Available online at www.sciencedirect.com
ScienceDirect
Renewable Energy 33 (2008) 694–702
RENEWABLE ENERGY
www.elsevier.com/locate/renene

Fuzzy control system for thermal and visual comfort in building

Živa Kristl*, Mitja Košir, Mateja Trobec Lah, Aleš Krainer

Faculty of Civil and Geodetic Engineering, Chair for Buildings and Constructional Complexes, University of Ljubljana, Jamova cesta 2, 1000 Ljubljana, Slovenia

Received 31 August 2006; accepted 19 March 2007
Available online 10 May 2007

Abstract

In the era of informational and technological breakthrough, the automatically controlled living and working environment is expected to become a commonly used service. This paper deals with dynamically controlled thermal and illumination responses of built environment in real-time conditions. The aim is to harmonize thermal and optical behaviour of a building by coordinating energy flows that pass through the transparent part of the envelope. For this purpose, a test chamber with an opening on the southern side was built. Changeable geometry of the opening is achieved by the automated external roller blind. A fuzzy control system enables the positioning of the shading device according to the desired indoor set points and the outdoor conditions. Through the experiments, the fuzzy controllers were tuned and gradually improved. Some sets of the experiments are presented here to illustrate the process.

Keywords: Fuzzy logic; Thermal comfort; Visual comfort; Heating; Daylighting; Control system

1. Introduction

Energy constantly flows through buildings and a building envelope plays the role of an interface between the inner and the outer space. The properties of a building envelope, especially of its transparent parts, have significant influence on interaction between the two spaces [1]. Solar radiation and the outdoor temperature are essential factors influencing the optical and thermal conditions in a building via thermal gains/losses and incoming light. The goal of making buildings energy efficient is achieved by effective use of natural energy sources, in our case heat and light. Due to the fact that the amount of available energy varies all the time, the building envelope requires some kind of regulation that has to be run automatically and has to be properly tuned in order to give good results. The development of technology enables automatic active response of the building envelope to the changeable outdoor conditions. The results are the increased positive aspects of solar heat and daylight use in a building.

Advances in the field of artificial intelligence have shown that the use of ‘‘intelligent techniques’’ for the automation of building envelope can lower energy consumption and also can keep internal living conditions in optimal range. Though the field of application of artificial intelligence automation in the built environment is still in its early phases, many studies have been conducted in the recent years. In most of these projects, the focus was on the formulation of algorithms for guiding the external shading devices according to the user demands regarding energy savings and internal comfort. In most cases, fuzzy logic controllers were utilized because of their flexibility and intuitive use. These in their basic architecture consist of two control loops, one regulating the illuminance and the other, the thermal aspects. The same basic composition is used in the application described in this paper. The major differences among examples described in the literature appear mostly in how the controller correlates the functioning of the system when illuminance and thermal conditions are in contradiction. Two basic approaches can be observed: one harmonizes the illuminance and thermal control loops, while the other only switches between them.

For the experimental part of the study, we built a test chamber with an opening facing south and an external

*Corresponding author. Tel.: +386 1 4768 609; fax: +386 1 4250 688.
E-mail address: zkristl@kske.fgg.uni-lj.si (Z. Kristl).

0960-1481/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2007.03.020

shading device mounted on the window. The shading device regulated the size of the collecting area of window regarding the external conditions and internal set-point parameters. The controlling system of the shading device was run automatically and was designed on the principles of fuzzy logic. Fuzzy logic was chosen to harmonize two environmental parameters (solar heat and daylight), which often have no linear connection, and two additional parameters within the chamber (heater and ventilator). We expected that the fuzzy regulator would adjust the shading device and heating/cooling system much better than the classical on–off system. The control algorithm for the thermal and optical process in the test chamber contained two basic control loops for thermal and for lighting regulation with the roller blind positioning. It had also two additional control loops for managing the heater and the ventilator in the framework of thermal control.

2. Test chamber, and the measuring and regulation equipment

The test chamber was built on the roof of the Faculty of Civil Engineering, University of Ljubljana (46.03° latitude, 300 m altitude). The test chamber had dimensions $1 \times 1 \times 1$ m and was designed especially for the purpose of this investigation. The chamber's floor and roof were ventilated in order to avoid the influence of surrounding surfaces. Walls, floor and ceiling were built of 20-cm-thick aerated concrete blocks. The south wall of the test chamber was completely glazed with two layers of clear float glass with air filling. The wooden frame was 5 cm thick. The changeable geometry of the window was achieved with an external roller blind. The following measuring equipment was tracking values of the outdoor and the indoor conditions:

- direct and reflected solar radiation: pyranometer CM-B (Kipp & Zonnen Delft BV),
- outdoor and indoor air temperature: thermocouples type T,
- indoor illumination: luxmeter LUX cells.

The regulation equipment contained of a programmable logic controller (PLC), a PC and an operator panel. PLC sent the signals for harmonized functioning to the actuators: roller blind with electromotor, heater and ventilator. The control algorithm for the thermal and illumination processes was developed in the IDR BLOCK environment and was loaded on the PLC [2,3]. A remote PC and control panel were used for the process supervision and for the visualization of experiments. The obtained values and process variables were collected and stored in the PC, which had application in Factory Link environment developed for this purpose. The framework of the system on the test chamber is shown in Fig. 1.

3. Application

Proper functioning of the control algorithm is essential for adequate adjustment and velocity of the roller blind alternations. Control algorithms with fuzzy controllers offer better response and efficiency in case of complex nonlinear and time varying working conditions when compared to conventional PID controllers. The advantage of the fuzzy controller's design derives from its similarity to human reasoning [4]. Linguistic model, which is expressed with a set of conditional rules (IF-THEN statements) presents an advantage because of the controller's ability for non-linear mapping between the external conditions and the corresponding roller blind position.

The presented algorithm is composed of two general loops (see Fig. 2). Each loop can act independently or the two can be linked to work simultaneously. The first loop is the "illumination loop" comprised of blocks that control the roller blind position according to the set-point illumination. The second is the "thermal loop" which is comprised of two separate controllers, one for the summer season and the other for the winter season. These are composed of blocks, which steer the roller blind according to set-point temperature. The thermal loop also includes the controlled functioning of heater and ventilator. All the control loops are designed as a cascade control system. Fuzzy controller is used as the main controller and PID controller (of a PID/V type) is used as the auxiliary one [2,3]. The main fuzzy controllers, processing the measured external and internal conditions and set-point values as inputs, determine the desired position of the roller blind as an output. On the basis of the output value PID/V controller defines the extent of the actuator's change of the roller blind position, which derives from the current and the desired position of the roller blind. In the presented diagrams, a completely exposed window is represented by 100% value, which correlates to a completely retracted roller blind (e.g. fully open roller blind). On the other hand, a fully shaded window is represented by 0% value (e.g. fully closed roller blind). The control algorithm for adaptable roller blind is designed as application in the IDR BLOCK environment, which is a programmable environment for designing control schemes for different areas where time constants are not too short (e.g. thermal process, chemical process, etc.).

3.1. Thermal loop

The thermal control system on the test chamber is a synergy of modelling and simulation approach. It derives from the thermal theoretical mathematical model [5,6], established in the MATLAB SIMULINK environment. The basic goal is to keep the indoor temperature as close as possible to the set-point temperature profile. The system is modelled by differential equations and defined as a relation among physical variables of the thermal process modelled into the corresponding mathematical structures. The first