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Dynamic simulation of solar thermal collectors for domestic hot water production

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Abstract

In this paper a system for the Domestic Hot Water (DHW) production based on solar collectors is analyzed by means of a dynamic approach based on a Simulink model and by using the F-chart method, able to evaluate system performances on a monthly basis. Following the dynamic approach, it is possible to evaluate hour by hour the energy collected by the solar panels and the temperature of the hot water produced by the system, by taking into account the impact of different daily DHW consumption profiles on the percentage of thermal energy produced by the solar collector (Solar Coverage Factor, SCF). The comparison between the prediction made both by using the Simulink model and the F-Chart method in terms of SCF is shown by taking into account the effect on SCF of the typology of solar collector (unglazed, glazed and evacuated collectors), of the storage tank volume connected to the solar panels and of the hourly DHW consumption profile. The results point out that SCF is strongly dependent on the daily DHW consumption profile, which cannot be taken into account in a quasi-static approach like the F-chart method.

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Keywords: Solar thermal collectors; Matlab/Simulink; dynamic simulation; domestic hot water; thermal storage.

1. Introduction

Nowadays, two complementary approaches are available for the designers of HVAC systems: the first one (*quasi-static approach*) is based on a steady-state analysis of the system in which the seasonal behavior of the HVAC system is reconstructed by a set of monthly static analyses where the main status parameters of the system are freezed. The second approach (*dynamic approach*) is based on a dynamic analysis of the system in which the hourly evolution of the significant status parameters is taken into account by considering the heat storage and discharge capacity of the different HVAC components by means of dynamic codes (i.e. Energy+, ESP-r, TRNSYS). The results obtained by simulating a thermal

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plant by using these two approaches can give different results especially if the thermal loads strongly depend on time and/or if the performance of the HVAC components varies significantly during the day and the season, like for HVAC systems based on renewable sources. In these cases, the *dynamic approach* must be preferred in order to obtain an accurate evaluation of the performance of HVAC systems.

A thermal plant based on solar thermal collectors for the production of Domestic Hot Water (DHW) is a typical example of HVAC system characterized by a strong variation of the thermal load during the day and during the different seasons, as well as by a significant variation of the performance of the heat generation system, based on solar energy. This kind of HVAC system is very diffuse in Italy where the production of at least 50% of thermal energy consumptions for DHW production must be provided by renewable sources, as imposed by law [1]. The technical UNI TS 11300-4 [2] suggest to use the F-chart method [3] in order to estimate the efficiency of a solar hydronic system composed by thermal collectors. This method employs a *quasi-static approach* that allows to evaluate the performance of the system only on a monthly basis. However, due to the variability of the thermal loads and of the performance of solar collectors, a dynamic simulation of these systems can be recommended, as pointed out by many researchers. For example, Ahmed et al. [4] suggest to use the *dynamic approach* for the estimation of the performance of solar hydronic system for DHW production after the deep investigation of the effect on the solar coverage factor of different DHW load profiles, by taking into account the change of DHW energy demand during weekend and weekdays in Finnish apartments. The *dynamic approach* is also recommended when the variation of the performance of the solar components must be taken into account in order to obtain a reliable simulation of the system: Da Silva et al. [5] and Tsai [6] have used MATLAB/Simulink environment to simulate the behavior of a hybrid PV/T plant coupled to residential buildings.

As evidenced by the open literature [5-7], MATLAB/Simulink environment is a powerful instrument to approach dynamically HVAC systems. In fact, thermal plants can be modelled through blocks simulating the behavior of real components by a lumped formulation of the conservation equations. By following the trend indicated by the cited papers, in this work a dynamic model of a hydronic solar system for DHW production based on a series of customized blocks made by using MATLAB/Simulink, is presented. The dynamic model includes all components that constitute the system and its control system. The model is used in order to investigate the influence of the typology of solar collectors (unglazed, evacuated and glazed), of thermal inertia of the storage tank coupled to the collectors and of different DHW profile loads on the global system performance for a typical Italian residential building. A comparison, in terms of monthly and annual solar coverage factors, with the values obtained by means of the F-chart method is presented. The results point out that the solar system efficiency is strongly dependent on the DHW profile load, which cannot be taken into account in a *quasi-static approach* like the F-chart method.

2. Simulink model description

As shown by Morini and Piva [8-9], Simulink can be proficiently used in order to build a “thermal library” for the modeling of HVAC systems in which any HVAC component is modeled by means of a specific sub-block containing the lumped formulation of the main conservation equations. In Fig. 1 the layout of the solar heating system coupled to a residential building built with MATLAB/Simulink is shown; the HVAC system considered in this paper is composed by a series of sub-blocks: *Parameters, Climatic Data, Collector, Pump, Back-up, DHW load* and *Solar thermal storage*.

More in detail, the *Climatic Data* block is a sub-system, described in [10], that, by using as input the hourly climatic data from a Test Reference Year (TRY), calculates the hourly total solar radiation incident on the thermal collectors as a function of the tilt angle and orientation. Through the *Parameters* block in