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Building and Environment 41 (2006) 1881–1891

BUILDING AND ENVIRONMENT

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Quasi-adaptive fuzzy heating control of solar buildings

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Received 4 September 2003; received in revised form 2 June 2005; accepted 1 July 2005

Abstract

Significant progress has been made on maximising passive solar heat gains to building spaces in winter. Control of the space heating in these applications is complicated due to the lagging influence of the useful solar heat gain coupled with the wide range of construction materials and heating system choices. Additionally, and in common with most building control applications, there is a need to develop control solutions that permit simple and transparent set-up and commissioning procedures. This paper addresses the development and testing of a quasi-adaptive fuzzy logic control method that addresses these issues. The controller is developed in two steps. A feed-forward neural network is used to predict the internal air temperature, in which a singular value decomposition (SVD) algorithm is used to remove the highly correlated data from the inputs of the neural network to reduce the network structure. The fuzzy controller is then designed to have two inputs: the first input being the error between the set-point temperature and the internal air temperature and the second the predicted future internal air temperature. The controller was implemented in real-time using a test cell with controlled ventilation and a modulating electric heating system. Results, compared with validated simulations of conventionally controlled heating, confirm that the proposed controller achieves superior tracking and reduced overheating when compared with the conventional method of control.

Keywords: Solar building; Space heating; Fuzzy logic control; Neural network; Adaptive control; PI control; Real-time control

1. Introduction

In response to demands for buildings with increasing levels of energy efficiency as well as reduced environmental impact, significant progress has been made on the development of building designs which maximise passive solar heating in winter whilst reducing envelope heat loss. This is achieved through the choice of glazing surface area, orientation and material, together with a judicious balance between insulation and thermal capacity when selecting the opaque materials of construction.

As a consequence, the space heating systems to be found in such buildings are now required to operate for increased periods of time at low, or very low, output capacity. Additionally, there is a requirement for these systems to give responsive and stable performance characteristics under control in situations where the mix of space and system dynamics can vary considerably. Finally, space heating control systems are traditionally difficult to commission because of the widely varying operating characteristics to which the plant is required to respond as well as interaction with other linked control systems. This situation is rarely rectified post-commissioning due to the poor maintenance management that many buildings suffer from.

Thus there is a need for a new generation of space heating system controllers that can cater for the following:

- Stable response at light load (traditionally an operating region which tends to be especially non-linear).

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0360-1323/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.buildenv.2005.07.008

- Good set-point tracking with the ability to anticipate the lagging influence of passive solar heat gain.
- Easy and transparent set-up and commissioning with minimal post-commissioning intervention.

Thus the aim of the work reported here is to develop a new controller for space heating in passive solar buildings which is responsive to the lagging effects of solar energy inputs, whilst offering good robustness and tracking properties and minimal commissioning.

2. Previous work

Early developments in adaptive control applicable to energy plant in buildings were due to Jota and Dexter [1], who developed general minimum-variance and general predictive controllers for heating and cooling coils in air handling plant. Problems with robustness of these early controllers led to work on "jacketing" [2] and receding-horizon controllers [3]. In spite of these early efforts, a generally applicable robust control method for building energy plant that could be applied without the need for a sophisticated model of the plant remained elusive and progress was generally overtaken by new approaches using fuzzy and neuro-fuzzy systems.

The using of fuzzy logic methods to develop controllers applicable to the inherently non-linear and multi-modal plants found in buildings has received widespread attention [4–6]. Early progress tended to concentrate on "static" fuzzy logic controllers (FLCs) (i.e. those with a fixed rulebase and inference mechanism) with one or two inputs (usually the feed-back controlled variable and its rate-of-change) and thus these developments lacked adaptiveness to changes in plant operating mode or changes in boundary conditions.

Some attention has been given to mechanisms for making fuzzy controllers adapt to their operation domains. Haissig and Woessner, [7], introduced an adaptation mechanism based on updating the location of the output membership function of a domestic hot water boiler FLC. Kolokotsa et al. [8], describe the development of a model-following FLC based on scaling fuzzy inputs and outputs to respond to an idealised second-order model of a building space in order to achieve control over a variety of internal comfort conditions. The use of artificial neural networks (ANNs) as a means of adapting the parameters of a fuzzy controller has also been considered a promising way of addressing the adaptiveness shortcomings of static FLCs. ANNs have found applications in areas ranging from pattern recognition to feed-back control [9]. So et al. [10] reported on the development of a self-learning FLC for a building air handling plant which used an ANN to monitor plant conditions and update the parameters of the FLC. Egilegor et al. [11] used an ANN to adapt a daily comfort offset parameter as a control target for a FLC applied to the control of heating and cooling in a dwelling.

Of the adaptive fuzzy controllers developed for the control of energy and environmental comfort in buildings, most have a limited adaptation horizon and none of them account for the substantially lagging influences of the major microclimate variables. The same applies to the earlier model-based adaptive controller developments. This problem forms the basis of the work reported here.

3. Test site

The vehicle for controller development and testing was a 3.5 m × 3 m × 2.3 m (approx.) Test Cell located at Cranfield University in Bedfordshire (Fig. 1). The site co-ordinates are latitude 52.07° (north), longitude 0.63° (west) and altitude 100 m above sea level. A single glazed wall section of the Test Cell (as can be seen in Fig. 1) faces due south, the window panel measuring 2 m × 1.2 m (high). The walls and roof consist of a thin proprietary cladding panel on the outside with 50 mm styrofoam insulation and an air space forming inner layers, finished internally with plasterboard. The Test Cell floor is 900 mm above the ground and constructed similarly but, in addition, with a 36 mm dense concrete slab with a vinyl tile finish to the interior. This provides the main contribution to the thermal storage capacity of the space.

The Test Cell was equipped with a 2 kW (nominal capacity) oil-filled electric convector-radiator mounted beneath the window panel. A pulse-width-modulation power control system was developed for the control of power supply to the convector-radiator as shown in Fig. 2. The power supply was adjusted to saturate at 1.1 kW—established as the design heating load for the Test Cell under normal UK design conditions.

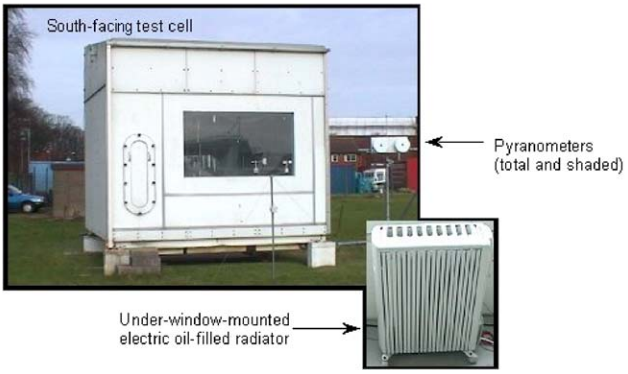

Fig. 1. Test Cell (viewed from approximately south).