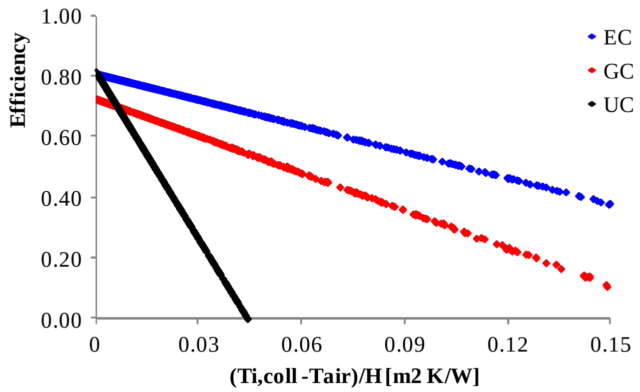


Fig. 4. Instantaneous efficiency of the selected solar collectors as a function of the climatic abscissa.

Table 1. Solar collectors technical data and swimming pools geometrical data

Solar collector type	EC	GC	UC	*Swimming pool*	SP1	SP2	SP3
$_0$	0.821	0.738	0.828	Length [m]	10	15	25
a_1[W/m^{2}K]	2.824	4	18.52	Width [m]	4	6	10
a_2 [W/m^{2}K^2]	0.0047	0.012	0	Depth [m]	0.5	1.5	2
A_{abs} [m^2]	2.11	1.82	2.77				
m [kg/s m^2]		0.015					

Fixed the solar collector, the pool and all the variables appearing in the above-mentioned equations, the forcing parameter of the system is the number of installed solar panels (N_c). Varying N_c leads to a change in the total thermal power collected by solar collectors; for this reason, in order to highlight the role played by the ratio A_c/A_{sp} (where A_c represents the total absorbing area of collector system and A_{sp} represents the surface of the pool) a series of simulations has been carried out for each combination pool-solar collector. Each simulation presents a different value of the A_c/A_{sp} ratio, which ranges from about 0.2 to 1.5.

The pool water temperature is the main parameter which influences the thermal comfort of the users. In the *Swimming Pool* block a controller has been inserted with the aim to switch off the solar collectors when T_{sp} exceeds the upper limit (i.e. 32°C).

In Table 2 all the input parameters used in the simulations presented in this paper are summarized. It was assumed that the initial temperature of the water in the pool (T_{sp0}) on 1st June was equal to the aqueduct water temperature (15°C).

By means of the Simulink model it becomes possible to analyze and to evaluate the hourly trend of the output variables. The warm-up period of the outdoor swimming pool, defined as the time needed to reach the minimum acceptable water temperature (i.e. 26°C) starting from an initial temperature of 15°C, can be estimated.

Table 2. Values of parameters used in the simulations

Albedo	0.2	-			
Tilt angle	0	°			
Swimming pool parameters					
Walls thermal resistance	1.25	m^2 K/W	Cp air	1000	J/kg K
Aqueduct water temperature	15	°C	Aqueduct water temperature	15	°C
Initial pool water temperature	15	°C	Pool water renewal rate	0.0025	vol/hr
Ground temperature	15	°C	Water absorbing coefficient	0.75	-
Water emissivity	0.9	-	Water density	1000	kg/m^3
Cp brine	3800	J/kg K	Cp water	4186	J/kg K
Water latent vaporization heat	2450	kJ/kg	Heat exchanger efficiency	0.85	-

Fig. 5 represents the trend of pool water temperature during the first 15 days of June, by considering the three swimming pools and by assuming a solar heating system made with unglazed collectors (UC) with A_c/A_{sp}=0.4 (Fig. 5a) and A_c/A_{sp}=1.5 (Fig. 5b). The warm-up period of the outdoor swimming pool is strongly influenced by the dimensions of the pool and by the size of the solar collectors: considering Fig. 5a, SP1 reaches the acceptable temperature (equal to 26°C) after about 4 days, while 9 and 10 days are needed for SP2 and SP3 respectively. Fig. 5b points out the influence of the size of the solar heating plant; by increasing the absorbing solar area of the collectors the warm-up period can be strongly reduced: for SP1 this period moves from 4 to 2 days, for SP2 from 9 to 4 days and for SP3 from 10 to 5 days.

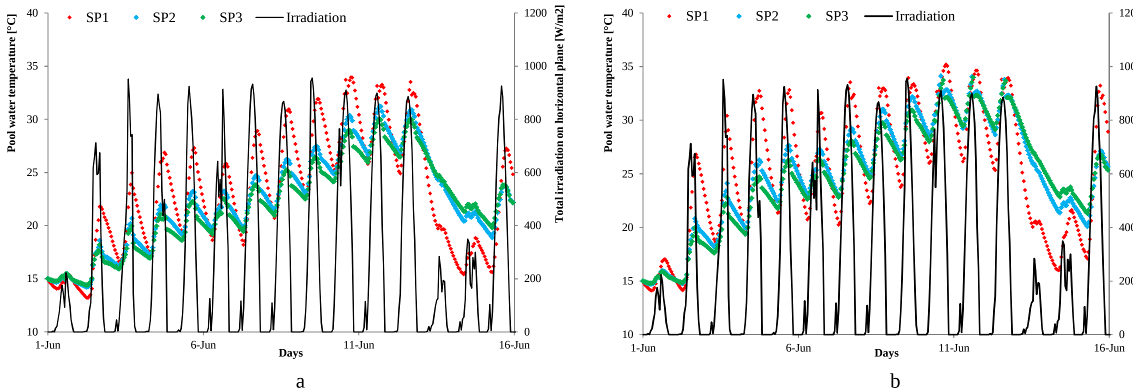


Fig. 5. Trend of the pool water temperature and of the total solar radiation on a horizontal plane during the first 15 days of June: (a) unglazed solar collectors with A_c/A_{sp}=0.4; (b) unglazed solar collectors with A_c/A_{sp}=1.5

Water thermal inertia influences also the pool temperature variation during a day; SP1 water temperature decreases of about 12°C passing from the day to the night (Fig. 5b), while SP2 and SP3, characterized by a higher mass, undergo a minor variation, 5°C and 4°C, respectively.

In Fig. 6 the pool water temperature (T_{sp}), the total solar radiation incident on the pool surface ($H*A_{sp}$) and all heat gains and losses terms introduced in Eq. (4) ($Q_{sol,c}$, $Q_{sol,p}$, Q_{rep}, Q_{cv}, Q_{cd}, Q_{irr} and Q_{ev}) are evaluated during a typical summer day in which the pool water temperature is in the optimal range (26-30°C). The results quoted in Fig. 6 have been obtained by considering the pool SP2 and a solar heating system made by unglazed collectors with a total absorbing surface equal to 62% of the swimming pool area (A_c/A_{sp}=0.62). Dashed curves depict the heat gains due to solar contributions. Heat losses terms are instead represented in continuous lines. By comparing the curves shown in Fig. 6 it is evident that the conductive term can be considered as negligible with respect to the other pool heat losses. The most significant heat losses are due to the heat irradiation towards the sky, to the water evaporation and to the water renewal, according to the literature [15]. This result highlights that it is possible to achieve significant energy savings for pool water heating if a recovery heat exchanger on the exhaust water is used in order to pre-heat the feed water and especially by covering the pool during the night, in order to prevent irradiation and evaporation losses.

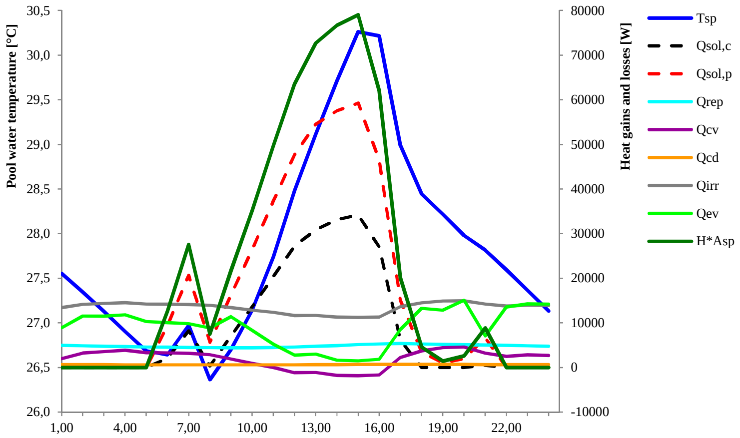


Fig. 6. Pool water temperature, global solar radiation and heat gains and losses for SP2 pool heated by means of unglazed collectors with A_p/A_{sp}=0.62 during a typical summer day.

The seasonal efficiency of the system is evaluated through the N_u/N_{tot} ratio that is calculated as the ratio between the number of hours in which the pool water temperature T_{sp} drops within the acceptable range (N_u) and the total number of hours during which the outdoor pool is used during the summer (N_{tot}).

In order to highlight the influence of the pool thermal inertia and of the kind of used solar collectors on the system performance, N_u/N_{tot} trends as function of the A_c/A_{sp} ratio are shown in Fig. 7, for different kind of pools and different solar collectors. The results have been obtained by considering the acceptable range for the pool water between 26 and 32°C. As pointed out by Fig. 7, increasing the pool thermal inertia the value of A_c/A_{sp} which maximizes N_u/N_{tot} increases, moving from about 1 for SP1, to about 1.5 for SP2 and SP3. It is important to observe that N_u/N_{tot} never reaches the value of 0.8 for SP1; as shown above (Fig. 5) the low thermal inertia of SP1 causes a decrease of the pool water temperature below 26°C for almost every night of the selected period. The increase of solar collectors surface doesn't lead to a significant increase of N_u/N_{tot} ratio for SP1 (red lines in Fig. 7).

The results quoted in Fig. 7 demonstrate that the best performance can be obtained by using evacuated collectors (ECs) and unglazed collectors (UCs), while the glazed collectors (GCs) present always the lowest value of N_u/N_{tot}. Since for this kind of application (summer pool heating) the solar panels work at very low values of climatic abscissa, evacuated and unglazed collectors work with an instantaneous efficiency larger than the efficiency of glazed collectors (see Fig. 4) and this explain the results shown by Fig. 7.

The same evaluations have been conducted by considering different acceptable pool water temperature ranges. N_u/N_{tot} trends as functions of A_c/A_{sp} have been evaluated not only by varying the kind of pool and the solar collector type, but also by considering three different temperature ranges. The maximum accepted temperature is fixed at 32°C to avoid bacterial proliferation, while the minimum temperature increases from 23°C to 25°C.

For each fixed acceptable pool water temperature range a dynamic simulation of the thermal behaviour of the pool during the whole period (1st June- 31th August) has been conducted and the minimum value of A_c/A_{sp} which leads to a N_u/N_{tot} ratio larger than 0.8 has been obtained for all the cases. Fig. 8 shows how the sizing of the solar heating collectors depends on the minimum value of the pool water acceptable temperature, on the pool dimensions and on the kind of solar collectors. The dependence of A_c/A_{sp} on the minimum acceptable water pool temperature, for a fixed N_u/N_{tot}, is linear. The value of temperature in correspondence of $A_c/A_{sp}=0$ represents the average value of the water pool temperature during the summer in absence of a solar heating plant: this value depends on the characteristics of the considered pool and it can be obtained by solving Eq. (4) imposing $Q_{sol,c}=0$.

The results reported in Fig. 8 confirm that evacuated (EC) and unglazed (UC) collectors are the best for the heating of a swimming pool: for each value of the minimum acceptable water temperature a solar heating system composed by glazed collectors needs a larger absorbing surface compared to other kind of systems. It also important to observe that the choice of the minimum acceptable pool water temperature strongly influences the sizing of the solar absorbing surface: by increasing this value from 24°C to 25°C the needed collector area increases of 50-100%, depending on the panel and the pool characteristics.

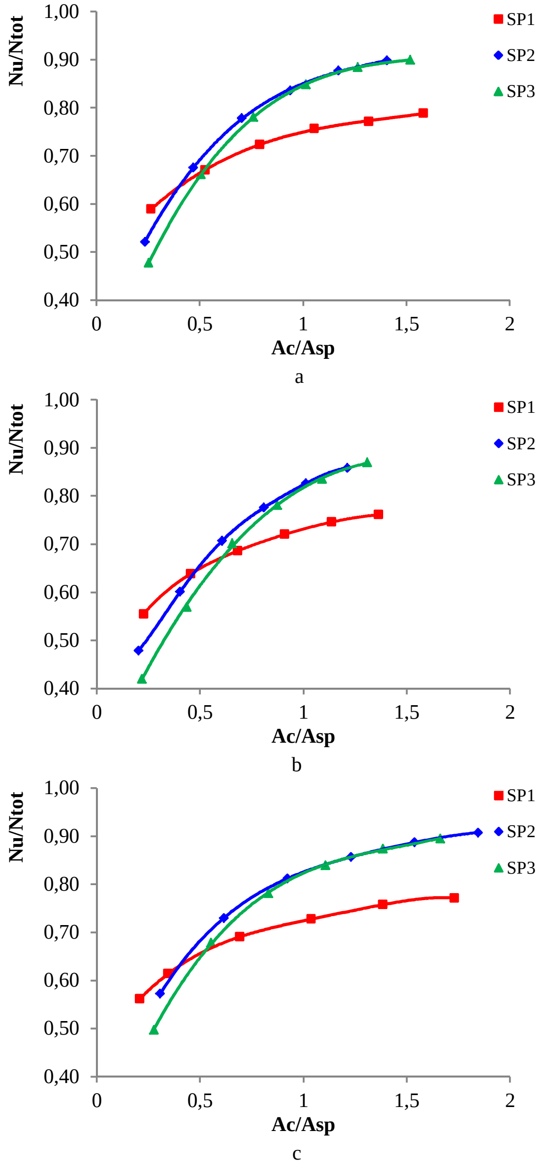


Fig. 7. N_u/N_{tot} as a function of A_c/A_{sp} for a pool water temperature range equal to 26-32°C: (a) EC (b) GC (c) UC.

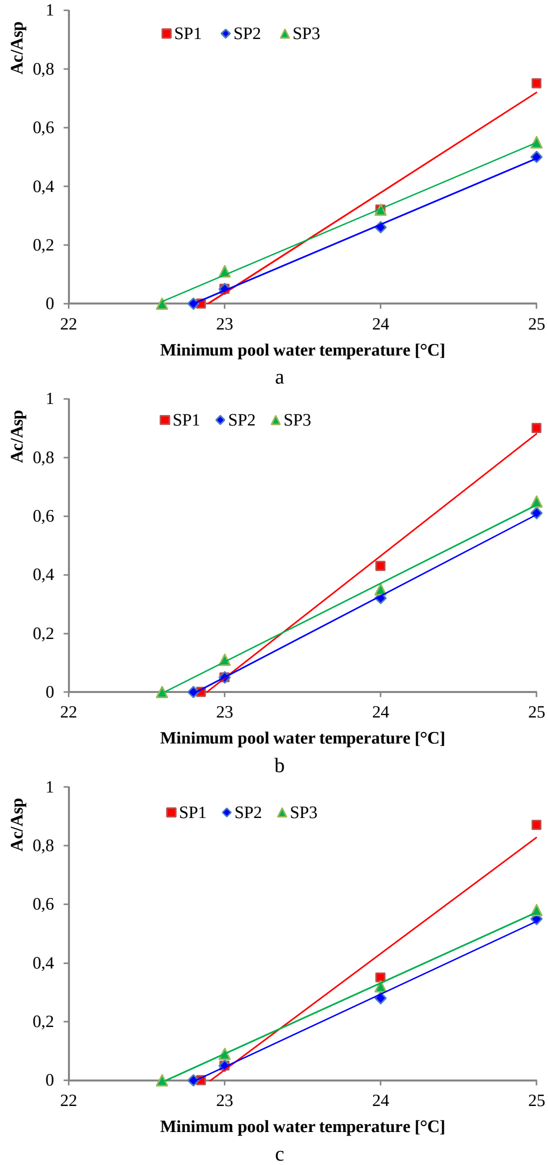


Fig. 8. A_c/A_{sp} needed in order to obtain a value of N_u/N_{tot}=0.8 as a function of the acceptable minimum pool water (max temperature=32°C): (a) EC (b) GC (c) UC.

4. Conclusions

In this paper a dynamic model for the simulation of a solar heating system composed by flat collectors coupled to an outdoor swimming pool is presented. The developed model allows to obtain as output the hourly trends of the most important parameters of the system: the solar radiation absorbed by the solar collectors, their instantaneous efficiency, the pool heat gains and losses, the inlet/outlet collector working fluid temperature and the mean pool water temperature. The model has been used in order to investigate the influence of the pool thermal inertia and of the solar collector typology on the seasonal performances of a fully passive solar heating system; three kinds of solar collectors (glazed (GC), unglazed (UC) and evacuated (EC)) and three different pools (paddling pool, common outdoor pool and competitive pool) have been considered. The numerical results highlight that for the heating of outdoor swimming pools EC and UC collectors are the most suitable typologies, due to their high efficiency at low climatic abscissa values. The results show how the minimum value of the acceptable pool water temperature strongly influences the sizing of the solar collectors.

References

[1] Morini, G.L., Piva, S. The simulation of transients in thermal plant. Part I: Mathematical model. Applied Thermal Engineering, 2007, Vol. 27, Issues 11-12, pp. 2138-2144.
[2] Morini, G.L., Piva, S. The simulation of transients in thermal plant. Part II: Applications. Applied Thermal Engineering, 2008, Vol. 28, Issues 2-3, pp. 244-251.
[3] Chen, Y., Treado, S. Development of a simulation platform based on dynamic models for HVAC control analysis. Energy and Buildings, 2014, Vol. 68, pp 376-386.
[4] Karmacharya, S. et al. Simulation of energy use in buildings with multiple micro generators. Applied Thermal Engineering, 2014, Vol. 62, Issue 2, pp 581-592.
[5] Kiyan, M. et al. Modelling and simulation of a hybrid solar heating system for greenhouse applications using Matlab/Simulink. Energy Conversion and Management, 2013, 72, pp. 147-155.
[6] Beghi, A. et al. Energy efficient control of HVAC systems with ice cold thermal energy storage. Journal of Process Control, 2014, Vol. 24, pp 773-781.
[7] CONI – Comitato Olimpico Nazionale Italiano, Deliberazione n.851 – Norme CONI per’impiantistica sprotiva, 15 July 1999.
[8] Klein, S.A. et al. A design procedure for solar heating systems. Solar Energy, 1976, Vol. 18, No. 2, pp. 113-127.
[9] European standard UNI EN 15316-4-3: Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 4-3: Heat generation systems, thermal solar systems. 2008.
[10] Italian standard UNI/TS 11300-4: Energy performance of buildings - Part 4: Renewable energy and other generation systems for space heating and domestic hot water production. 2012..
[11] http://shop.cti2000.it/schedadoc.php?id=12 - Anno tipo climatico: Province della Regione Emilia Romagna.
[12] Italian standard UNI/TR 11328-1: Solar energy – Calculation of energy gains for building applications – Part 1: evaluation of radiant received energy, 2009.
[13] Bernard, J. Energie solaire – Calculs et optimisation, Ed. Ellipses, Paris, 2004.
[14] Italian standard UNI 10637: Swimming pools – Water quality and requirements for swimming pool water circulation, treatment and disinfection equipment, 2006.
[15] Martinez, P. J., Ruiz, E. Analysis of an open-air swimming pool solar heating system by using an experimentally validated TRNSYS model, Solar Energy 84, 2010, pp 116-123.