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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.