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Contributed article

Development of a neural network heating controller for solar buildings

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Abstract

Artificial neural networks (ANN's) are more and more widely used in energy management processes. ANN's can be very useful in optimizing the energy demand of buildings, especially of those of high thermal inertia. These include the so-called solar buildings. For those buildings, a controller able to forecast not only the energy demand but also the weather conditions can lead to energy savings while maintaining thermal comfort. In this paper, such an ANN controller is proposed. It consists of a meteorological module, forecasting the ambient temperature and solar irradiance, the heating energy switch predictor module and the indoor temperature-defining module. The performance of the controller has been tested both experimentally and in a building thermal simulation environment. The results showed that the use of the proposed controller can lead to 7.5% annual energy savings in the case of a highly insulated passive solar test cell.

Keywords: Artificial neural networks; Heating system control; Solar buildings; Neural controllers; Energy management; Ambient temperature forecasting; Solar irradiance forecasting; Feed forward back propagation

1. Introduction

The use of artificial neural networks in various applications related to the energy management has been growing significantly over the years. Current applications not only are related to energy demand forecasting (Han, Xiu, Wang, Chen, & Tan, 1997; Khotanzad et al., 1997), but also include heating, ventilation and air conditioning systems of buildings (Curtiss, Kreider, & Brandemuehl, 1993; Kreider, 1995). The results have revealed the potential usefulness of artificial neural networks for the energy management of individual houses or small residential buildings (Bellas-Velidis, Argiriou, Balaras, & Kontoyannidis, 1998; Kanarachos & Geramanis, 1998).

Artificial neural networks (ANN's) can be very useful in optimizing the energy demand of buildings, especially those having high thermal mass (and therefore an important time constant) and systems that maximize the use of solar energy for space heating. For the so-called solar buildings, a controller being able to forecast the energy demand but also the weather conditions can lead to energy savings, while maintaining acceptable indoor conditions. The controller decreases the potential of overheating, usually observed in this type of building during days with highly variable solar radiation availability and passive solar gains.

The aim of this paper is to investigate the performance of ANN's, in order to control the indoor temperature of a solar building. The following sections present an overview of the design concept for the artificial neural network-based controller and its theoretical and experimental performance assessment.

2. Concept of the controller

Buildings consume about one third of the total final energy in the industrialized world, for heating, cooling, ventilation, lighting and services. Therefore, worldwide efforts have concentrated on developing new systems and techniques to increase energy savings by the rational use of energy in the building sector.

The controller presented in this paper is intended for single-family solar houses. The term "solar" implies that the house exhibits the following general characteristics, compared to ordinary type of constructions:

- Reduced thermal losses, by improving the building envelope thermal performance (i.e. increased thermal insulation, double glazing, reduced air infiltration).

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Nomenclature

C_f	cost-function
E_a	final status (ON or OFF) of the heating energy system
E_s	heating energy system status prediction from the inverse model
N_d	day of the year
N_h	hour of the day
S_r	global solar irradiance
T_i	indoor air temperature
T_o	ambient air temperature
T_s	indoor air temperature setpoint
δT	allowed maximum deviation for T_s
Superscripts	
$+$	forecasted value

- Increased direct solar gains, through passive solar features of glazed surfaces like windows and sunspaces, that significantly reduce the heating load by collecting and storing solar thermal energy.

The energy consumption of a building to reach the desirable indoor thermal comfort conditions depends on the thermal characteristics of its envelope and on the local climatic conditions. However, not all the weather parameters have the same impact on the heating energy consumption of a building. Accordingly, the solar irradiance and the ambient air temperature, rather than other weather parameters mostly influence solar houses, provided with the general features described above.

Solar irradiance is a parameter that can vary significantly in time and space. The time scale of these variations can be as short as of the order of some minutes. This variability is usually observed during spring and autumn, depending on the geographical latitude of the location. The majority of heating systems in buildings operates by a simple thermostatic control. This type of control can lead to overheating periods during the day, since the controller can not forecast neither the evolution of the weather conditions nor the reaction of the building under a certain weather excitation. The term overheating implies that the building indoor air temperature exceeds the desirable thermal comfort levels because of an increase of the solar heat gains. As a result, there is a twofold negative impact causing indoor thermal discomfort and energy waste from the operation of the heating system. Alternatively, a controller having the ability to forecast, up to a certain extend, the 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 thermal comfort zone. For example, if properly accounted for, the predicted daily variation of solar radiation availability in the morning can be used to control the heating system in such a way as to avoid the anticipated overheating in the afternoon. Neural networks exhibit features that allow them to learn and reproduce the behaviour of data time series. This fact together with the adaptive character of some of the ANN's provides them with the necessary features that an intelligent controller should have, that is achieve rational use of energy while maintaining thermal comfort.

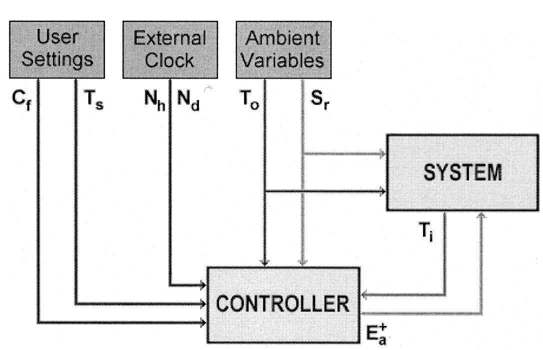

Fig. 1. Solar house heating system controller set-up (C_f: cost function; T_s: indoor air temperature set-point; N_h: hour; N_d: day of the year; T_o: ambient air temperature; S_r: Solar irradiance; T_i: indoor air temperature; E_a^+: heating energy required during the next time period).

Having in mind that a controller to be widely used must be reasonably priced, it has to have the strict minimum of input requirements. Accordingly, the input parameters for the new controller were selected to include the solar irradiance (S_r), the ambient temperature (T_o), and the indoor temperature (T_i), as illustrated in Fig. 1. These inputs are measured in regular time intervals, set at 15 min. This time interval allows the controller not to loose information even in the case of a fast responding building. Based on the values of the input parameters at a given time step and their history, the controller output is an estimate of the status (ON or OFF) of the heating energy system required by the building during the next time interval. The controller optimally (e.g. by minimizing some cost function (C_f) maintains the T_i within the thermal comfort zone set by the user. An example of such a cost function is linear combination of the energy savings achieved and the thermal comfort obtained.

This paper presents the design and test results of an artificial neural network controller for a simple ON/OFF electrical heating system. The controller has a modular structure