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A neural network controller for hydronic heating systems of solar buildings

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Abstract

An artificial neural network (ANN)-based controller for hydronic heating plants of buildings is presented. The controller has forecasting capabilities: it includes a meteorological module, forecasting the ambient temperature and solar irradiance, an indoor temperature predictor module, a supply temperature predictor module and an optimizing module for the water supply temperature. All ANN modules are based on the Feed Forward Back Propagation (FFBP) model. The operation of the controller has been tested experimentally, on a real-scale office building during real operating conditions. The operation results were compared to those of a conventional controller. The performance was also assessed via numerical simulation. The detailed thermal simulation tool for solar systems and buildings TRNSYS was used. Both experimental and numerical results showed that the expected percentage of energy savings with respect to a conventional controller is of about 15% under North European weather conditions.

Keywords: Artificial neural networks; Heating system control; Hydronic systems; Neural controller; Energy savings; Feed forward back propagation; Thermal simulation

1. Introduction

The range of applications of artificial neural networks (ANNs) is constantly increasing. Their use in applications related to energy management started in the early 1990s. Kalogirou (2001) provides a comprehensive overview of ANN applications in renewable energy systems and in buildings. ANNs appear to be particularly suited to control the heating systems of solar buildings. The thermal behaviour of solar buildings is mostly influenced by the solar irradiance and ambient temperature and it involves large time constants. Therefore, a controller having the ability to forecast up to a certain horizon these weather parameters and also their impact to the thermal behaviour of the building can reduce the energy required for maintaining the indoor conditions within the comfort zone.

The need of forecasting is shown in Fig. 1 (Kummert, 2001), showing the typical behaviour of a building with important solar and internal heat gains, during a sunny mid-season day. This situation can be encountered in a passive solar building or a modern commercial building with large south-facing windows. If there is no cooling plant, overheating can occur during a sunny afternoon, despite the fact that heating has been required in the morning. If overheating occurs then it is too late to take a control decision for the heating plant: the heat stored in the building structure cannot be removed. A reduction of energy consumption would have certainly been achieved if the temperature rise had been forecasted, in order to prevent unnecessary heating during the morning hours.

Argiriou, Bellas-Velidis, and Balaras (2000) presented an ANN controller for buildings with such forecasting capabilities. It consisted of a meteorological module, forecasting the ambient temperature and solar irradiance, a heating energy predictor module and the indoor temperature-defining module. The controller was applied to a simple ON/OFF electrical heating system. The performance of

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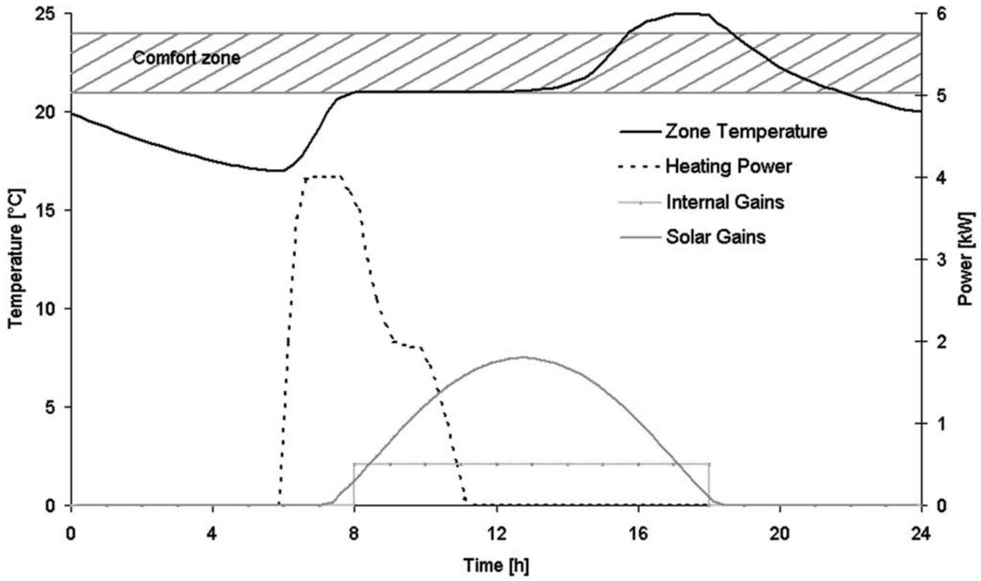

Fig. 1. Typical passive solar building behaviour on a sunny day.

the controller was tested experimentally, in the PASSYS outdoor test facility (Vandaele & Wouters, 1994) and in a building thermal simulation environment. It was found that when applied to the PASSYS test building cell, a 7.5% decrease of the annual heating energy consumption was achieved, under the weather conditions of Athens, Greece. The usefulness of that work was mainly to demonstrate the feasibility and the importance of forecasting capabilities of a heating system controller. In practice the applications of such ON/OFF control devices are limited, since the majority of residential buildings use hydronic heating plants. Therefore, it would be interesting to extend the above control concept to hydronic heating systems too. Kanarachos and Geramanis (1998) proposed an ANN for the control of single zone hydronic heating systems. The inputs and outputs of this controller included parameters related to the heating plant and the indoor set-point temperature. No forecasting of either weather parameters or indoor conditions was performed.

The present paper describes the further development of the concept proposed by Argiriou et al. (2000) and its application for the control of hydronic heating systems. The controller was realized and tested experimentally in two rooms of an office building. The following sections present the design concept of the controller and its performance assessment—experimental and in simulation environment. The structure and the development of the controller is presented in Section 2. Section 3 describes the criteria applied for the performance assessment of the controller. The performed experiments and their results are described in Section 4. Since the experimental period could not cover the complete operating season of the heating plant of a building, numerical simulations were required in order to assess the annual behaviour of the system. The simulation results are presented in Section 5. The conclusions of this work are given in Section 6.

2. Description of the controller

The inputs to the controller are: N_d (yearly normalized), day number (1–365); N_h (daily normalized), hour (1–24); T_{amb}, ambient air temperature; G_s, solar irradiance on the south vertical plane (i.e. solar radiation impinging on a south facing vertical plane); T_i, indoor air temperature; T_s, water supply temperature (temperature of water supplied to the radiators by the boiler of the heating plant); T_r, water return temperature (temperature of water returning to the boiler). The controller aims to maintain the indoor conditions as defined by the user via some cost function (J) and the indoor air temperature set-point (T_u). The set-up of the controller and its modular structure are shown in Fig. 2. It includes a meteorological module, forecasting the ambient temperature and solar irradiance, an indoor temperature predictor module, a supply temperature predictor module and a supply temperature optimizing module. This last module calculates the final output from the controller to the heating system, i.e. the forecasted water supply temperature for the next time step, taking into account the user set point, T_u and the requirements for energy savings as given by the cost function J. The controller operates with a 15-min time step.

Supervised training with the method of Back Propagation with Momentum Term was used. The various ANN modules were developed under the Stuttgart Neural Network Simulator software package (Zell et al., 1995). The various modules were optimized via extensive off-line training. The optimization procedure included the selection: